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Original article

A methodology for detecting the level of fungal contamination in the French Film Archives vaults

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ABSTRACT

The *Archives françaises du film* ([AFF] French Film Archives) of the Centre national du cinéma et de l'image animée (National Center for Cinema and the Moving image [CNC]) is regularly facing problems of molds growth on cinematographic films enclosed in plastic and metal containers. This study is conducted through comprehensive microbiological testing on films, shelves and air quality for the AFF storage sites (Saint-Cyr and Bois d'Arcy), in order to understand the origin of fungal development and subsequently to suggest a suitable solution to eradicate ongoing mold growth and to combat further contamination. The air analysis shows that the amount of airborne mold on both sites is small with concentrations 3 times less than level 1 (<170 CFU m^{-3}), which is considered as a weak threshold for indoor environment concentrations. An increase of outdoor air concentration of mold has no effect on indoor concentrations. On the other hand, on surfaces, fungal concentration can reach 4 times the limiting value (50 CFU dm^{-2}). No direct relationship was observed between the contamination in the air and shelves. Molds that have grown on film rolls include mainly and at a high frequency two xerophilic species with a strong gelatinolytic capacity: 62.5% were identified as *Penicillium corylophilum* (Aw 0.80) and 18.75% as *Aspergillus versicolor* (Aw 0.78). Because they are scarce in the air and on surfaces, it indicates that the films were not contaminated inside the storage areas. However, unfavorable climatic conditions in the storage vaults have triggered mold development inside the plastic or metal containers.

1. Introduction and research aims

The Archives françaises du film ([AFF] French Film Archives) of the Centre national du cinéma et de l'image animée (National Center for Cinema and the Moving image [CNC]) holds the largest film collections deposited in France that are invaluable holdings for cultural heritage. Storage facilities are housed in two former military forts in west of Paris, Fort de Saint-Cyr and Batterie de Bois d'Arcy, built at the end of the 19th century and located 2 km from each other. The two sites are surrounded by large vegetation. To date, about 1.2 million film cans are stored in different buildings. Film rolls are first segregated according to their film base prior to storage. The cellulose nitrate based films, produced between 1895 and 1953, due to their highly flammable and unstable nature, are stored in 223 individual concrete compartments to avoid the risk of fire spread. They self-destruct by emitting corrosive and harmful gases (nitric and nitrous acids), including powerful oxidants (nitrogen and sulfur oxides). Cellulose acetate based films were first introduced in the 1920s and are non-flammable but release acetic acid when deteriorating, a phenomenon known as the "vinegar syndrome". Since the 1960s all endangered films items are being copied onto a new safety base film and stored in air-conditioned vaults located in multistory buildings constructed in the second half of the 20th century. Generally, for a given movie film, negative, positive, intermediate elements and magnetic sound elements are enclosed separately in different containers.

Indeed, these films are very sensitive and subject to various factors in particular temperature, moisture, chemical compounds and biological contaminants. Chemical compounds (sulfur dioxide, nitric acid, nitrogen peroxide, ozone, formaldehyde, formic acid...) come both from the atmospheric pollution, the building and furniture materials and the collections themselves.

In general, chemical aspects of film degradation are widely described by many authors for both nitrate and acetate films

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[1,2]. In contrast, microbiological aspects are more scarcely studied whereas the contamination of films by mold is a recurring problem in the storage areas [3]. The offending species are little known. In fact, film stock has two primary layers: a transparent plastic base layer supporting at least a gelatin emulsion layer carrying photosensitive materials. As a potential source of nutrients for mold, both the base and the emulsion are subject to fungal decay. Opela [4] was the first to complete an extensive study in the Film archives of the Slovak Republic, by determining the level of fungal contamination in the air, on the surfaces and the objects, and identifying species. Fungal biodiversity was shown to be higher in the air than on the films, the predominant species belonging to the two genera: *Aspergillus* and *Penicillium*. In the Spanish Film Archives, Abrusci et al. isolated and identified, on black and white films, yeasts, 14 bacterial species including 7 having a gelatinase activity, and 17 fungal species capable of degrading gelatin [5]. In addition to film material decay, microorganisms may constitute a health hazard for persons handling contaminated films. Bingley and Verran [6] analyzed the concentration of mold spores released into the air by the films. It ranges from 0 to 3000 CFU per cubic meter, while 1000 CFU per cubic meter is considered to be an exposure threshold above which there would be a risk to human health [7,8].

In the AFF, although indoor environmental conditions are adjusted to setpoint values (10 °C, 35% of relative humidity "RH") as closely as possible to the international recommendations for Film preservation [9], large areas of mold growth were detected during a visual inspection conducted in the storage vaults, not only on the walls and ceilings surfaces but also inside many plastic or metal (sometimes rusty) film cans (Fig. 1). Only acetate base films, particularly cellulose triacetate (CTA) are contaminated at the moment. Consequently, it was decided to study the microbiological status of the premises on the two sites of the AFF and identify the species present in the air, on surfaces and film rolls enclosed in cans, in order to define the relationship between the fungal contaminations of these three elements. As it is known that outdoor airborne microorganisms infiltrate indoor [10], we reported further on the concentration and nature of fungi in the outdoor air in order to compare. Results will allow managing the microbiological problem (s), by developing treatments for contaminated films, returning the building to a satisfactory level of performance and assessing the risk of adverse effects on employee health.

2. Materials and methods

2.1. Storage vaults

This work was conducted in late winter (March 2013) when weather has still dry and repeated in mid spring (May 2013) because it is a favorable time for vegetation to regenerate but also a greater outdoor mold activity. Moreover the testing campaign in May was preceded by days of rain. The lush landscaping and numerous trees surrounding the storage buildings create a microclimate that may impact the ingress of mold spores indoors through heating, ventilation and air-conditioning (HVAC) ducts or opening elements.

Sampling operations are carried out in 2 vaults of Batterie de Bois d'Arcy (in Building B) and 4 vaults of Fort de Saint-Cyr (in buildings Z1 and Z2). The buildings have no window and were designed for the purpose of film storage. In each vault, stored materials always include a mix of films on polyester, cellulose triacetate, black and white, color, negatives and positives. Storage areas on each floor consist of successive rooms interconnected by simple doors.

Building B was constructed in 1974. The load-bearing structures for walls and roofs are metal; the floors are concrete slab, and external and internal walls are red bricks. In 2007–2008 was added an external wall insulation involving glass wool covered with an exterior aluminum-PVC cladding.

Buildings Z1 and Z2 were constructed, respectively in 1986 and 1991, of reinforced concrete. They are partly buried and the flat roofs emerging from the ground were insulated with PUR foam panels together with a green roofing system (partly).

New air-conditioning facilities were put into service respectively in 2005 (Batterie de Bois d'Arcy) and in 2008 (Fort de Saint-Cyr): each building is served by its own and only central air-conditioning system that implements 100% fresh outside air for Building B and 97% recirculated air for Z1 and Z2, and completed with dehumidifiers; for both B and Z, air change rate is 2.5 volumes of air per hour in the room, and air filtration consists in a set of 2 types of filters: polypropylene pleated media, EN779 class G3, gravimetric efficiency of 80%, and pocket filters, EN779 class G4, gravimetric efficiency of 92%. The filters are periodically changed and the floor surface is cleaned (dust free) every 6 months.

Within the framework of a larger survey conducted by The Centre de recherche sur la conservation des collections (CRCC), temperature and RH of the air inside the vaults were recorded by means of PEM2 thermohygrometers for a period of 6 months for Building B (from March 2013) and one year for buildings Z1 and Z2 (from September 2012). In general, temperature is fairly controlled around 10 °C but with an amazing rise up to 25 °C in Z2 during the summer (Fig. 2). On the other hand, though fluctuating strongly and suddenly, the RH range is roughly acceptable (30 - 60%) for Building B but remains very high (45–85%) for Z1 and Z2, and raising great concern because high humidity is the principal cause of mold growth. Moreover, the survey shows that the ambient RH fluctuations inside the vaults are smoothened inside the film cans, due to the buffering effect of the film materials.

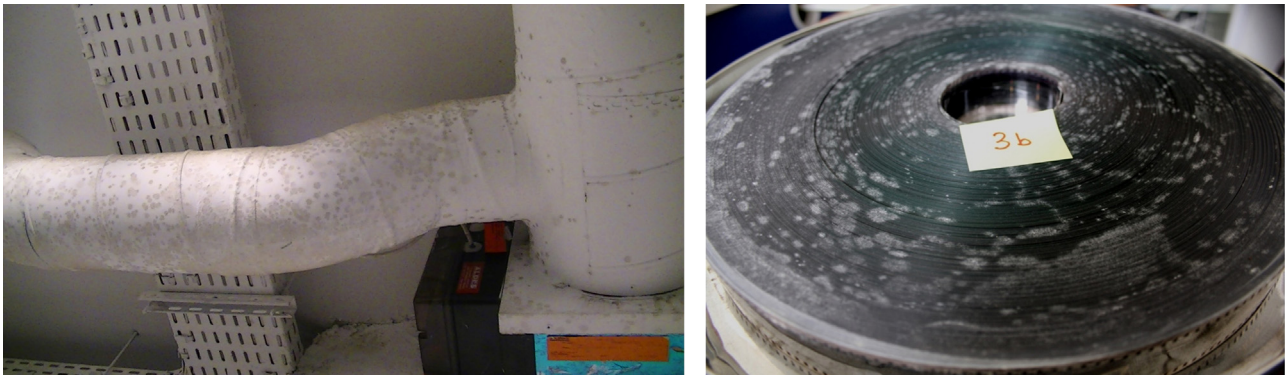

Fig. 1. Mold growth spots on walls and ceilings (left) and film roll contaminated by mold (right).