# LOW PRESSURE UV TREATMENT FOR BARNACLE GROWTH CONTROL UNDER OPEN SEA CONDITIONS

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## ABSTRACT

*Barnacle growth on solid surfaces, such as ship hulls, tidal gates and equipment submerged in seawater, augments poor aesthetics, deteriorates their performance, increases their operational and maintenance costs, and causes premature failure of the facilities. Most of the currently available measures to manage the problem of barnacle growth are not environmentally friendly and have no long term effect.*

*The effectiveness of UV treatment in preventing the invasion of barnacle colonies under a tropical marine environment was investigated. Two metal plates were prepared and submerged in water: one as the control and the other for UV treatment. The UV system consisted of one metal surface, on which barnacles could attach, grow and form colonies; six 120-W low pressure lamps were installed parallel to the metal plate surface, and a UV reflector was employed. The surfaces of the metal plates were examined for the growth of the barnacles at least once every month. Within 7 weeks, the entire control plate was colonized by barnacles, where the barnacles grew to approximately 0.5 cm in diameter. However, barnacles did not attach to the UV treated metal plate, and there were no barnacles on this plate after 11 weeks. The result of the study conclusively showed that UV treatment completely prevented Nauplius barnacles from attaching, colonizing and growing on the metal plate surface. While the UV transmittance of the seawater could be the principal factor controlling barnacle development when using UV, the required UV dose could be as low as 60 μW/cm$^2$.*

***Key words: Nauplius and Cyprid, barnacle fouling, low-pressure UV lamp).***

## INTRODUCTION

Barnacle growth can be observed everywhere on surfaces submerged in natural seawater, including seawater intake pipes, channels, ship hulls, tidal gates and other facilities. Barnacles multiply rapidly under tropical coastal conditions. Besides its nuisance and aesthetic impact, the presence and growth of barnacles on surfaces of various materials disrupts the operation of devices (such as tidal gates and seawater pumps) and deteriorates their performance. Such surface attachment warrants more frequent and expensive maintenance under a marine environment. When fouling and growth occurs on hulls of ships, it increases drag, adversely affects fuel consumption as much as 50%, increases pollution (via the workload on the machinery) and downtime due to dry-docking. When colonies form on the inner surface of the seawater intake pipes, barnacle growth reduces the flow rate. The detached barnacle particles may also affect normal pump operation. The annual global cost of barnacle cleaning alone is in the range of billions of dollars.

A barnacle life cycle has two distinct larval stages, *Nauplius* and *Cypri*d, before developing into an adult barnacle. This life cycle provides opportunities for its early control and mitigation. At the early stage, the eyes of the organism could be impaired by UV-B (Chiang et al., 2003, 2007).

The existing techniques for barnacle growth mitigation include options such as: anti-fouling coatings (chemicals or biological extracts) using non-toxic (Efimenko et al., 2009; Skattebøl et al., 2006) or toxic substances (Freiman, 1977), that are poisonous to acorn barnacles and other crustaceans, hypochlorite dosing (Sasikumar, 1993; Tan et al., 2919), electrochemical (Pérez-Roa et al., 2009; Swain et al., 1982) and low density electric current (Wake et al., 2006), mechanical removal, and low frequency resonance (Rabbette, 1992). Another proactive approach in barnacle fouling prevention is the development of barnacle repelling surfaces (Tan et al., 2010). These surfaces, however, are only effective for a period of several weeks. Ultraviolet (UV) light has been widely used for disinfection of waterborne pathogens, particularly protozoa and for the control of slime films (Disalvo and Cobet, 1974); however, there is a lack of information on UV for barnacle mitigation. UV treatment is an effective and environmentally friendly practice, as it does not involve chemicals, thus eliminating the risk of water contamination whilst maintaining a clear and clean water body.

The objective of this study was to design, build and test a novel pilot UV system and investigate its effectiveness in eradicating barnacle growth on metal surfaces under a tropical marine environment.

## METHODOLOGY

### *UV System Set-Up*

The UV system consisted of a local control panel, 6 low-pressure 120 W amalgam UV lamps with ballasts for seawater

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applications, a 100 cm x 100 cm x 1cm metal plate coated with marine paint, and a UV cover with interior reflecting surface. The metal plate is the surface on which barnacles are expected to attach and grow.

The cover supports 6 UV lamp sockets and a bank of 6 UV lamps arranged horizontally with a distance of 15 cm between lamps. Upon installation, the distance between the UV lamps and the metal plate surface is about 8 cm. The gap of the edges of the cover and the metal plate was covered with a ¼" metal wire mesh to prevent debris and large marine animals from entering the space between the metal plate and the UV sleeves. The interior part of the cover reflects back at least 80% of the UV light from the UV lamps (see **Figure 1**).

For better quantification of the UV impact on barnacle growth, an identical metal plate was fabricated and used as a control. The historical low tide levels were used as reference for the submersion depth of the plates so that both the control and the UV irradiated metal plates were submerged in seawater at all times. The plates were only taken out of the water during barnacle growth inspection.

### Barnacle Growth Inspection

The UV lamps were kept on at all times during the study. Both the control and the UV treated plates were taken out of the seawater weekly or fortnightly to inspect for barnacle growth. During the 60 min inspection period, the plates were examined for the distribution of the barnacles on the surface, barnacle count and sizes as well as species. The metal plates with and without UV treatment were put back into the seawater after the inspection. The investigation started in early July 2009 and was completed in late September 2009 for a total of 11 weeks.

## RESULTS AND DISCUSSION

### Barnacle Growth

On the surface of the control plate (no UV), the presence of barnacles over the entire plate was observed within two weeks. The attached barnacles were tiny with sizes smaller than 0.5 mm. The growth continued and at Week 7 (see **Figure 2**) the sizes of the barnacles were up to 0.5 cm in diameter, and the entire plate was covered, with the majority being acorn (*Balanus* sp.) and volcano (*Tetraclita* sp.) barnacles. The barnacle density increased exponentially on the control plate during the weeks of observation.

On the surface of the UV treated plate, there were no barnacles observed during the inspection period (see **Figures 2 and 3**). The presence of several empty barnacle shells on the UV treated plate was due to an accidental electricity power shut off for 3 days during the first week. The growth of the barnacles that attached to the surface during the power shut down was prevented when the electricity supply resumed. No additional barnacle growth was observed, either in terms of density, size or surface coverage (see **Figures 2 and 3**). Similar observations were made in a previous study (Patil et al., 2007), in which UV light was effective in reducing the population of microfoulers from existing biofilms.

This system is the first of its kind using UV for in-*situ* barnacle growth control under field conditions. The observations showed that UV had completely controlled barnacle growth on the UV treated metal surface in a tropical marine environment. Possible mechanisms of UV for barnacle growth mitigation include: (a) inactivation of algae cells preventing algae from multiplying in seawater and therefore reducing the food supply to barnacles (Disalvo and Cobet, 1974); (b)

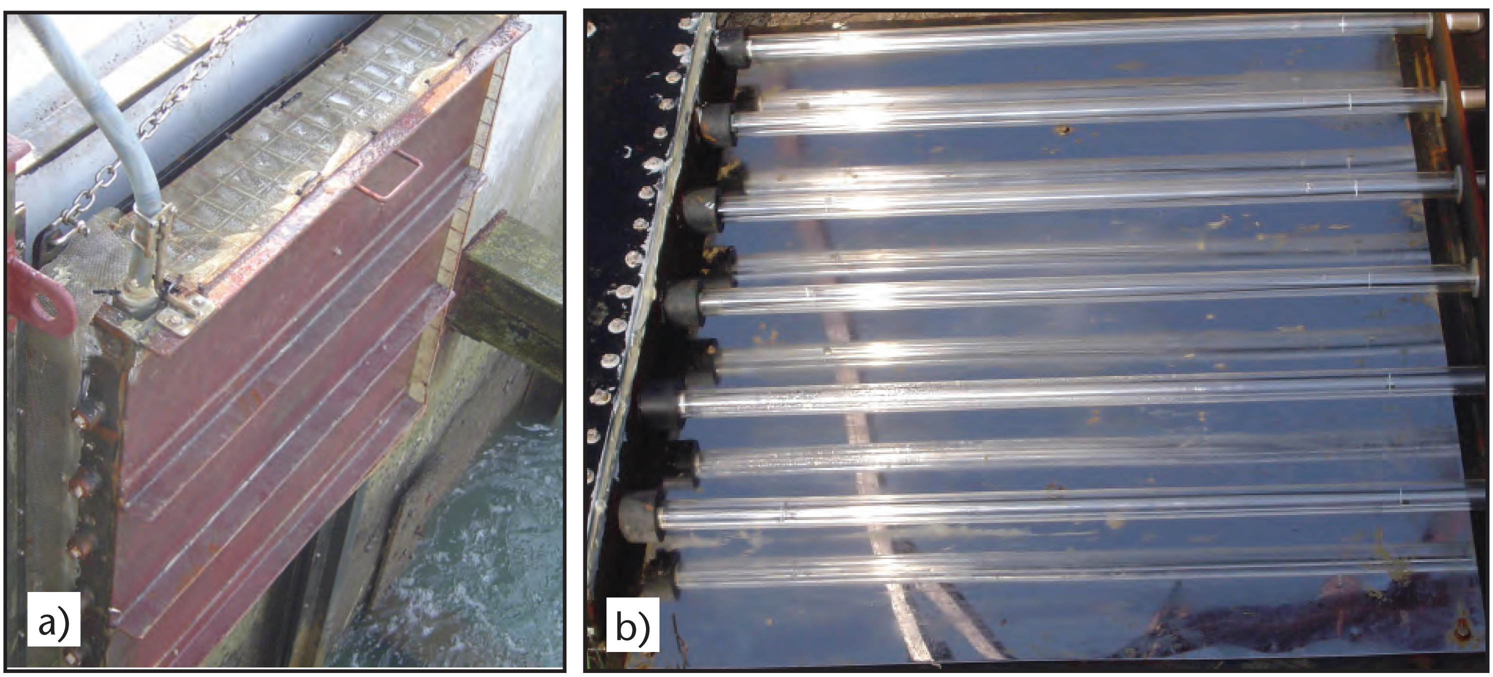


**Figure 1**. *Pilot ultraviolet system for barnacle growth control under field conditions. [a) UV system being lowered, b) inside view of the UV system*

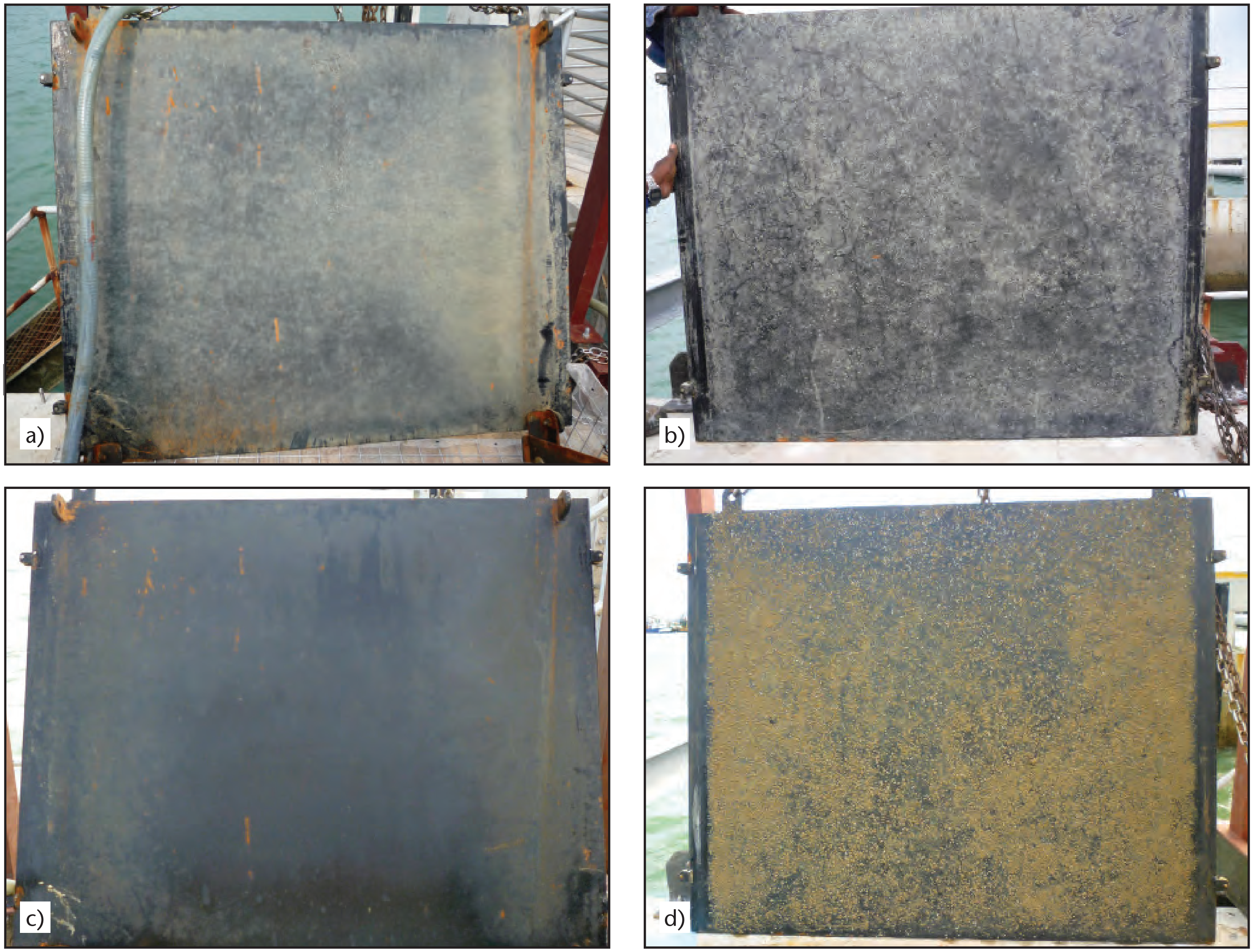


**Figure 2**. *Barnacle growth on the metal plates – Entire plate (1 m x 1 m) observed at week 2 [a) UV irradiated, b) control) and after week 7 [c) UV irradiated, d) control].*

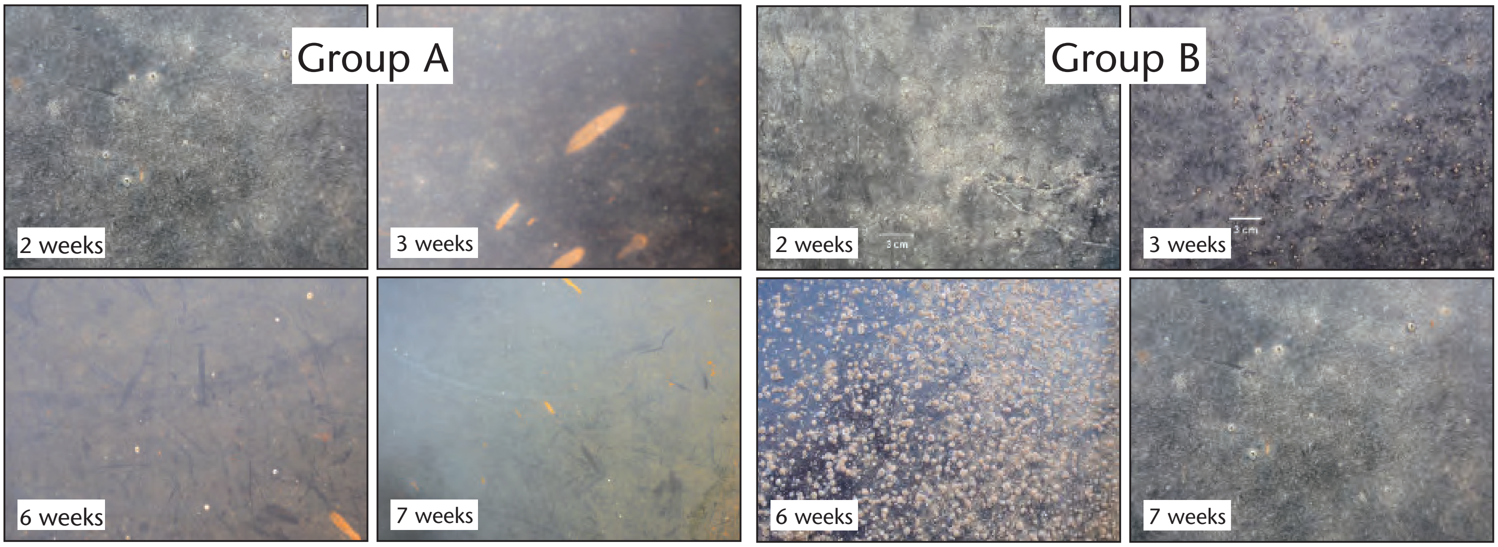


**Figure 3**. *Barnacle growth on the metal plates – a close look. Group A: UV irradiated plate observed at week 2, 3, 6 and 7 (the yellow spots are the drops of rust materials from the cover); Group B: control plate observed at week 2, 3, 6 and 7.*

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inactivation of the eggs released by adult barnacles; (c) inactivation of microscopic *Nauplius* larvae when it swims and drifts through the water; (d) damage of the DNA preventing reproduction; and (e) deterioration of cement / proteinaceous substances secreted by *Cyprids* therefore making attachment less effective.

## *UV Radiation*

Considering the dynamic movement of the seawater, changes in seawater characteristics, and the ability of the *Nauplius* to swim and attach onto the metal surface at any time, it would be more reasonable to assess the effectiveness of UV treatment based on irradiance rather than UV dose.

There were six 120-W low pressure UV lamps mounted on the surface of the 100 cm x 90 cm metal plate. Assuming that an average of 50% of the UV output is reflected back to the water by the UV reflecting cover sheet and that the $UVT_{254}$ of the seawater varied between 50% and 80%, the irradiance at the metal surface could range from 0.06 to 11.5 $mW/cm^2$ (see **Figure 4 and 5**). As expected, the higher the UVT, the greater the irradiance observed on the metal surface (see **Figure 4**).

As there was no barnacle growth on the UV treated metal plate, it is reasonable to conclude that an irradiance as low as 60 $\mu W/cm^2$ was sufficient to prevent *Nauplius* and *Cyprid* from attaching to and growing on the metal plate surface. The locations where the irradiance was lowest were the strips between two UV lamps. The low irradiance observed here has the same magnitude that was used in testing for the control of micro-fouling on optical glass surfaces (Dilcalvo and Cobet, 1974; Patil et al., 2007). There an irradiance of 10 to 30 $\mu W/cm^2$ on the glass surface was effective in preventing bacterial slime film formation and settlement of metazoan larvae (Dilcalvo and Cobet, 1974). In the work reported by Patil et al. (2007) the irradiance was 730 to 1479 $\mu W/cm^2$. In another study, Chiang et al. (2003) reported that UV-B at an irradiance of 7.5 $\mu W/cm^2$ was sufficient to cause damage to the *Naupliar* eyes and impair their phototactic responses, which eventually stopped the organism from living. Considering that there was fouling on the UV lamps during the later part of the study and that there was no barnacle growth on the UV treated metal plate until the end, it can be concluded that the irradiance on the metal plate surface could actually be much lower than the calculated values (see **Figures 4 and 5**).

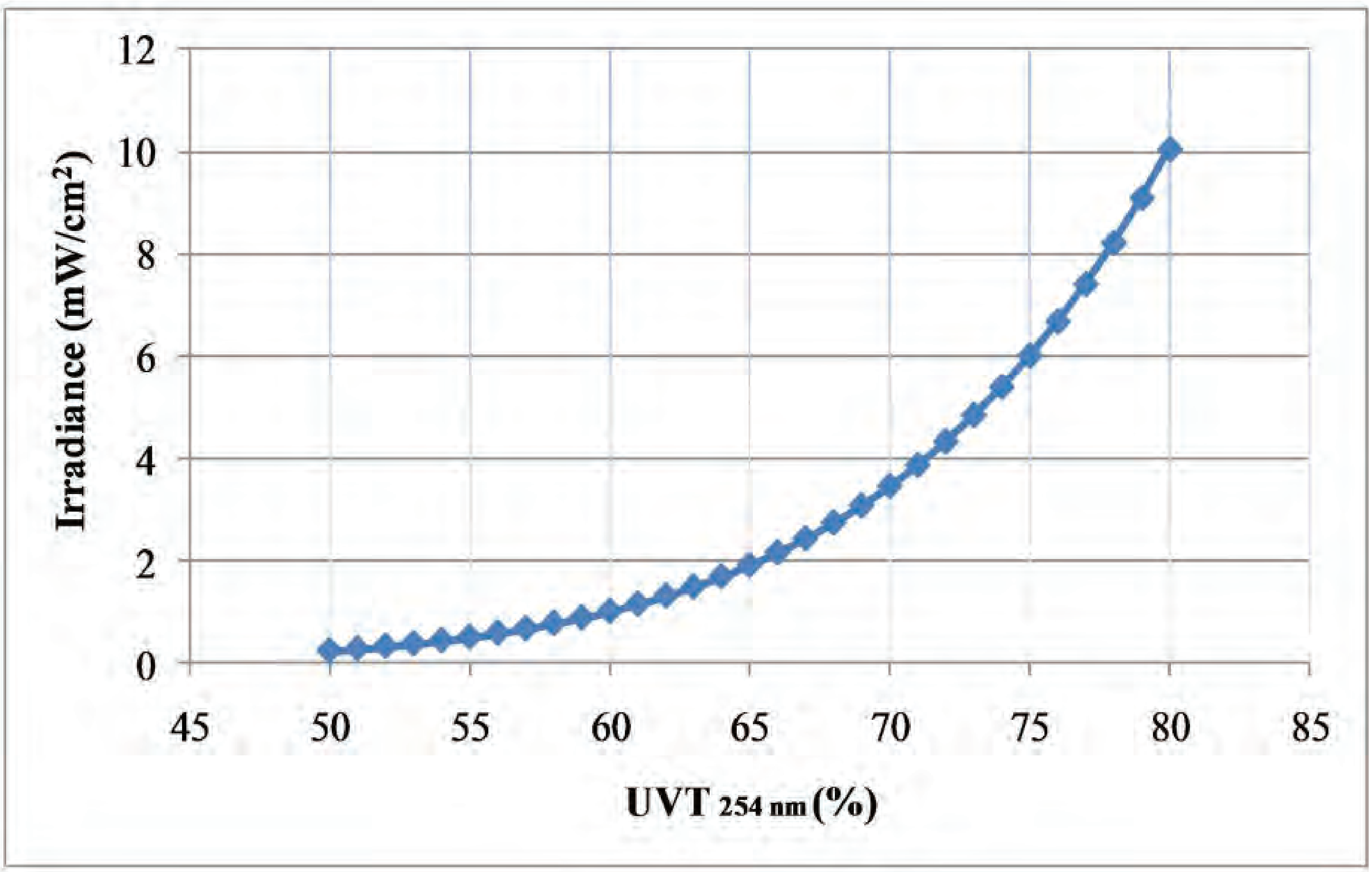


**Figure 4**. *Calculated changes in the irradiance on the metal plate surface as a function of the seawater UVT (254 nm, 1 cm). The metal plate surface was 8 cm away from the 120-W UV lamps.*

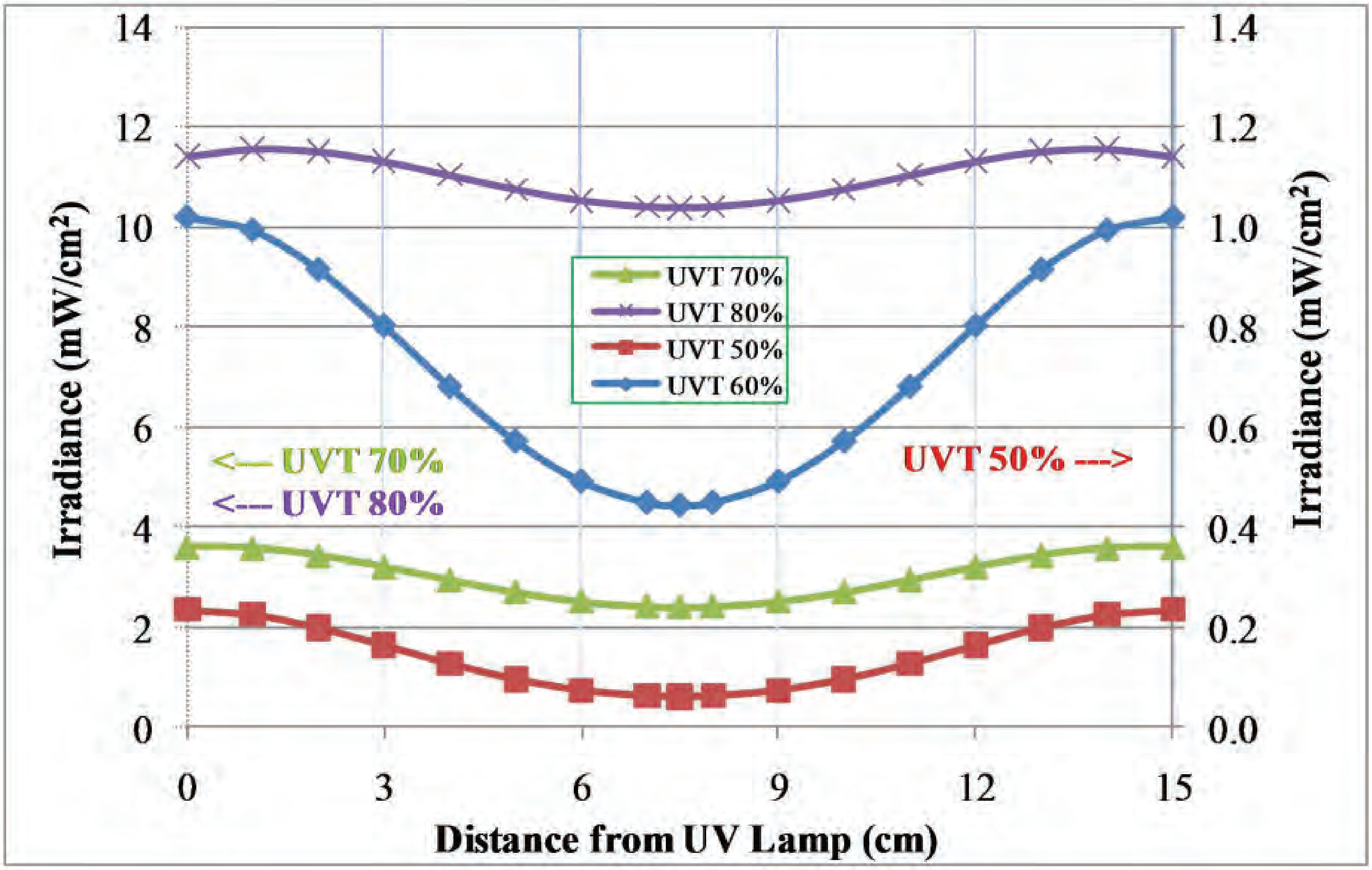


**Figure 5.** *Calculated changes in the surface irradiance from the UV lamps, which could reach the metal plate surface between two UV lamps (at 0 and 15 cm positions).*

# CONCLUSIONS

During the 11 weeks of the study, low-pressure UV treatment effectively prevented barnacles from establishing colonies on a metal plate surface submerged in seawater in a tropical environment. This treatment was also able to stop the growth of attached barnacles, as was observed during a temporary power shutdown of the equipment. The irradiance requirement was used as a measure of the UV treatment required rather than the UV dose. The irradiance requirement could be as low as 60 $\mu$W/cm$^2$ for efficient control of the marine fouling organism.

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