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Phototrophic biofilms on the interior walls of concrete Iterson-type cooling towers

Tomáš Hauer

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Abstract Algae and cyanobacteria form noticeable biofilms in the open spaces of natural draught cooling towers. In spite of this, our knowledge of these communities is still poor. During this study, phototrophic biofilms of seven cooling towers at four different plants in the Czech Republic were collected and studied in order to obtain information on the composition of the communities of these biofilms. Fresh material and cultures of collected material were analyzed with light microscopy. Twenty-five cyanobacterial and four algal taxa were found.

Keywords Cyanobacteria · Algae · Cooling towers · Biofilms · Concrete · Czech Republic

Introduction

Cyanobacteria and algae colonizing buildings, constructions, and artifacts have been studied very extensively (Crispim et al. 2006; Rindi and Guiry 2004; Uher et al. 2004). They cause not only esthetic changes of the sites they settle on but also contribute actively, sometimes substantially, to their damage (Urzi 2004). This destruction may be caused chemically by metabolic activities leading to the dissolving of the substrate (Brehm et al. 2005) or physically by changing the volume of their mucilaginous sheaths during drying/rehydration cycles (Gorbushina 2007).

Cooling is a common and necessary part of many processes, such as in the generation of electricity, in the chemical industry, and in metallurgy. Important components of the cooling system are devices for the dissipation of unwanted heat into the environment. One such device is the hyperbolic natural-draught cooling tower invented by the Dutch engineer Frederik Karel Theodor van Iterson in 1918.

These towers are filled to approximately one quarter of their height with packing material, through which the cooled water flows and eliminators prevent water droplets from being carried away by the rushing air. Aquatic species of phototrophs are present on these eliminators.

The other three quarters of the towers is a walled open space, mostly without contact with the cooling water. Walls of this part of the cooling towers are (often) like a tropical wet wall—ideal for the colonization of several types of living organisms. Here, we find relatively stable temperature, moisture, air flow, and supply of nutrients in comparison with the natural environment. Inner walls of the tower are usually treated with paint to reduce the corrosive action of the condensed water on the concrete shell.

The biota of the lower quarter of the towers is being studied quite intensively for several reasons. The number one priority is the fight against living organisms, which causes the reduction of cooling performance and damages the cooling technology (e.g., Liou 2009). The second important reason is to control the occurrence of pathogenic organisms such as *Legionella* (Gaylarde and Morton 1999; Gobin et al. 2009; Pagnier et al. 2009) and *Amoebae* (Pagnier et al. 2009). The algae of the cooling systems have been studied by Sládečková and Sládeček (1958) and Liou (2009); however, algal communities from the upper part of

T. Hauer
Institute of Botany, Czech Academy of Sciences,
Dukelská 135,
Třeboň 37982, Czech Republic

T. Hauer (✉)
Faculty of Science, University of South Bohemia,
Branišovská 31,
České Budějovice 37005, Czech Republic
e-mail: hauer@butbn.cas.cz

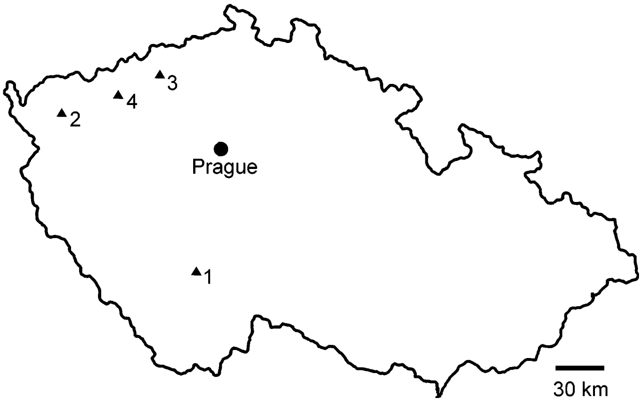

Fig. 1 Map of sampling sites in the Czech Republic: 1 Temelín power plant, *2* Vřesová power plant, *3* Záluží petrochemical plant, *4* Prunéřov II power plant

the towers have been studied only rarely. They are mentioned in technical literature by Doyle et al. (2004) only in general, without any information on the community composition.

This paper provides the results of the phototrophic biofilms research in the upper parts of seven cooling towers in the Czech Republic.

Methods

Biofilms for this study were taken from four different plants in the Czech Republic (Fig. 1): (1) Temelín power plant—two towers, (2) Vřesová power plant—one tower, (3) Záluží petrochemical plant—one tower, and (4) Prunéřov II power plant—three towers. A total of 66 samples were analyzed. The samples were taken once in each tower, according to the access possibilities of the towers: from the inner side of the tower's shell—directly above the eliminators—all towers; from the uppermost part of the tower—one tower; from the flakes of dried biofilms which have fallen onto the eliminators—all towers; and from maintenance foot bridges above the eliminators and their railings—all towers. All of the investigated objects were covered by epoxy paint on the inner walls. The towers, even at the same location, differed in the amount of time that has passed since the last renovation. The dates are mentioned in Table 1.

The biofilms were scratched from the substrate using autoclaved disposable sticks and inoculated on agar plates with WC medium (Guillard and Lorenzen 1972) directly at the sampling site. Part of each sample was also taken to be studied by bright field, differential interference contrast and epifluorescence microscopy using an Olympus BX 50 microscope. Photographs were taken with Olympus DP71 digital camera.

For taxonomic identification, Komárek and Anagnostidis (1998, 2005), Starmach (1966), and Ettl and Gärtner (1995) were used. The inoculated material was cultivated under 12:12 light/dark cycle at 23°C for 3 months.

Results and discussion

A total of 25 taxa of cyanobacteria and four taxa of green algae were found in the cooling towers (Table 2). Most of the taxa were aerophytic species; only one thermophilic type, *Aphanothece bullosa*, was found forming a minority of the biofilm in one tower. Interestingly, no aquatic type commonly present in the cooling water was recorded in the biofilms. A pantropical type *Brasilonema* was found in one tower in Vřesová. The biofilms were most abundant in the upper part of the hyperboloid (Fig. 2), where there are good light conditions, and also on the maintenance foot bridges. Microalgal communities also occurred on walls in the lower part of the towers near the eliminators, but did not form biofilms of significant thickness.

Towers in particular localities have very similar, but not the same, composition of biofilms and also, as is can be seen in Table 2, the number of species in the biofilms does not always correlate with the time since last renovation. Both are probably caused by different utilization of the towers according to the needs of power generation, which is driven, above all, by electric power demand and is not reliably predictable. Another factor involved when dealing with a grouping of towers is the shade caused by water vapor plumes of the neighboring towers.

The biofilm species composition of the cooling towers was also found to be rather different from the composition of natural aerophytic epilithic communities previously studied in the Czech Republic (Hauer 2007, 2008; Hauer and Pažoutová 2009).

The very common species in the upper parts the towers is *Gloeocapsa compacta*; however, it occurrs rarely in natural habitats within the Czech Republic. On the other

Table 1 Years of renovation of particular towers

Tower	1	2	3	4	5	6	7
Year of last renovation	2007	2005	2000	2007	2008	2008	2008

1 Záluží, *2* Temelín, tower IV, *3* Temelín, tower II, *4* Vřesová, *5* Prunéřov, tower I, *6* Prunéřov, tower II, *7* Prunéřov, tower III

Table 2 List of species found in particular towers

Species/locality	1	2	3	4	5	6	7
Cyanoprokaryota							
Aphanocapsa muscicola (Meneghini) Wille	x						
Aphanothece bullosa (Meneghini) Rabenhorst				x		x	
Aphanothece cf. *pallida*		x	x			x	
Brasilonema sp.				x			
Calothrix sp.						x	
Chroococcus cohaerens (Brébisson) Nägeli	x	x					
Chroococcus cf. *turicensis*	x						
Chroococcus cf. *varius*	x	x	x				
Cyanosarcina sp.	x					x	
Gloeocapsa biformis Ercegović							x
Gloeocapsa compacta Kützing		x	x		x	x	x
Gloeocapsa rupestris Kützing					x		
Gloeocapsopsis sp.		x	x			x	
Gloeothece palea (Kützing) Rabenhorst		x					
Hassallia sp.	x						
Leptolyngbya cf. *cataractum*					x		
Leptolynbya hennigsii (Lemmermann) Anagnostidis	x						
Nostoc cf. *microscopicum*							
Phormidium sp. 1	x					x	
Phormidium sp. 2	x						
Pseudanabaena cf. *minima*	x				x	x	x
Schizothrix sp.					x	x	x
Scytonema sect. *Myochrotes*			x		x	x	x
Symploca muralis Kützing ex Gomont	x						
Tolypothrix sp.	x						
Green algae							
Chlorella sp.	x				x		
Gloeocystis sp.	x			x	x		
Pseudococcomyxa simplex (Mainx) Fott	x						
Ulothrix variabilis Kützing	x						

1 Záluží, *2* Temelín, tower IV, *3* Temelín, tower II, *4* Vřesová, *5* Prunéřov, tower I, *6* Prunéřov, tower II, *7* Prunéřov, tower III

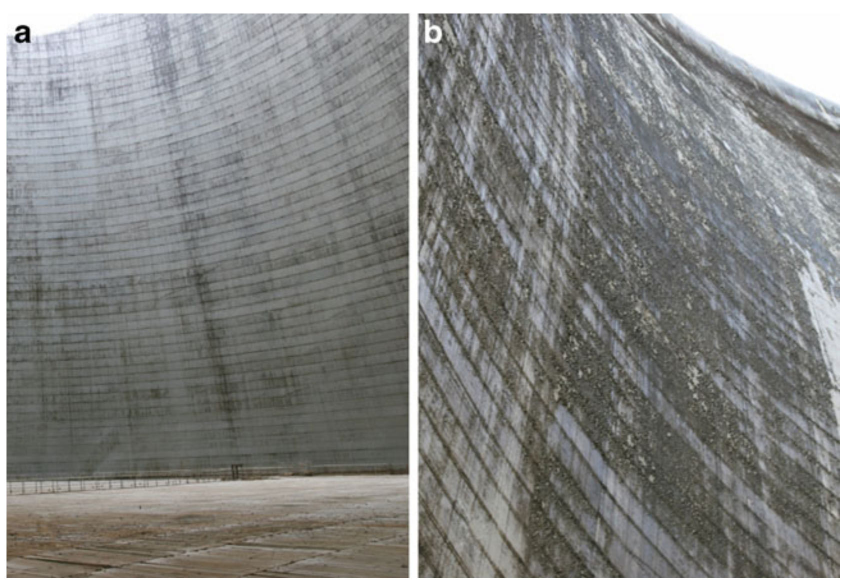

Fig. 2 Biofilms (*dark spots*) on inner walls of cooling towers. **a** Lower part near eliminators with biofilms less abundant; **b** upper part with biofilms more abundant

Fig. 3 Drying biofilm with pieces of protective paint on its bottom side

hand, thick mats of *Phormidium* species, typical for shaded sites, occurred on the maintenance bridges.

The conditions above the eliminators, namely 100% humidity and shade caused by the escaping water vapor, generally favor fast-growing, often heliophobic species, such as *Leptolyngbya* and *Schizothrix*. These species, complemented by members of the *Aphanocapsa*, *Aphanothece*, and *Chroococcus*, form the largest biomass of the biofilms. Only in the most insolated parts did the dominance of other species occur in higher amounts. All of these species, e.g., *Gloeocapsa*, *Scytonema*, and *Hassallia*, possess the capability of synthesis of shield pigments.

According to the observations, the drying biofilm stresses the inner protective paint of the cooling towers and contributes to its damage (Fig. 3), probably by mechanically stressing the paint coat during drying. This deterioration is pronounced especially underneath the biofilms formed by cyanobacteria possessing large compact mucilaginous sheaths such as *Schizothrix*, *Gloeocapsa*, or *Aphanothece* in the upper third of the cooling towers. Mechanisms of the degradative effect of the biofilms to the protective paint are subject of further long-term research.

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