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ORIGINAL PAPER

Solar Pond devices: free energy or bioreactors for *Artemia* biomass production?

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Abstract The recent exponential growth in industrial aquaculture has led to a huge increase in *Artemia* biomass production in order to meet increased fish production needs. The present study explores the potential use of salt gradient solar ponds (SGSPs) for production of *Artemia* nauplii. An SGSP is a basin of water where solar energy is trapped and collected via an artificially imposed gradient. Three zones can be identified in an SGSP: upper and lower zones, which are both convective, and a middle zone, which is intended to be non-convective. The latter acts as a transparent insulation layer and allows for storage of solar energy at the bottom, where it is available for use. The combination of salt, temperature and high transparency could make SGSPs promising bioreactors for the production of *Artemia* nauplii. Using particle image velocymetry (PIV) and Shadowgraph visualisation techniques, the behaviour of *Artemia* nauplii under critical cultivation parameters (namely, salinity, temperature and light) was monitored to determine movement velocity, and how movement of *Artemia* affects the salt gradient. It was observed that *Artemia* nauplii constantly follow light, irrespective of adverse salinity and/or temperature conditions. However, despite the substantial displacement of *Artemia* following the light source, the salt gradient is not disrupted. The suitability of SGSPs as bioreactors for *Artemia* biomass production was then tested. The results were disappointing, probably due to the lack of sufficient O_2 for *Artemia* survival and growth. Follow-up trials were conducted aimed at using the SGSP as a green and economically attractive energy source to induce faster hatching of cysts and improved *Artemia* nauplii growth. The results of these trials, and a case study of *Artemia* nauplii production using an SGSP, are presented. The authors constructed a Solar Pond device, which they suggest as a novel way of supplying thermal energy for *Artemia* biomass production in an aquaculture enterprise. Finally, the authors suggest a method of producing and collecting *Artemia* biomass, and of heating a fish larval tank, in an 'ideal' Solar Pond device, profiting from the low investment costs of using a decommissioned salt works.

Keywords Solar Pond · *Artemia* nauplii · Particle image velocimetry · Shadowgraph

Introduction

Aquaculture

The influence of diet on good health is clear. This fact is supported by considerable epidemiological evidence and is well recognized by the scientific community as well as the general public in developed countries.

The consumption of fish and fish-derived products has been documented as having beneficial effects on human health due to the presence of omega-3 polyunsaturated fatty acids (PUFA). PUFA are important building blocks in neonatal, retinal and brain development [5, 12], as well as in the prophylaxis and therapy of chronic and degenerative diseases, including the reduction of blood cholesterol [3]. PUFAs also protect against cardiovascular conditions such as coronary heart disease and atherosclerosis, as well as diabetes, hypertension, rheumatism, skin diseases, digestive conditions, metabolic diseases and cancer [6, 8, 12, 13].

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However, global fish stocks are declining due to general over-fishing, and the increasing world dependence on fish as a food source has led to a growing interest in intensive aquaculture.

The farming and stocking of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants, is growing more rapidly than any other animal food producing sector [9]. Aquaculture has increased at an average compounded rate of 9.2% per year since 1970, compared with only 1.4% for capture fisheries and 2.8% for terrestrial farmed meat production systems. China remains the largest producer, with 71% of the total volume and nearly half of the total value [9]. Currently, the global aquaculture industry accounts for over 45% of all seafood consumed [2], and this has been projected to increase to 75% over the next 20 years.

Artemia

With the development of fish and shellfish hatchery aquaculture, the use of the brine shrimp *Artemia* as a diet for larval culture of many species has become widespread due to its convenience of use and high nutritional value [14, 15, 17]. Dormant cysts of *Artemia* are available year-round in large quantities along the shorelines of hyper saline lakes, coastal lagoons and solar salt works scattered over the five continents.

After harvesting and processing, cysts are made available in cans as stored ‘on demand’ live feed. After about 24-h incubation in seawater, these cysts release free-swimming nauplii that can be fed directly as a nutritious live food source to the larvae of a variety of marine, as well as freshwater, organisms, making *Artemia* the most convenient, least labour-intensive live food available for aquaculture.

However, the expansion of aquaculture production has meant that the demand for *Artemia* cysts now exceeds supply. Prices have risen exponentially, turning *Artemia* into a bottleneck for the expansion of the hatchery aquaculture of marine fishes and crustaceans. In particular, many developing countries can barely afford to import the very expensive cysts.

Both temperature and salinity affect *Artemia* survival and growth significantly, although a broad range of temperatures and salinities meets the requirements for >90% survival [16]. A temperature range of 20–28°C and salinity 120–200% ensure optimal maturation rates, fecundity and generation times in *Artemia franciscana* [16]. Heavy continuous aeration, constant illumination (2,000 lux) and pH = 8.9 are fundamental to healthy *Artemia* growth.

Solar ponds

A salt gradient solar pond (SGSP) is a basin of water that traps and stores solar energy. The energy trapping objective is achieved by imposing a vertical salinity gradient, decreasing from the bottom, in order to prevent convection motion induced by absorption of solar radiation. A second temperature gradient is created naturally by the solar radiation itself (Fig. 1). This second gradient tends to destabilise the first, and care must be taken in order to prevent convective motion in the middle zone of the pond. Thus, three zones can be identified in a SGSP: the upper and bottom zones, which are both convective, and the middle gradient zone, which should be non-convective. This middle zone, acting as a transparent insulating layer, allows the storage of solar energy at the bottom, where it is available for use. Due to its large inertia, solar radiation trapped in the bottom zone during summer is available yearlong, including in winter [11].

The upper surface area of the SGSP can vary between a few square metres to 1,000s of square metres. Applications of SGSPs include electricity production, industrial heating, extraction and purification of chemical products, desalination processes, heating of buildings, greenhouses, stables, fisheries and drying of agricultural products [4, 7].

An obvious application for SGSPs is the growth of aquaculture plants, as SGSPs naturally provide salt, water and insulation. Salt works are excellent places to construct SGSPs for the production of *Artemia*, which naturally seek out the layers that are ideally suited for their growth. Due to the high market price of this organism, direct production in SGSP structures will be of great economic interest because it can help decrease dependence on importation, and make use of old and decommissioned salt works. The reuse of old salt works for *Artemia* biomass and energy production in the same device, would give such industrial sites a new and economically viable purpose.

Portugal, situated on Europe’s southwest coast, with a latitude of about 38°42′N, 9°11′W, has conditions ideal for SGSP operations, with an average of 2,700 h/year sunlight (max 3,100 h/year) (http://www.igeo.pt) and an average temperature of 18–20°C/year.

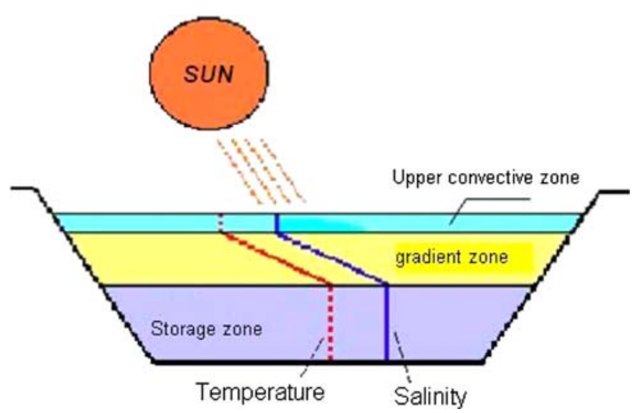


Fig. 1 Solar Pond device, showing temperature and salinity gradients and the three fundamental zones: convective, gradient and storage (from *top* to *bottom*)

The aim of this study was to evaluate the technical feasibility of using a Solar-Pond-type device as a bioreactor for *Artemia* biomass production, monitored by particle image velocimetry (PIV) and Shadowgraph techniques.

Materials and methods

Trial 1. *Artemia* nauplii behaviour in relation to salinity, temperature and light

Trials were conducted in a 10 × 10 × 15 cm container (Fig. 2). *Artemia* nauplii behaviour regarding salinity, temperature and light was observed using the PIV system. *Artemia* velocity was determined, and the effect of *Artemia* displacement on salt-gradient stability was also evaluated. Figures 3 and 4 show the PIV system with charge coupled device (CCD) cameras and the Shadowgraph set-up, respectively.

A 10 Hz Nd:YAG Q-switched laser with a doubled 532 nm wavelength frequency emits a circular light beam, and an optical set-up (beam-shaping optics) creates a sheet of light 1 mm wide, and with low divergence height. This sheet of light crosses the container; a CCD camera perpendicular to the light sheet visualises the light scattered by the seeding particles.

For each PIV acquisition, 30 images of particles, exposed to an individual frame and with an acquisition rate of 10 Hz, were captured. The images were then processed using specific software (Dynamic.Studio; Dantec Dynamics, Skovlunde, Denmark). The processing consists of cross-correlation of each pair of images of particles captured, producing a vector map of the instantaneous velocity field within the field of view. In the present study, the field of view of the PIV system is a rectangle with a height of 64 mm and a width of 84 mm.

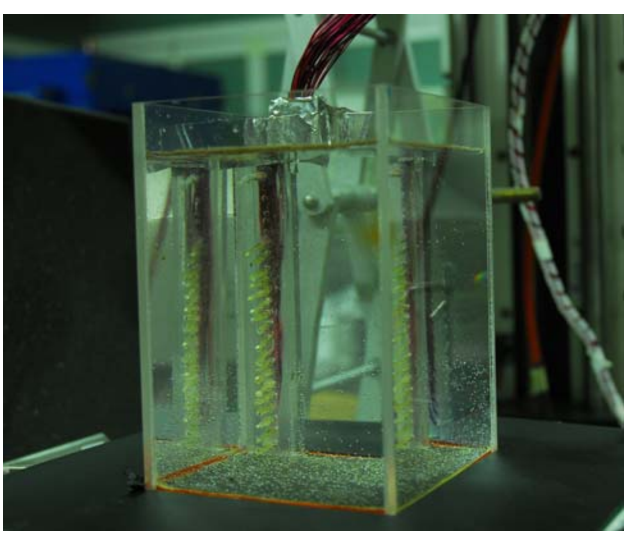


Fig. 2 Container (10 × 10 × 15 cm) used to study *Artemia* in a homogeneous layer (Trial 1.1) and in a salt gradient layer (Trial 1.2)

Fig. 3 Container (10 × 10 × 15 cm), showing the particle image velocimetry (PIV) system and charge coupled device (CCD) cameras used in Trials 1.1 and 1.2

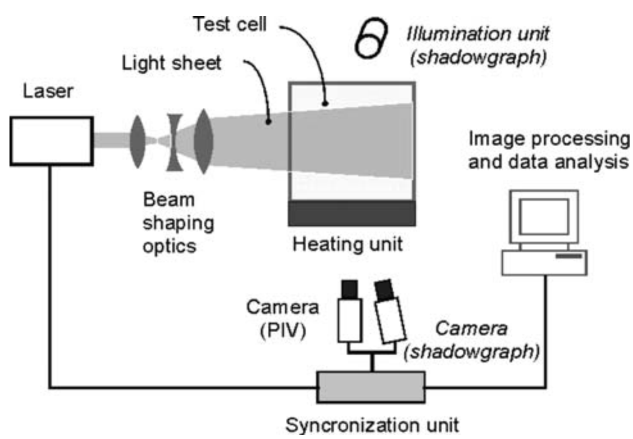


Fig. 4 Schematic of the set-up used for both PIV and Shadowgraph techniques

This method makes use of a 100 W halogen lamp that projects the emitted light onto a semi-transparent screen placed near the test cell. This allows close to a 1:1 relationship between the object and the projected Shadowgraph image. Using this technique, the position of *Artemia* nauplii in the container can be determined, and their movement analysed. A CCD camera, alternating with the PIV analysis, visualises the Shadowgraph images, which capture the sudden changes in *Artemia* positions. Both CCD cameras were adjusted to 640 × 480 pixels and a 8.6 × 8.3 μm pixel pitch.

Trial 1.1: Artemia nauplii in a homogeneous layer

Trial 1.1 was conducted in a 10 × 10 × 15 cm container (Fig. 2) with water containing 5% salt, without a gradient (i.e. homogeneous layer), at ambient temperature and without light incidence. Heating from the bottom was turned on to simulate the storage zone temperature during a specified period of time and then switched off. A light focus was passed through the container at several positions. The behaviour and movement of the *Artemia* nauplii were monitoring by PIV and Shadowgraph. The average speed of the *Artemia* nauplii was determined. Digital photos were also taken.

Trial 1.2: Artemia nauplii in a salt gradient layer

This trial was performed in the same (10 × 10 × 15 cm) container (Fig. 2), but with a stratification of salt (10% at the bottom, 5% in the middle and 0% on the top). Each layer was 4.5 cm in height (total 13.5 cm). Hatched *Artemia* nauplii were introduced at specific timepoints into each salinity layer. *Dunaliella salina* microalgae were added as live food for the *Artemia* nauplii. The container was heated from the bottom by a heater resistance (only during the night), simulating the temperature usually found in the bottom zone of a Solar Pond device (storage zone). A laser device crossing the container (Fig. 5) and a light focus also illuminated the device from different points, namely top, middle and bottom. The movement and position of *Artemia* nauplii were observed visually and by PIV methodology. The temperature and salinity of the Solar Pond layers were evaluated throughout.

Trial 2: Growth and performance of *Artemia* nauplii in a Solar-Pond-type device and in a reactor with homogeneous salinity, ambient temperature and aeration

In this trial, two similar (17.5 × 17.5 × 17.5cm) containers (Fig. 6) were used to evaluate *Artemia* nauplii growth. In the first container (SP), a Solar Pond device was constructed using seawater, creating a gradient of salinity of 20%, 10%, and 5% (from bottom to top); different dyes were used to facilitate salinity gradient visualisation (Fig. 6). Fresh water (0% salinity) was added slowly to the top section to avoid disrupting the salinity gradient. The container was heated from the bottom in order to simulate actual Solar Pond conditions (storage zone). In the second container (TA), *Artemia* nauplii were grown in sea water, without heating and with aeration from an air pump. *Dunaliella salina* microalgae were added as live food for *Artemia* nauplii in both containers. Besides *Artemia* nauplii growth, the temperature and salinity of the Solar Pond layers were evaluated throughout.

Trial 3: Hatching time, growth and performance of *Artemia* nauplii in two reactors, one being connected to a Solar Pond device

Two similar (17.5 × 17.5 × 17.5cm) containers were used to evaluate the hatching time of *Artemia* cysts (Trial 3.1), and the growth and performance of *Artemia* nauplii (Trial 3.2). The same environmental conditions [i.e. quantity of *Artemia* cysts added (Trial 3.1), quantity and density of

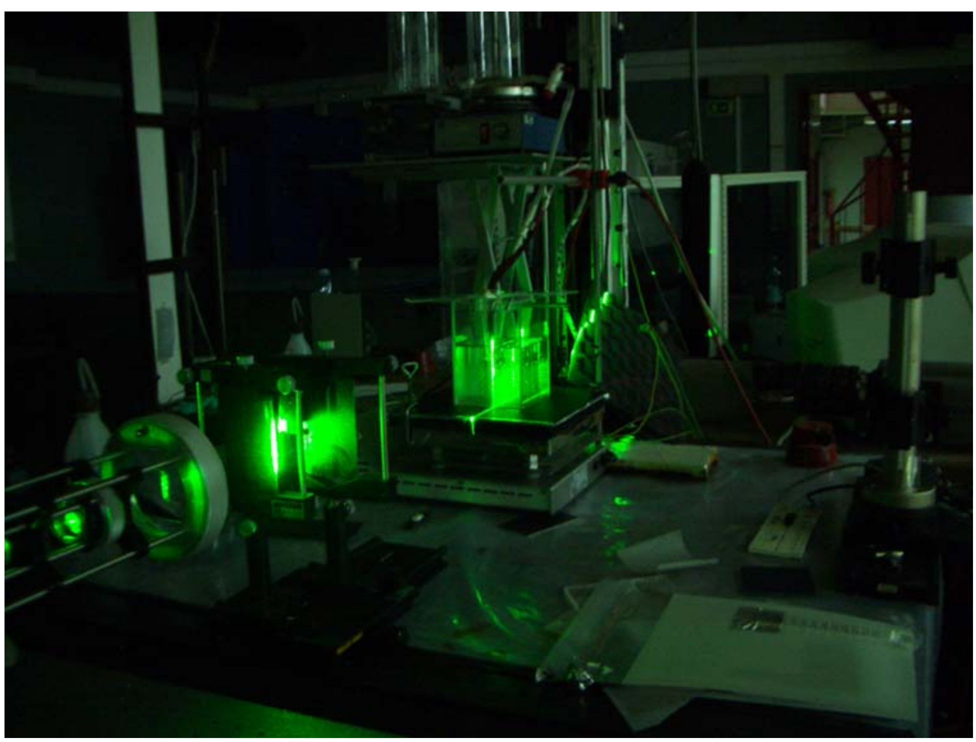


Fig. 5 Laser device showing light crossing the 10 × 10 × 15 cm container (Trial 1)

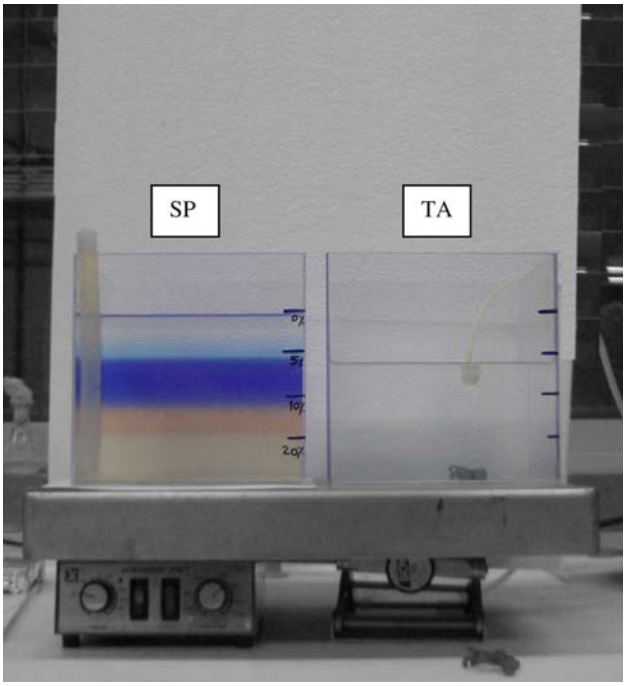


Fig. 6 Solar Pond device (*SP*) with an artificially created salinity gradient (indicated by *different tonalities*), and a second tank (*TA*) containing seawater at ambient temperature with aeration provide by an air pump. (Trial 2)

hatched *Artemia* nauplii (Trial 3.2), seawater, aeration and daily microalgae quantity added] were applied to both containers. However, the first container was connected to the Solar Pond through a heat exchanger (fresh water closed-loop circuit) transferring heat from the Solar Pond to tank TH (Fig. 7a, b). *Dunaliella salina* microalgae were added as live food for *Artemia* nauplii in both containers, which were closed on the top to avoid evaporation. Temperature, salinity, and the hatching time of cysts were evaluated throughout (Trial 3.1), and the number and size of *Artemia* nauplii in both containers was noted (Trial 3.2).

Results and discussion

Trial 1: *Artemia* nauplii behaviour in relation to salinity, temperature and light

Trial 1.1: Artemia nauplii in a homogeneous layer

At ambient temperature, without additional light incidence or heating, *Artemia* nauplii showed a uniform distribution at time = 0 s (Fig. 8a). Upon shining a laser across the container (Fig. 5), *Artemia* nauplii followed the light, resulting in agglomeration on the left side of the container (Fig. 8b).

Figure 9a and b show average speeds (from statistics taken from PIV images) of 1.3 and 0.8 mm/s, respectively, in the movement of *Artemia* nauplii following a light source. The results at $t = 720$ with the laser crossing half the length of the container are shown in Fig. 10.

Trial 1.2: Artemia nauplii in a salt-gradient layer

The first experiment was done by introducing the *Artemia* nauplii into the 10% salinity layer. At $t = 0$ s, they remained in that layer, but a few moments later they moved to the upper layer interface. After heating the bottom layer to 35°C with a resistance heater, the *Artemia* nauplii moved to the 5% salinity layer, as recorded using the PIV and Shadowgraph techniques (Fig. 11a) and digital photos (Fig. 11b).

After cooling, the *Artemia* nauplii were found to be present in the layer between 7.5 and 3.5% salinity (note that the salinity of the layers was altered by heating). On the 2nd day, almost all the *Artemia* nauplii were in the upper layer, possibly trying to get some oxygen from the air. An almost identical pattern of behaviour was observed when the *Artemia* nauplii were introduced into the 5% salinity or into the 0% salinity layers. The *Artemia* nauplii always moved to the 2.5–5% salinity layers, regardless of the layer into which they were first introduced (10, 5 or 0% salinity) and regardless of the temperature (Tables 1, 2, 3).

These results show the similarity in behaviour of *Artemia* nauplii in relation to salinity and temperature (note: Tables 1, 2, 3 are very similar). However, light is undoubtedly the principal parameter determining *Artemia* nauplii movement and their preferred location. Despite adverse salinity and/or temperature, *Artemia* nauplii follow light (Fig. 12).

Due to the small scale of the Solar Pond type device used here, heating leads to convective motion and a slow destruction of the salinity values and gradients (Tables 1, 2, 3) after 1 day. In other experiments without heating from the bottom, the salinity gradient remained stable even after 6 days (results not shown). Nevertheless, it was observed that *Artemia* nauplii movement in the container did not affect the salinity gradient, despite large displacements of *Artemia* nauplii following the light, which was moved from place to place (from top to bottom and from right to left).

In these experiments, even with the addition of *D. salina* microalga as live food, the *Artemia* nauplii in the Solar Pond type device died after 3 days. Thus, the Solar Pond type device proved inadequate as a bioreactor for *Artemia* nauplii development and production, probably due to the absence of sufficient oxygen. This hypothesis was supported by the reddish colour of the *Artemia* nauplii indicating lack of oxygen (photo not showed), as described in previous studies (http://www.netfysh.com), in spite of appropriate temperature, salinity and light conditions.

The *Artemia* nauplii lived for only 3 days and, towards the end of their lives, they agglomerated at the upper layer (1.2–2.5% salinity), probably in search of oxygen.

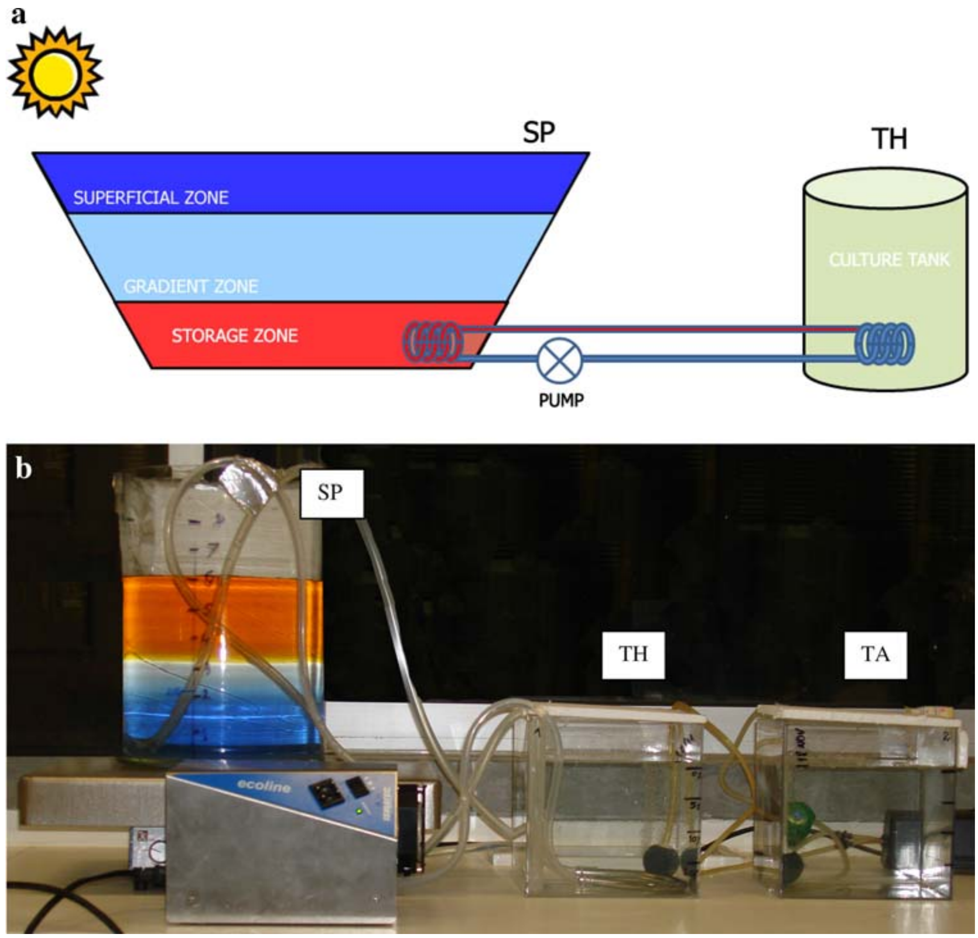


Fig. 7 Solar Pond device (*SP*) as a thermal energy source. Schematic (**a**) and experimental (**b**) set up showing salinity gradient (indicated by *different tonalities*) connected to an external tank (*TH*; **a**, **b**), and a second tank at ambient temperature (*TA*; **b**). *Artemia* cysts (500 mg) were introduced into both tanks (*TH* and *TA*) and aeration was provided by an air pump (Trial 3)

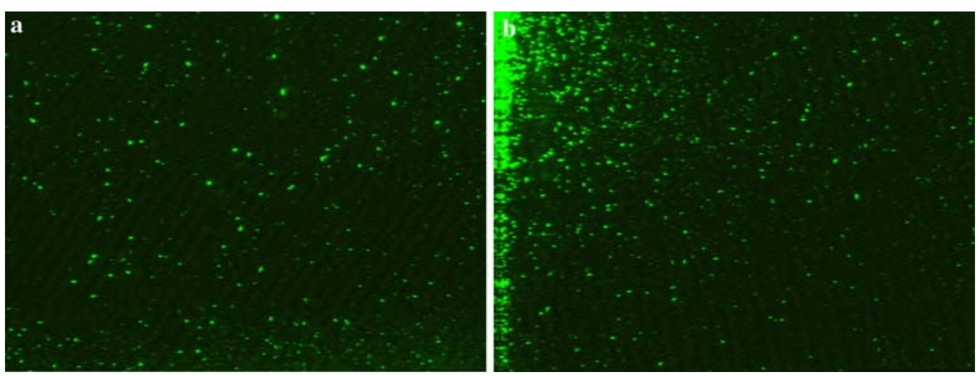


Fig. 8 PIV images. **a** Uniform distribution of *Artemia* nauplii in the container, at $t = 0$ s in a homogeneous layer. **b** *Artemia* nauplii distribution at $t = 720$ s after shining a laser across the container with homogeneous layer (Trial 1.1). The nauplii followed the light and accumulated on the left side of the container regardless of temperature and salinity

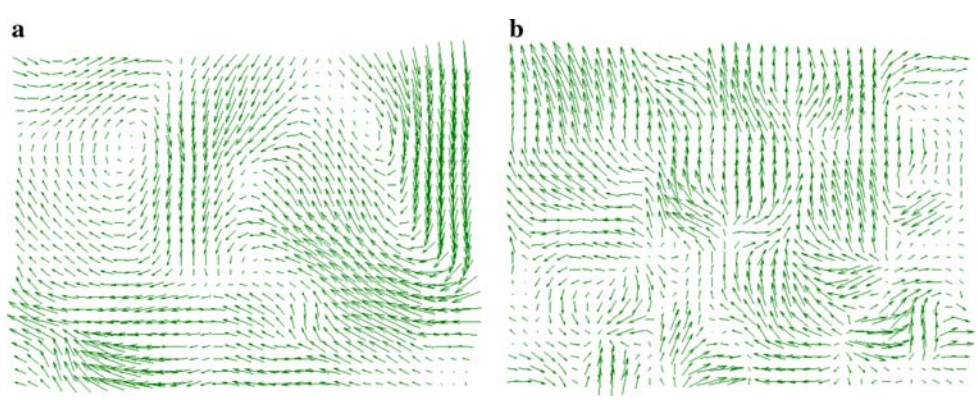


Fig. 9 Statistical PIV images of *Artemia* nauplii movement in the container with homogeneous layer at $t = 0$ s. **a** Average speed 1.3 mm/s, **b** average speed 0.8 mm/s

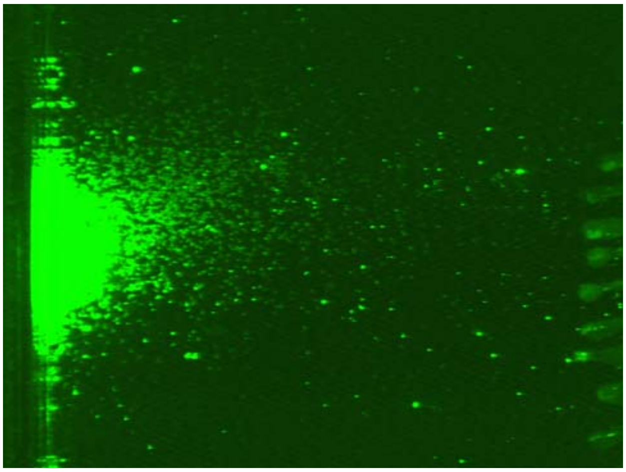


Fig. 10 PIV image. *Artemia* nauplii distribution at $t = 720$ s after laser crossing the container at half-length with homogeneous layer (Trial 1.1)

Nevertheless, this first experiment was important in order to discover a means of collecting *Artemia* nauplii. As they are attracted to light (phototropic), it will be easy to concentrate them in one area for harvest by shining a flashlight.

Trial 2: Growth and performance of *Artemia* nauplii in a Solar Pond type device and in a reactor with homogeneous salinity, room temperature and aeration

Based on the results of the first trial, we attempted to compare *Artemia* nauplii growth and performance in a Solar Pond type device with that in a container at ambient temperature and homogeneous salinity with aeration provided by an air pump. Live food (*D. salina* microalga) was administrated daily and similarly to both containers. As in the first trial, hatched *Artemia* nauplii remained in the 3.5–5% salinity layer during the 5 days of the trial, but nauplii in the aerated container grew faster than those in the Solar pond type device despite the lower temperature (22–23°C vs 30–40°C). After 5 days, the *Artemia* nauplii in the TH tank died, in contrast to those in the TA tank, which were healthy and much bigger. The reason was probably the same as in the first experiment, namely the lack of oxygen in the 'Solar Pond' (SP) tank.

Table 1 Data from Solar Pond type device and *Artemia* nauplii location with *Artemia* nauplii introduced in 10% salinity extract (Trial 1.2)

Time (day)	Distance[a] (cm)	Salinity (%)	Temperature (ºC)	*Artemia* nauplii[b]
0	0–4	10	23	++++
	4–8	5	23	
	8–12	0	23	
1	0–1	8	35	
After heating light on	1–7	5	29	+++
	7–10	2.5	25	+
	10–12	1	23.5	
After cooling	0–1	8	22	
	1–5	7.5	22	++
	5–8	3.5	21.5	++
	8–10	2	21.5	
	10–12	1	21	
2	0–1	7.4	33	
After heating light off	1–5	6	32.5	
	5–8	3.5	28	++
	8–10	2.5	26	+
	10–12	1.2	24	+
3	0–2	7.5	20	
	2–5	6.5	20	
	5–10	3.5	19.5	+
	10–12	2.5	19	+

[a] From the bottom of the container

[b] Main position in the container

Trial 3: Hatching time, growth and performance of *Artemia* nauplii in two reactors—one connected to a Solar Pond device

Trial 3.1: Hatching time of Artemia cysts

The results of this experiment are presented in Table 4, where the temperatures in both reactors (TH, connected

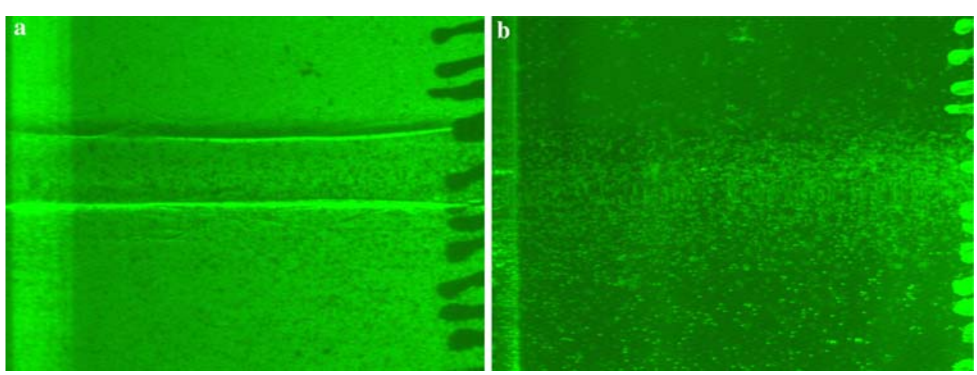


Fig. 11 PIV image (**a**) and digital photo (**b**) showing salt gradient and *Artemia* nauplii's preferred position (salinity = 3.5–5%)

Table 2 Data from Solar Pond type device and *Artemia* nauplii location, with *Artemia* nauplii introduced in 5% salinity extract (Trial 1.2)

Time (day)	Distance[a] (cm)	Salinity (%)	Temperature (ºC)	*Artemia* nauplii[b]
0	0–4	10	23	
	4–8	5	23	++++
	8–12	0	23	
1	0–1	8	35	
After heating light on	1–7	5	29	++
	7–10	2.5	25	++
	10–12	1	23.5	
After cooling	0–1	8	22	
	1–5	7.5	22	
	5–8	3.5	21.5	++
	8–10	2	21.5	++
	10–12	1	21	
2	0–1	7.4	33	
After heating light off	1–5	6	32.5	
	5–8	3.5	28	++
	8–10	2.5	26	++
	10–12	1.2	24	
3	0–2	7.5	20	
	2–5	6.5	20	
	5–10	3.5	19.5	+
	10–12	1.5	19	

[a] From the bottom of the container

[b] Main position in the container

Table 3 Data from Solar Pond type device and *Artemia* nauplii location, with *Artemia* nauplii introduced in 0% salinity extract (Trial 1.2)

Time (day)	Distance[a] (cm)	Salinity (%)	Temperature (ºC)	*Artemia* nauplii[b]
0	0–4	10	23	
	4–8	5	23	
	8–12	0	23	++++
1	0–1	8	35	
After heating light on	1–7	5	29	++
	7–10	2.5	25	++
	10–12	1	23.5	
After cooling	0–1	8	22	
	1–5	7.5	22	
	5–8	3.5	21.5	++
	8–10	2	21.5	++
	10–12	1	21	
2	0–1	7.4	33	
After heating light off	1–5	6	32.5	
	5–8	3.5	28	++
	8–10	2.5	26	+
	10–12	1.2	24	+
3	0–2	7.5	20	
	2–5	6.5	20	
	5–10	3.5	19.5	
	10–12	1.2	19	+

[a] From the bottom of the container

[b] Main position in the container

to the Solar Pond; and TA, at ambient temperature and homogeneous salinity with aeration provided by an air pump), as well as the development of *Artemia* cysts and *Artemia* nauplii, are shown. It is obvious that the temperature in TH is 5–6°C higher than in TA. The hatching time in TH is 5 h less than in TA, which is a very important way of saving energy in an industrial aquaculture enterprise.

Trial 3.2: Growth and performance of Artemia nauplii

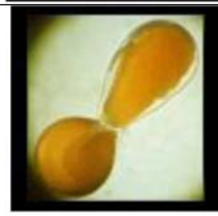
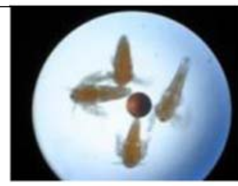
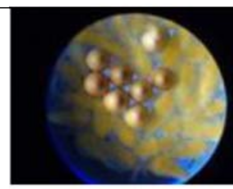
In this trial, development of *Artemia* nauplii was more evident in the TH tank, where the temperature was higher than in the TA tank (Table 5), which is again an excellent way to reduce energy costs.

Case study

A case study was conducted in a Portuguese hatchery producing 100 million fish (6–7 million sea bream and 3–4 million sea bass) annually. Taking Portugal's average

Fig. 12 *Artemia* nauplii follow a light focus regardless of adverse salinity and temperature

Table 4 Temperatures and cysts hatching evolution process in the hot tank (TH) connected to the Solar Pond type device, and in the tank at ambient temperature (TA) (Trial 3) (Fig. 7a, b)

	Tank connected to the *Solar pond* (TH)		**Tank at ambient temperature (TA)**	
Time (h)	**Temp (ºC)**	***Artemia* nauplii**	**Temp (ºC)**	***Artemia* nauplii**
0	23		20.5	
15	26.0		20.0	
16	27.0		21.5	
20	29		22.5	
24	28		21.5	

sunlight into consideration, the Solar Pond device (50,000 L) must have the following dimensions in order to provide the necessary thermal energy to hatch *Artemia* cysts for 2 years:

Total area: 1,000 m^2
Upper zone: 0.2 m
Gradient zone: 0.8 m
Storage zone: 0.5 m

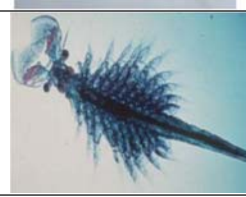
The results of the Solar Pond performance and temperatures are presented in Fig. 13.

Solar Pond devices constitute one of the cheapest way to convert solar heat in a feasible installation with low investment costs and very low maintenance requirements [1, 10]. Solar Ponds are reliable and effective over an extended period of operation (life cycles of 15–25 years) under the severe environmental conditions [1] that are common in aquaculture sites.

Conclusion

From the results of this study, it can be concluded that a Solar Pond device is not the ideal bioreactor for *Artemia* nauplii biomass production, in spite of optimal water temperature, salinity and irradiation. This is probably due to

Table 5 Temperatures and *Artemia* growth in the hot tank (TH) connected to the Solar Pond type device, and in the tank at ambient temperature (TA) (Trial 4) (see Fig. 7a, b)

	Tank connected to the *Solar Pond* (TH)		Tank at ambient temperature (TA)	
Time (h)	**Temp (ºC)**	***Artemia* nauplii**	**Temp (ºC)**	***Artemia* nauplii**
0	21.0		20.0	
4	28.0		20.0	
24	28.0		21.0	
48	31.0		23.0	

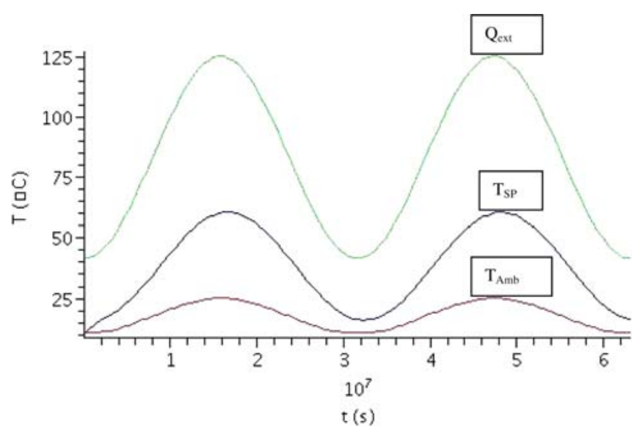


Fig. 13 Solar Pond device performance over 2 years. Q_{ext} Energy extracted from the Pond (in 10^3 MJ), T_{SP} temperature of pond, T_{Amb} ambient temperature for a given Portuguese latitude (38°42′N, 9°11′W)

the lack of oxygen in the salt gradient zone where these organisms are able to develop. This precludes the use of Solar Pond devices as perfect low cost bioreactors for *Artemia* cultivation. Aeration is not an option because it would disrupt the salt gradient, which is essential to the collection and storage of thermal energy by the Solar Pond device.

However, the use of a device such a Solar Pond (a green and renewable energy source) would save energy and time, in speeding up both *Artemia* cyst hatching time and *Artemia* nauplii development.

The authors propose an 'ideal' Solar Pond device that 'works' simultaneously as a bioreactor for *Artemia* nauplii biomass production and as a thermal energy source for a marine larval fish tank (Fig. 14). By using a laminar flux (to avoid salt gradient damage), *Artemia* cysts would be introduced into the upper storage zone at a temperature of approximately 26–28°C, where they would hatch after about 24 h and could then be used to feed marine larval fish.

Since the newly hatched *Artemia* nauplii are attracted to light, it would be easy to concentrate them in one area and harvest them by shining a flashlight at the exit of the bioreactor. The Solar Pond would also be connected to the hatchery tank, in order to furnish thermal energy and consequently promote fish growth.

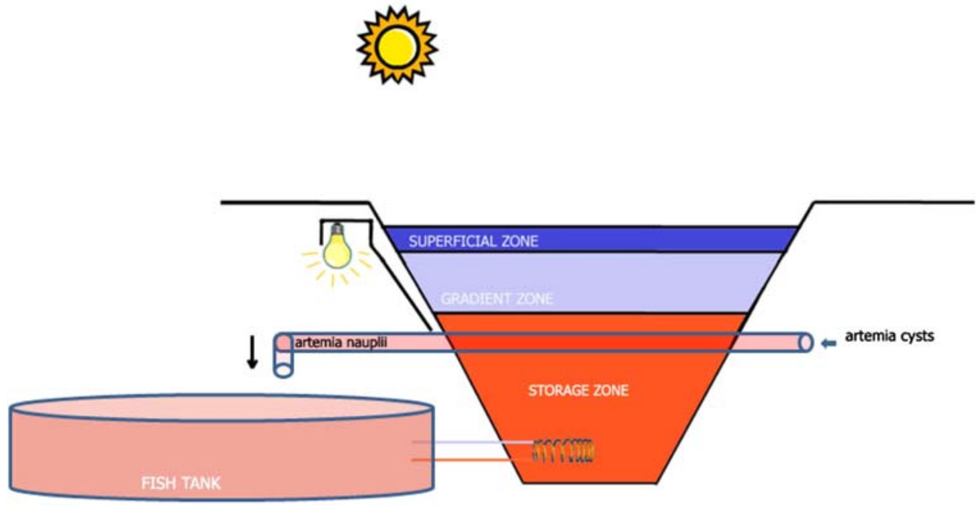


Fig. 14 "Dual" Solar Pond as a thermal energy source for marine larval fish tank and a bioreactor for hatching *Artemia* cysts. *Artemia* cysts would be introduced via a tube (to avoid salt gradient damage) inserted into the storage zone (28–30°C temperature) of the Solar Pond. Nauplii would hatch after 24 h. The *Artemia* nauplii would then be harvested with the help of a flashlight, and added to the larval fish tank that is heated (to promote fish growth) by the Solar Pond via a resistance heater

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