FIRST RESULTS ON USE OF A HYDROGEN PEROXIDE SOLUTION IN POSTOJNSKA JAMA (SLOVENIA) TO REMOVE LAMPENFLORA

Janez Mulec[1], Stanislav Glažar[2]

[1] Karst Research Institute, Scientific Research Centre of the Slovenian Academy of Sciences and Arts, Titov trg 2, SI-6230 Postojna, Slovenia; janez.mulec@guest.arnes.si
[2] Postojnska jama, Jamska 30,SI-6230 Postojna, Slovenia; stanislav.glazar@turizem-kras.si

Abstract: To attract visitors in many show caves, artificial lighting is installed. As a result of artificial lighting in close and remote proximity of lights a community of phototrophic organisms develops. Lampenflora is a cause of biodeterioration of various types of substrata on which it is attached, especially for speleothems and other objects of natural and cultural value. Postojnska jama is a world-famous show cave with electric illumination first installed in 1884. Due to high number of visitors (around 500,000 per year) and a relatively long illumination period (average 1,000 hrs/sector/year) in the tourist part of the cave, lampenflora extensively colonizes some exposed parts. Before 2010 lampenflora was removed by spraying with solution containing active chlorine. 30 % of illuminated cave was treated in 2010 with an environmentally-friendly and odour-free 15 % solution of buffered hydrogen peroxide (pH 7.0-7.5). Solution was applied three times in one-month period. To increase the contact surfaces, biocidal effectiveness and to remove the unaesthetic appearance, taluses of mosses and ferns were removed before the application of hydrogen peroxide. When lampenflora is encrusted with calcium carbonate, the oxidizing effect of hydrogen peroxide is reduced.

Keywords: caves, Postojnska jama, lampenflora, growth control

INTRODUCTION OF CAVE LIGHTING IN POSTOJNSKA JAMA

Caves contain many important records of past geological periods and various cave formations. Many times these structures in caves are exposed to visitors. With an exception of areas near to cave entrances, these structures in show caves are artificially illuminated. In caves till the end of 19th century different sources of light were used, e.g. torches, oil lights, which emitted smoke and soot. In Postojnska jama, for example oil lamps were used for special "grand illuminations" for 12 various occasions between 1860 and 1885 (Shaw 2010).

To avoid smoke emissions and to keep step with development some caves were early equipped with electric illumination. The first cave equipped with permanent electric lighting in 1881 was Luray Caverns, (Virginia, USA), followed by Kraushöhle (Austria) in 1883 and Postojnska jama (Slovenia) in 1884. The entrance of Postojnska jama was known from the medieval age. In 1814 a team rediscovered Rov starih podpisov, a gallery near the mean entrance of the cave with a lot of inscriptions on cave walls. The oldest dated back to 1213 and is not visible today. According to Pierre Minvielle, the author of the signature from 1213 was the first speleologist (Minvielle 1967). The internal parts of Postojnska jama were discovered by Luka Čeč in April 1818. The cave was officially opened as a show cave on 17 August 1819. Like in other caves candles, torches, portable oil lamps and stationary lamps were used to lit the cave, but glass oil lamps are specific to Postojnska jama (Shaw & Čuk 2002, Shaw 2010). Limelight (also known as calcium light, discovered in the 1820's by Goldsworthy Gurney) was not adopted for the cave. As early as 1883 Postojnska jama was illuminated by electric lamps for the first time for a short visit of Emperor Franz Joseph of Austria. There were only three electric lamps. A year after a permanent electric lighting system was installed and put into operation (Table 1).

Table 1. Development of early electric lighting system in Postojnska jama.

Year	Lighting setup	Location
1833	3 electric lamps	Plesna dvorana
1884	12 arc lights	Kalvarija, Plesna dvorana,Veliki dom
1887	40 arc lights	Kalvarija, Plesna dvorana,Veliki dom
1901	12 arc lights, 977 low power bulbs	Kalvarija, Plesna dvorana,Veliki dom
1929	522 lamps from 40 to 2000 W	The whole tourist part of the cave

LAMPENFLORA

Lighting in caves changed human perception of underground, speleothems and space dimensions. On the other hand the introduction of light in light deprived environment enabled growth of phototrophic organisms. This complex community of organisms near artificial light sources is called lampenflora. The German term "Lampenflora" adopted also in the English vocabulary designates phenomenon – proliferation of phototrophic organisms near artificial light sources. Lampenflora grows at sites where under natural circumstances it would not appear. Various aerophytic cyanobacteria and algae, as well as some mosses and ferns dominate. In the early phase, cyanobacteria and eukaryotic algae usually play the most important role, while mosses and ferns appear later in succession. Vascular plants are sometimes found around lamps, but almost always only as germinating shoots (Mulec *et al.* 2008; Mulec & Kubešová 2010).

Lampenflora is a cause of biodeterioration of various types of substrata on which it is attached: speleothems, sediments, prehistoric paintings and historic signatures. Although in some caves lampenflora is presented to tourists as an attraction, for example in Natural Bridge Caverns (Texas, USA), it must be stressed that lampenflora is a consequence of light eutrophication in the underground. The occurrence of green patches deep in caves is interesting, but from the nature protection aspect unacceptable.

Lampenflora in caves represents a triple problem: (1) strange and unnatural greenish appearance of caves and other underground formations, (2) biodeterioration of solid surfaces on which it is attached due to its presence and biochemical activity, (3) effect on cave (troglobiotic) fauna. Effect on cave fauna is mainly indirect, because lampenflora represents huge amount of freshly introduced nutrients in the cave environment, which is normally poorer. Biomass of new formed lampenflora is available for cave-adapted animals and other occasional dwellers of caves. Along with easier available nutrients new comers become more competitive for a new ecological niche and a population of troglobiotic animals can be affected, both in diversity and abundance.

REMOVAL OF LAMPENFLORA

Lampenflora occurs in show caves as (active growing) green patches and encrusted with calcium carbonate. Lampenflora can become gradually encrusted because of its location under the oversaturated seeping water, or because of biologically enhanced carbonate deposition of some lampenflora organisms. Such an amorphous mix of dead phototrophs and carbonate irreversibly destroys speleothems or other objects of cultural value.

Many approaches to control lampenflora have already been tested, including physical, e.g. reduction of light intensity and lighting period, and chemical by applying various biocidal chemicals, such as formalin, bromine and cupric solutions, and solutions based on active chlorine (Mulec & Kosi 2009). Removing lampenflora by using brush might destroy fragile cave minerals. When planning the lighting setup it is important to define duration, intensity and appropriate sites to illuminate. A very promising recent approach is installation of LEDs (Light Emitting Diode) because of low energy consumption, long lasting LEDs and potential to tune the desirable emission spectrum (Toomey *et al.* 2009). In several caves around the world this new type of illumination is already in use.

CONTROL OF LAMPENFLORA IN POSTOJNSKA JAMA

Due to high number of visitors in Postojnska jama (around 500,000 annually) and a relatively long illumination period (average 1,000 hrs/sector/year) in the tourist part of the cave, lampenflora represents a serious problem for speleothems and other objects of cultural value, for example historic signatures and inscriptions in the gallery Rov novih podpisov.

Till 2010 regular removal of lampenflora in Postojnska jama included application of active chlorine (bleach) in working concentration of 100 mg/l. Every two years a team of professionals (Zavod za zdravstveno varstvo Maribor) applied active chlorine. They sprayed in the winter period for about a week, starting from the main entrance of Postojnska jama through the old cave along the railway to the railway terminus below Velika gora. Velika gora is the starting point of the tourist walk and also the biggest room in Postojnska jama with the dimensions: 40 m width, 100 m length and 32 m height. After lampenflora in Velika gora was sprayed, the application of the solution proceeded through the tourist part named Lepe jame to Črna jama and finally to Pivka jama. Spraying has been performed after daily tourist visits. On average 150 litres of solution were introduced into the cave during one application. Bad odour of chlorine was detected in cave air at least one month after application. Besides formation of unpleasant smell of chlorine, in nature chlorine compounds react with many different natural substances what results in formation of different toxic products. In addition chlorine compounds in water lower pH, what leads to corrosion of carbonate speleothems (Faimon *et al.* 2003). Such an aggressive chemical is not appropriate for sensitive cave environment.

USE OF HYDROGEN PEROXIDE SOLUTION

Based on literature (Faimon *et al.* 2003), laboratory tests and experiments from test sites in Postojnska jama, a novel procedure has been developed to remove lampenflora. In 2010, instead of chlorine solution an environmentally-friendly and odour-free 15 % solution of hydrogen peroxide was prepared with carbonate buffer (pH 7.0-7.5) and applied three times in a one-month period. Once hydrogen peroxide is buffered, it becomes unstable and losses its biocidal activity. To increase the biocidal activity and to remove the unaesthetic appearance, taluses of mosses and ferns have to be removed before application. Application of solution over speleothems covered with lampenflora has to be done as fast as possible. Prior application the treated surface area has to be estimated. On this base appropriate volume of solution has to be prepared in a cave where application will take place. Because hydrogen peroxide is an unspecific oxidant, proper protection measures have to be implemented during its application, such as protection gloves, masks, clothes and boots.

Approximately 30 % of lightened passages and the most exposed parts in Postojnska jama were treated in 2010 (Table 2). An average consumption of buffered hydrogen peroxide solution volume was 1050 ml per 10 m^2. Based on our experience maximum volume to apply at once was 2.0 l what corresponds to the surface of 60 m^2. For one application 20 minutes were needed on average. In a team of personnel which sprayed speleothems with hydrogen peroxide solutions there were always three persons: a leader, a person responsible for preparation of working solution and a person who did the application. In Lepe jame during the first application in April 2010 humidity was high due to heavy rains in that period, and optically the results of lampenflora removal were less effective compared to the second application in July 2010 which was done during the dry and hot period.

In Postojnska jama the hydrogen peroxide solution was efficient in killing lampenflora. In comparison with bleach, hydrogen peroxide solution is less effective and its application is more time consuming, but on the other hand it is odour-free, less hazardous for users and environmentally friendly with less toxic end products of oxidation reactions.

CONCLUSIONS

The buffered solution of hydrogen peroxide was effective when applied to active grow-

Table 2. Details on application of hydrogen peroxide solution in Postojnska jama for lampenflora removal.

Location	Period	Treated area	Volume of applied solution
	dd/mm/yy	m^2	l
Speleobiološka postaja	25/03 – 08/04/10	60	2.0
Lepe jame	01/04 – 16/04/10	400	14.0
Lepe jame	16/07 – 30/07/10	400	14.0

ing lampenflora. General guidelines for cave management based on this procedure will be prepared when no-, or negligible effects on carbonate substrata on micro level are proven and concentration of working solution and other parameters optimized. Once lampenflora is covered with flowstone, the oxidizing effect of hydrogen peroxide is reduced.

It has to be stressed that the above described procedure is not the ultimate solution for removal of lampenflora in show caves, because its growth is not stopped, but it is just slowed down. More sustainable approach in restricting lampenflora growth lies in the change of existing lighting to LEDs or other corresponding system. It is also important to change the concept of lighting in show caves: sometimes it is better not to present everything in the brightest light.

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