MICROBIAL DETERIORATION OF PAPER MATERIAL

—A Literature Review

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The microbiodeterioration of paper material like books, archival material, manuscripts both illustrated and written, decorative wall papers, etc. is a serious problem throughout the world in museums, libraries, archives, etc. where these materials are placed. (See, 1917; 1919; Omelianskii, 1925; Bakhatin, 1928; Marcella, 1936; Bryan, 1937; Anchabaze, 1949; Armitage, 1949; Kowalik, 1952, a and b; 1956; 1962; 1963; 1972; 1977; 1980; Belyakova, 1953; Rybakova, 1953; Kathpalia, 1960; Nyuksha, 1961; Gallow, 1963; Deshpande and Mantri, 1966; Hughes, 1968; Flieder, 1969; Lazar and Dumitru, 1972; Fischer, 1977; Lelis, 1980; Miller and Harold, 1981; Nair, 1981; Camargo, 1982; Dhawan and Agrawal, 1986). In India in addition to the above materials, different varieties of miniature paintings were also done on paper which are known as miniature paper paintings (Agrawal, 1984). This problem needs special attention where the climate is hot and humid (Nair, 1972 and Agrawal, 1977).

The basic component of paper is cellulose. In addition to cellulose, it also contains lignin, hemicellulose, pectins, waxes, tanins, proteins, minerals etc. Further more paper may contain resinous materials, fillers, and dyestuffs. Various impurities are added during its productive cycle which forms the basis for microbial nutrition (Kowalik, 1980).

Micro-organisms growing on paper are actinomycetes, bacteria and fungi. These organisms multiplying on paper utilize intentional additives of adventitious impurities and prepare substrate for typical cellulolytic micro-organisms.

Scientists after prolonged observations have mentioned that fungi are exceptionally abun-

dant on the earth, they have a variety of fermentive complexes and high ecological adaptability which give them the leading place in damaging paper material.

It has been experienced by microbiologists that abundance of micro-organisms takes place after the ravages of flood.

Omelianskii (1953) reported after the flood of river Neva in Colombia 1924 where 62,000 books were destroyed, a number of fungal forms were isolated.

In Toscany, in 1966, over 30 libraries and archives suffered extensive damage by fungi after disastrous flood. In Lisbon, in 1967 many valuable manuscripts belonging to the Calouste Gulbenkien were also damaged (Reed, 1972). Similar damages have been reported in the USA, Canada and Poland libraries, archives and museums, (Fisher, 1977; Cunha, 1977; Martin, 1977; Stanojlowic, 1978).

In India Narayanan (1963 a and b) reported microbial attack on paper after the flood in Poona 1961.

Such disasters involve, rapid movement of flood waters which carry with them materials derived from manifold activities of modern cities, chemicals, oils and different biological agents from sewage which additionally devlop rapidly, after contact with the constituents of atmosphere (Reed, 1972).

Microbial spores which are always present in air light on the paper material, and after getting proper humidity (more than 75%) and temperature (25-35°C), start to germinate. Anchabagze (1949) published a report of an investigation of manuscripts at the Georgian State Museum. He enlisted 17 species of fungi and considered air to be the principal cause of the abundant contamination of the material.

Nyuksha (1954 a and b) isolated fungi from books, and at the same time a mycological analysis of the air in the library rooms. Finally the relationship between the mycoflora of paper were studied. Then an investigation of finished paper and new books was carried out and the change in contamination of books was observed as a function of their handling and library processing. On the basis of these studies, the investigator was able to get a clear picture of the constitution, distribution and changes of mycoflora, the manner of their deve-

lopment under different conditions and in different materials during various stages in the existence of the stores.

Nyuksha (1956) explained that many species are known which take no active part in the destruction of paper fiber but are found in large quantities. The particular species referred to was *Mucorals*, *Monilia sitophyla* and many representatives of *Penicillium* variety (asymetrica). These fungi, widely distributed in nature, light on books also in a large number from the surrounding air, so that it is difficult in practice to protect the samples from them as completely as might be desired. Therefore, it was suggested that in the characterisation of book-mycoflora one must not attribute primacy to this group of fungi on the basis of the prevalence but on the ability of the fungi to destroy book material.

In India for the first time aerobiological studies inside the library was conducted by Tilak and Vishwe (1976). They indicated the presence of *Aspergillus*, *Torula*, *Penicillium*, *Trichoderma*, and *Chaetomium* spores.

It is a well known fact that books, and manuscripts, etc. stored under improper atmospheric conditions are likely to become mouldy (Rybakova, 1953). On the basis of his wide studies, 92 different strains of fungi belonging to the 16 genera were reported and a correlation was established between the number of damaged books and the condition of storage. Aleksi (1965) studied the mycoflora of an archival store-room.

Under normal book storage conditions, book bindings are the first to take on moisture from the air while the interior parts do so later. In other words when the RH of the air increases in the room the spores can germinate most quickly on the bindings. It has sometimes been observed that books become mouldy even at a RH of 50-60% which is the recommended RH for keeping paper material. Repeated experiments were also carried out by Thomas and Beckwith (1935) by planting fungi on filter paper to which had been added small amounts of a nutrient solution, it was observed that on various papers of known sizing contents the spore would not germinate, when the RH surrounding the cultures was kept below 75%. It was also noted that with any increase in humidity above 75%, marked acceleration of growth takes place.

Book mould therefore is produced first of all by the type of spores requiring very moderate amounts of moisture or by those which are capable of germinating at relatively low humidity.

They are for the most part adopted to the bindings and in the first stage do not participate in the destruction of cellulose. Somewhat later, other species appear and the penetration of the mould into the depth of the material begins. The book-mycoflora becomes more diversified and fungi capable of destroying cellulose requiring greater humidity than the first occupier of bindings assumes the principal role.

A number of fungal genera have been reported from various paper materials (Sartory, *et al.*, 1934; 1935; Beckwith *et al.*, 1940; Waksman, 1940; Kowalik, 1952 a; Belyakova, 1961; Nyuksha, 1954 b; 1956; Fausta, 1963; Flyate, 1968; Dohlakia and Chhalpar, 1980; Leznicka, 1980; Strzelczyk and Leznicka, 1981; and Lea Nol and Knneth 1983). Some of them are given below:

1. *Acrothecium*
2. *Alternaria*
3. *Aurobasidium*
4. *Aspergillus*
5. *Botryotrichum*
6. *Byossochlamys*
7. *Cephalosporium*
8. *Chaetomium*
9. *Cladosporium*
10. *Curvularia*
11. *Epicoccus*
12. *Eidomella*
13. *Fusarium*
14. *Gliomastix*
15. *Hormodendrum*
16. *Humicola*
17. *Memnoniella*
18. *Monilia*
19. *Myrothecium*
20. *Mucor*
21. *Neurospora*
22. *Paceilomyces*
23. *Penicillium*
24. *Phialophora*
25. *Phoma*
26. *Pestalotia*
27. *Pelicularia*
28. *Pulluraria*
29. *Spicaria*
30. *Scopulariopsis*
31. *Stemphylium*
32. *Stachybotrys*
33. *Trichoderma*
34. *Verticillium*
35. *Ulocladium*

Joshi (1958), Narayanan (1963 a and b) reported species of *Stachybotrys lobulata* Berk. *Trichocladium opacum* (Crd.) Hughes, *Monotospora cuneiformis* (Rich) Sacc. Tilak and Jadav (1970) isolated *Melanomma marthwadensis* from the decaying brown paper of Maharashtra Deshpande and Mantri (1966) reported *Cunnighmella* sp. from the rotten filter paper. Nair (1977) conducted studies on fungi growing on old manuscripts and identified *Aspergillus niger*, *A. glacus*, *A. flavus*, *A. restrictus*, *Alternaria* sp., *Cladosporium* sp., *Curvularia* sp., *Fusarium* sp., *Penicillium* sp., *Trichoderma* sp.

Recently Dhawan and Agrawal (1986) have studied fungal flora of miniature paper paintings and lithographs of State Museum, Lucknow, and have isolated 23 fungal species which were-*Aspergillus chevalieri* (Mangin) Thom and Church, *A flavus*. Link., *A. melleus* Yukawa., *A. nidulans* (Eidam) Winter., *A. niger* van Tieghem., *A. stellatus* Curze. Rend. *A. sydowi* (Bainier and Sertory) Thom and Church., *A. terreus* Thom., *A. ustus* (Bainier) Thom and Chruch., *A. versicolor* (Vuillemin) Tiraboschi., *A. wenti* Wehmer., *Alternaria alternata* (Fr.) Keissler., *Cephalosporium acremonium* corda., *Chaetomium globosum* Kunze. ex stend., *Cladosporium cladosporioides* (Fres) de vreis., *Fusarium oxysporum* Schlechtendalid., *Paceilomyces varioti* Bainier., *Penicillium chermesinum* Biourge., *P. chrysogenum* Thom., *P. citrinum* Thom., *P. coryophilum* Dierckz., *P. frequentans* Westling, *Trichoderma viridi* Pers. ex Gray.

Fungi growing on paper produce black, brown, and yellow pigmentation which peneterate the paper (Nyuksha, 1956; Kathpalia, 1960 and Kowalik, 1962; 63 and 80) these stains are difficult to remove by the usual restoration methods.

Nyuksha (1956) studied the pigmentation of different fungi growing on paper and reported that the colour of the pigment may change depending on the condition of the growth and the properties of paper. It was explained that *Gymnoascus sitosus* forms no pigment at all on paper, with colophony. On baryta paper, it produces a fine crimson red colour and on rag paper, with starch sizing, a lemon yellow. In the same way *Penicillium pinophilium* forms a red pigment on rag paper with gelatin sizing and on filter paper a pink shade.

Later on Kowalik (1962, 1963) isolated the following fungi and also observed the pigmentation on paper.

Phoma humicola Gilman and Abbott. grey brown or black spots.

Chaetomella horrida, Oudemans-grey brown spots.

Cephalosporium acremonium, Corda-orange to rose tints according to pH.

Trichoderma viride, Pers. ex. Fr-stained light green.

Aspergillus fumigatus, Fresenius—In the beginning grey, afterwards green, and at last dull brown.

A. Wentii, Wehmer-light rose.

A. niger, Van Tieghem-minute black superficial colonies will appear.

Paecilomyces varioti, Bainier - light yellow brown shade.

Spicaria, Harting - gave lilac spots.

Botryotricum atrogriseum, Van Beyma - steel grey shades.

Sepedonium, Link - Grey spots.

Acrostalgmus cinnabarinus, Corda - stained paper rusty shades.

Eidamella spinosa, Matruchot and Dassonville - developed amaranthine spots.

Mycogone nigra, (Morgan) Jensen - developed green spots.

Stachybotrys atra, Corda - stained and covered paper with black or greenish black growth with greenish grey or brown zones.

Torula, Persoon - caused black spot.

Gliomastix convoluta, (Marchal) Mason-stained paper black.

Gliocladium roseum (Link) Thom. stained paper rose.

Trichocladium, Harz-stained greenish yellow or greenish rusty depending on strain and pH.

Cladosporium herbarum, (Persoon) Link-covered paper by blackish green spots-

Helminthosporium, Link-stained paper greyish white.

Curvularia lunata, (Walker) Boedijn-covered paper by black spots and afterwards developed larger spots.

Trichothecium roseum, Link, developed on paper fluffy colonies, growing well. They formed at the begning white afterwords pale rose stains.

Acrothecium, Preuss-stained it olive green.

Alternaria, Nees. and *Stemphylium*, Wallroth-stained brown greenish spots.

Epicoccum nigrum, Link-black colonies adhering tightly to the fibers.

Fusarium, Link-discoloured paper giving violet tints, blue spots, pink violet spots and yellowish pink spots.

Nyuksha (1976) demonstrated that during the cohabitation with other fungi *A. flavus*, stimulates pigmentation of other fungi like *Myxotrichum deflexum* on paper supresses the growth of *Verticillium tenerum*, *Stachybotrys chartarum*, etc.

A Number of actinomycetes strains injurious to old books, manuscripts and archival documents have been interestingly reported by Czerwinska, *et al.* (1953); Kowalik and Sadurska (1956). These also produce variety of colours.

Several bacteria were also isolated from paper material where the relative humidity was quite high (more than 85%). *Pseudomonas*, *Bacillius*, *Micrococcus*, *Saprocytophage*, *Cytophage* and *Cellvibrio* (Firipi and Mazzucchetti, 1963; Berg *et al.*, 1972; Lazar and Dumitru, 1972; Strzelcyk Leznicka, 1981. Oppermann and Wolfson (1961) isolated *Aerobactor*, *Chromobacterium*, *Clostridium*, *Flavobacterium* and *Klebsilla*. They intensely discolour paper.

All these micro-organisms produce different organic acids like oxalic, fumaric, succinic, citric etc., and reduce the pH of the paper. The optimum acidic values of nutrient media for fungi are mostly below pH 7 (Lilly and Barnett, 1953). The upper and lower may be different for different fungi. Bacteria need pH-6.8-8.0, Actinomycetes grow best at pH-5.0-8.0.

The utilization of cellulose for the nutrition of fungi is well known for a long time. Eggins and Pugh (1962) have demonstrated the utilization of cellulose by fungi by using cellulose-agar media.

The complete degradation of cellulose in paper is effected by two groups of celluloses: endoglucanases which hydrolyse internal beta-1,4 glucosidic linkages and exoglucanases which split off mono and disaccharide units from the non reducing end of a cellulose chain. (Berghem and Petterson, 1973; Eriksson and Petterson, 1975; Shikata and Nizisawa, 1975). The intermediates of cellulose degradation have been found to be oligosaccharides with muscose properties (Gascoigne and Gascoigne, 1960; Berg *et al.*, 1972; Rosa and Strzelczyk, 1979).

In the formation of muscilage, fungi and cellulotytic bacteria as well as bacteria forming muscilaginous capsules are responsible (Martin and Dobson, 1945; Gascogine and Gascogine 1960; Sanborn, 1965; Turner, 1967; Hughes, 1968; Rosa and Strzelczyk, 1979; Strzelczyk and Leznicka, 1981). These muscilagenous substances may be assumed to play a vital role in the consolidation of a book (affected by flood or high moisture) into a block.

Siu and Reese (1953) introduced data concerning the destruction of different forms of cellulose by several type of fungi and remarked that the course of process depends in considerable measure on the properties, purity and composition of cellulose. However, Belaya, *et al.*, (1964), Nyuksha (1964), Zagulyaeva and Flyate (1973) Rosa and Strzelczyk. (1979), explained that the intensity with which paper is degraded by cellulolytic micro-organisms is affected by the presence of natural glues in the paper.

Strzelczyk and Leznicka (1981) studied succession of micro-organisms on the XVIIth and XIXth century paper and they observed that in the XVIIth century paper the first fungi to appear utilized first of all the glutin glue used in the manufacture of paper, e.g.

Verticillium sp. this fungus is known to have poor cellulose degrading ability (Gupta and Heale, 1979). Next fungi to appear on the sample had a full set of cellulolytic enzymes (*Chaetomium*, *Trichoderma* and *Penicillium* sp.). The genera to appear the last were adopted to the utilization of the products of cellulose degradation (*Rhizopus* and *Clodosporium* sp.) However, in case of a 19th century book the fungi isolated were known to have high cellulolytic activity but they showed very poor vigour which may be due to colophony and certain amount of lignin present in the paper.

Basu and Ghose (1962), Cowling and Brown, (1969), Berg *et al.* (1972) demonstrated that delignified short cellulose fibers are degraded more easily than long fibers with a higher lignin content.

In the restoration of paper material, paper is laminated with polyethylene at a temperature of 110°C, it was also found to be attacked by fungal form *A. flavus* (Nyuksha, 1983). *A. flavus* uses inaccessible source of carbon including synthetic and natural complex ethers and carbon chain polymers like polyvinylacetate, polyvinyl chloride, Polyvinyl alcohol, etc. (Greathouse and Wessel 1954; Davis, 1963).

Paraffined paper which is also used in restoration of books is easily affected by *A. flavus*. It loses the water repellant property, becomes yellowish (Touson, 1950; Nyuksha, 1983) and ultimately degrades paper.

As a result of microbial action on paper there is a considerable reduction in the alpha-cellulose (Pietrykowska Leznicka, 1979) and there is an increase in copper number (Nyuksha, 1956; Zagulyaeva, 1968, Strzelczyk and Leznicka, 1981). The weight of the cellulose usually shows only an insignificant decrease but its mechanical strength decreases considerably.

A characteristic brown or rusty spotted discolouration found commonly on old books, manuscripts etc. and even not so old books is referred to as 'foxing'. If we define foxing as the brown coloured spots on paper, in that case any type of brown spots will be termed as foxing. However, that may give rise to several misconceptions. Various studies were conducted to tackle this problem like, X-ray spectral analysis, T.L.C. analysis, Optical photomicrography, observation of spots under U.V. light, etc. (Thomas and Beckwith, 1935; Beckwith *et al.*, 1940; Ambler and Fenney, 1957; Chalk, 1960; Carter 1972; Baynes Cope

1976; Press 1976; Meynall and Newsman, 1978, 1979; Cain and Miller, 1982; Lea Nol *et al.*, 1983; Hey, 1983).

After going through the literature, it can be concluded that there are two schools of thoughts :—

1. The presence of iron, or similar metals either as concentration of salts or as an actual speck or particle present in the paper.

2. Fungal infection is the main cause of foxing.

The role of fungal activity and iron in the development of foxing is not very clear yet. In our opinion there may be some other reason which have not been so far pointed out. Thus study of foxing needs a continous and thorough research.

BIBLIOGRAPHY

1. Agrawal, O.P. (1977). Care and preservation of museum objects, Published by NRLC, New Delhi at present situated at Lucknow.

2. Agrawal, O.P. (1984). Conservation of manuscripts and paintings of Sourh-east Asia (Butterworths, U.K.).

3. Aleksi Meskishvill., L.G. (1965). Mycoflora of an archives store room and results of testing some physical measure against it. *Soobshch. Akad. Nauk. Gruz. U.S.S.R. 39*: 386-688.

4. Ambler, H.R. and Finney, C.F. (1957). Brown stain formed on wet cellulose. *Nature, 179*: 1141.

5. Anchabaze, T.T. (1949). Materials for the study of book destroying fungi. *Vestn. Gos. Muzeia Gruzii im. Dzhanashia, 14*A: 201-216.

6. Armitage, F.D. (1949). The cause of mildew on books and methods of prevention. *Book, Printing, Packaging and Allied Trades Research Association* (*Patra*) Leather-head, Surrey, England, 14 pp. 4 figs.

7. Bakhtin, V.S. (1928). The fungus pests of books. *Daily Journal of the All Union Congress of Botanists in Leningrad. Leningrad, January*, 169-170.

8. Basu, S.N. and Ghose, R. (1962). Structural changes brought about in thc jute fiber by microorganisms and their enzymes. *Textile Research Journal, 11*: 932-942.

9. Baynes Cope-D. (1976). Some observations on foxing at the British Museum Research Laboratory. *Int Biod. Bull, 12* (1) : 35-36.

10. Beckwith, W.H ; Swanson, A. and Iiams, T. (1940). *Deterioration af paper. The cause and effect of foxing.* Publications of the University of California at Los Angeles in Biological Science. *1* (13) : 299-356.

11. Belyakova, L.A. (1953). Mold fungi on books and their control. In *Restoration and Preservation of Library Resources, Documents and Books.* (Ed. By L.G. Petrova, L.A. Belyakova and O.V. Kozulina Moskva. pp. 183-194.).

12. Belyakova, L.A. and Kozulina, O.V. (1961). Book preservation in USSR Libraries. *In Unesco Bull. Libri, 75*: 198-202.

13. Belaya, J.K. ; Kozoolyna, O.W. ; Korneva, S.J. ; Tcheremysyna, J.A. and Nyuksha Iu. P. (1964). *Materyaly yz Kotoryh Sdelana Knyga Y prytchyny yh razrooshenya Gygyena y restavratzya byblyte-technyh fondow*, 5-20

14. Berghem, L.E.R. and Petterson, L.G. (1973). Purification of celluloytic enzyme from *Trichoderma viride* active on highly ordered cellulose. *European Jour. of Biochemistry, 37*: 21-30.

15. Berg, B., Hofsten, B. and Petterson, L.G. (1971). Growth and cellulose formation by *Cellvibrio fulvus. Jour of Applied Bacteriology, 35*: 201-214.

16. Berg, B. Hofsten, B. and Petterson, L.G. (1972). Electron-microscopic observations on the degradation of fibres of *cellvibrio fulvus* and *Sprocytophaga myxococoides. Jour of Applied Bacteriology, 35*: 215-219.

17. Bryan, A.H. (1937). Book contamination by bacteria. *Industrail Medicine*, 6 : 73-74.

18. Camargo, Guarnieri, A. (1982). Biodeterioration of documents. *Papel. 43*: 33-45

19. Cain, C. Eugene and Miller, Barbara, A. (1981). Proposed classification of foxing. *American Institute for Conservation of Historic and Art Works, Book and Paper group 1982 Post-prints.*

20. Carter. J. (1972). *ABC for Book Colleetors*, 5th Ed. (Hart Davies, London)

21. Chalk, M.L. (1960). Foxing of Prints, *PATRA Journal, 1* (12) : 12.

22. Cowling, E.B. and Brown, W. (1969). Structural features of cellulosic materials in relation to enzymatic hydrolysis. In *Celluloses and their Applications. Advanced Chemistry Series*, 95. *American Chemical Society, Washington, D.C.*

23. Cunha, G.M. (1977). An evalution of recent developments for the mass drying of books. *In Williams, J.C. (edit) Preservation of Paper and Textiles, of Historic and Artistic value.* (Advances in Chemistry Series. 164. American Chemial Society Washington) 95-104.

24. Czerwinska, E, Sadurska, I. and Kozlowska, D. (1953). Promieniowce niszczace papierz zabytkowy. *Acta Microbial Polon, 2*(2-3) : 160-164.

25. Davis, N.D. (1963). Growth and Kojic acid production by *Aspergillus flavus* growing on peanut oil. *Economic Botany, 17* (4) : 263-269.

26. Deshpande, K.B. and Mantri, J.M. (1966). A new species of *Cunnighamella. Mycopath et Mycol appl., 28*: 342-344.

27. Dhawan, Shashi and Agrawal, O.P. (1986). Fungal flora of miniature paper paintings and lithographs. *Int. Biod, 22* (2) : 95-99.

28. Dohlakia, J.N. and Chhalpar, H.S. (1980). Control of some fungi capable of degrading cellulose and also water based poster colours. *Int. Bio. Bull, 16* (1) : 17-21.

29. Eggins, H.O.W. and Pugh. G.J.F. (1962). Isolation of cellulose decomposing fungi from soil. *Nature, 193* (4810) : 94-95.

30. Eriksson, K.E. and Pettersson, L.G. (1975). Extracellular enzyme system utilized by fungus *Sporotrichum pulverulentum* for the breakdown of cellulose. III. Purification and physicochemical characterization of an exo-1, 4-beta glucanase. *European Jour of Biochemistry, 51* : 213-220.

31. Fausta, Gallo. (1963). Bilogical agents which damage paper materials in libraries and archives. *Recent Advances in Conservation* (Ed. Thomson G., Butterworths, London).

32. Firipi, M. and Mazzucchetti, G. (1963). II limo micro-biologico Laboratorio di Cartotecnica speciale del. *E.N.C.C., Loc. Triulzi*, 27-34.

33. Fischer, D. J. (1977). Conservation Research : Fumigation and sterilization of flood contaminated library office, photografic and archival materials. Williams, J.C. (Ed.) Preservation of Papers and Textiles of Historic and Artistic Value. (*Advances in chemistry series. 164. American Chemical Society, Washington.*) *pp* 139-148.

34. Flieder, Francoise. (1969). *La Conservation des Documents Graphiques. Researches Experimentales* (Eyralles, Paris).

35. Flyate, D.M. (1968). Preservation of Documents and Papers. *Academy of Sciences of the USSR Laboratory for the Preservation and Restoration of Documents.*)

36. Gascoigne, J.A. and Gascoigne, N.M. (1960). *Biological Degradation of Cellulose* (Butterworths, London).

37. Gallow, F. (1963). Biological agents which damage paper materials in libraries and archives. In *Recent advances in conservation* (*Ed. G. Thomson. Butterworths, London.*).

38. Greathouse, G.A. and Wessel, C.J. (1954). *Deterioration of materials. Causes and preventive techniques.* (New York Reinhold Publ. Co.) : 835.

39. Gupta, S.C. and Heale, J.B. (1970). Induction of cellulose in *Verticillium alboatrum*. *Jour. Gen. Microbiology, 63*: 163-173.

40. Hey, Margaret. (1983). Foxing: some unanswered questions. *Antiquarian Book Monthly Review, 10*: 340-343.

41. Hughes, R.L. (1968). Microbiological deterioration in the paper, printing and packing industries. *In Biodeterioration of materials. Ed.A.H. Walters and J.J. Elpluck, pp. 281-290 Elsevier Publishing Co., London.*

42. Joshi, N.C. (1958). Fungi of Ajmer (Rajasthan) III. *Proc. Nat. Acad. Science India, 28*: 303-307.

43. Kathpalia, Y.P. (1960). Deterioration and Conservation of paper I. Biological deterioration. *Indian Pulp. Paper, 15*(1) : 117-125.

44. Kowalik, R. (1952a). The micro-organisms that destroy the archival papers. In: *Prace Placowek Naukowo Bandow Czych, 2*: 49-67.

45. Kowalik, R. (1952b). Micro-organisms destroying paper in Polish Archives. Med. Doswiadczalana. *L Microbiol, 4*: 359-360; Chem Abstr. 47. 4953. (1953).

46. Kowalik, R. and Sadurska, J. (1956). Micro-organisms destroying paper, leather and wax seals in the air of archives. *Acta Microbiologica Polonica, 5*: 227-290.

47. Kowalik, R. Sadurska, I; Czerwinska, E. (1962). Microbiological deterioration of old books remedies. *Bolletino, dell' Instituto di Patologia del' Libro "Alfonso Gallo," 21*: 116-151.

48. Kowalik, R. Sadurska, I; Czerwinska, E. (1963). Zniszczenia papieru prezez Mikroflore. *Blok-Notes Muzeum Mickicwicza, 2*: 259-312.

49. Kowalik, R. (1972). Some problems of microbiological deterioration of paper. *Annali della Scula Speciale per Archivisti e Bibliotecari dell Universita di Roma. Nuova Tecnica Graffica Roma. 1-2*: 61-80.

50. Kowalik, R. (1977). Some Aspects of Microbiology of paper and parchment, In Peterson, D.E. (ed) Herzog August Bibliothik Wolfenbutteler Forschungen. Jacobi Verlag, Breman und Wolfenbuttel Band. 1 : 61-90.

51. Kowalik, R. (1980). Microbiodeterioration of Library materials. Part II. Microbiodecomposition of basic organic material Chapter IV. *Restaurator*, 4 : 135-219.

52. Lazar, I. and Dumitru, L. (1972). Researches concerning the bacteria on archive paper documents. *Rev. Roum. Biol. Bot. Tome*, 17 : 209-215.

53. Lea Nol, Y.H. and Kenneth, R.G. (1983). Biological factors of foxing in postage stamp paper. *Int. Biod. Bull*, 19 (14) : 19-25.

54. Lelis, A.T.De. (1980). Deterioration and preservation of documents. *Papel*, 41 :55-60.

55. Lilly, V. and Barnett, G. (1953). Physiology of fungi (Russian translation).

56. Marcella, Levi Della- Vida. (1936). The micro-organisms which attack books. *Academie e Biblio Theche d' Italia* (Rome, Biblioteca d' Arte Editrice) XIV, Anno X, 4 : 234-250.

57. Martin, R.B. and Dobson, J.G. (1945). Paper trade journal. *Mikirobilogiczna Korozja materialow B. Zyska.* (1977) Warszawa.

58. Martin, J.H. (ed) (1977). Museum under water. The Corning flood. (The Corning Museum of Glass. Corning, New York).

59. Meynell, G.G. and Newsam, R.J. (1978). Foxing of Fungal infection of paper. *Nature*, 274 : 466-468.

60. Meynell, Guy, (1979). Foxed paper and its problems. *New Scientist*, 83 : 567.

61. Miller, J. David. and Harold Hollard. (1981). Biodeteriogenic fungi in two Canadian historic houses subjected to different enviromental control. *Biod. Bull*, 17 (2) : 39-45.

62. Nair, S.M. (1972). Certain observations on the biodeterioration of museum materials in India. In Biodeterioration of materials vol. 2 pp 401-7 (eds Walters, A.H. and Huek-van Der Plas, E.H.) London. Applied Science publisher.

63. Nair, S.M. (1977). Biodeterioration of paper. *Conservation of Cultural property in India*, 10 : 22-28.

64. Nair, S.M. (1981). Biodeterioration of Palm leaf, Paper manuscripts and miniatures. *Cultural contours of India* (Dr. Satyaprakash Felicitation Volume). 78-83.

65. Narayanan, S.A. (1963a). Some interesting microfungi from flood-affected substrata in Poona, India. *Sydowia*, 16 : 77-84.

66. Narayanan, S.A. (1963b). Some interesting microfungi from flood-affected substrata in Poona India. *Sydowia*, 16 : 205-211.

67. Nyuksha, Iu.P. (1953). A physiological study of the fungus *Gymnoascus setosus*, Eidan. *Mikrobiologiya*, 22(1) : 15-22

68. Nyuksha, Iu.P. (1954a). The problems of hygienic conditions in the air of book repositories. *Opyt. Raboty No. 9. Gos. Publ. Bibl. Ins. M.E. Saltykova-Shchdrin, Leningrad.* 3-15.

69. Nyuksha, Iu.P. (1954b). Results of microbiological investigations of paper. *Opyt Raboty No. 9. Gos. Publ. Bibl. in. M.E. Saltykova-Shchedrin Leningrad.* 31-45.

70. Nyuksha, Iu.P. (1956). Microflora of books and paper. *Bot. Zh*, 41(6) : 797-809.

71. Nyuksha, Iu.P. (1961). A systematic survey of fungi encountered on paper, books and in paper pulp. *Botanicheskii Zhurnal*, 46(1) : 70-79.

72. Nyuksha, Iu.P. (1964). Ogrybostoykosty opytnyh obrazcov boomagy. *Akademia Nauk USSR*, 53-58.

73. Nyuksha, Iu.P. and Kossior, L.A. (1976). Fermentativnaja aktivnost gribov, povrezhdajushchkh. bumagu. *Mikologija i fitopatologija. t.*, 10 : 185-190.

74. Nyuksha, Iu.P. (1983). Some special cases of biological deterioration of books. *Restaurator*, 5(3-4) : 177-182.

75. Omelianskii, V.L. (1925). The book and micro-organisms. *Priroda*, (1-3) : 35-48.

76. Omelianskii, W.L. (1953). Izbrannyje Trudy Voll-II. *Izdatietstwo Akademii SSSR. Moskwa*, 380.

77. Oppermann, R.A. and Walfson, L.L. (1961). Mechanism of slime formation. *Fimbriae TAPPI*, 44 : 905-909.

78. Pietrykowaska-Le' Znicka, S. (1979). Ph.D. Thesis, N. Copernicus. University Torun, Poland.

79. Press, R.E. (1976). The foxing of paper. *Int. Biod. Bull*, 12(1) : 27-30.

80. Rosa, H. and Strzelczky, A. (1979). Badania nad Zdolnoscia tworzenia sluzow przez grzyby wyodre-bnione ze skamienialych ksiazek. *Acta. Univ. N. Copercici*, 7 (91) : 119-128.

81. Reed, R. (1972). Ancient skins parchments and leathers. Seminar press London and New York.

82. Rybakova, S.G. (1953). Mould fungi on books and their prevention. Collected material on the storage of book stocks 2nd ed. *Gos. Bibl. USSR. im.B.I. Lenin. Moscow.* 41-65.

83. Sanborn, J.R. (1965). Nature of slime forming and other troublesome micro-organisms. *Paper Trade Journ*, 42 : 15-20.

84. Stanojlowic, L. (1978). Mesure d' Intervention en Cas de Desastre' ou Creation d' un Centre National d' Intervention et de Sauvetage en cas d' urgence. *ICOM. Committee for conservation, Zagreb*, 78 : 14 :30.

85. Sartory, A. ; Sartory, R. ; Meyer, J. and Baumli, H. (1934). Experimental reproduction of the cryptogamic diseases of paper. *Compt. rend. de f' Acdes. Sci. Paris, 199* (3) : 22-224.

86. Sartory, A. Sartory, R ; Meyer. J. and Baumli, H. (1935). Some lower paper destroying fungi. *Le Papier*, 38 : 43-53. and 529-542.

87. See, P. (1917). Surles moisissures cousant 1' alleratiori du papier. Compt-Rend. Acad. Sci, 164 : 230-232.

88. See, P. (1919). The diseases of mouldy paper. *Paris*.

89. Shikata, S. and Nizisawa, K. (1975). Purification and properties of an exo-cellulose component of novel type from *Trichoderma viridi*. *Jour Biochem* (Tokyo), 78 : 499-512.

90. Siu, R.G.H. and Reese, E.T. (1953). Decomposition of cellulose by micro-organisms. *Bot. Rev*, 19(7) : 377-416.

91. Strzelczyk, A.B. and Leznicka, S. (1981). The role of fungi and bacteria in the consolidation of books. *Int. Biod. Bull*, 17 (2) : 57–67.

92. Tauson, V. O. (1950). On the problem of assimilation of paraffin by micro–organisms. *Izd. Akad. Nauk*. SSSR. Moscow–Leningrad. 29–41.

93. Thomas, M. Iiams, T. and Beckwith, T. D. (1935). Notes on the causes and prevention of foxing in books. *The Library Quarterly of America*. 5 (4) : 407–418.

94. Tilak, S. T. and Jadav. V. K. (1970). Contribution to our knowledge of Ascomycetes of India. *Sydowia*, 24 : 81–88.

95. Tilak, S. T. and Vishwe, D. B. (1976). Microbial content of air inside library. *Biovigyanam*, 1 : 25–27.

96. Turner, J. N. (1967). The Microbiology of Fabricated materials. (Churchill Ltd. London).

97. Waksman, Seman A. (1940). On paper fungi as quoted by St. George, Synder *et al.*

98. Zagulyaeova, Z. A. and Flyate, D. M. (1973). Effect of paper composition on its fungus resistance. *Waprosy Dolgowiecznosti Dokumientow* : 48–59.

99. Zagulyaeova, Z. A. (1968). Comparative biological stabilities of equiresistant long–fibered papers sized paste and with Poly Vinyl Alcohol. *Preservation of Documents and papers National Technical information service*, 99–103.

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