



Article: Water, heritage photographic materials and fungi

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WATER, HERITAGE PHOTOGRAPHIC MATERIALS AND FUNGI.

Mary-Lou Florian

Presented at the 2003 PMG Winter Meeting in San Juan, Puerto Rico.

Introduction

Water. What could be a more important chemical? Not only in conservation of heritage photographic materials but in the whole discipline of conservation. On the one hand, water in heritage materials may be involved in many damaging chemical reactions, i.e., photooxidation, acid/alkaline reactions, etc. Excess of water may cause physical disruption of colloids, i.e. solubilization, swelling etc., and too little water may cause concentration effects or crystallization. If the heritage materials have the right amount and right characteristics of water they can support fungal activity. On the other hand just the right amount of water is required for the photographic materials stability. Thus there is a love-hate relationship between water and materials of photographic materials. The commonest material of photographic materials is gelatin. The very nature of the material gelatin depends on water. It is a colloid in which fibril crystals of collagen form an electrically charged mesh in which water is held. The photographic film must have enough water to retain its colloidal physical state and the supporting materials their strength and suppleness. The science of colloids is an interdisciplinary science, chemistry, physics, and is dominated by water.

In conservation sometimes surfaces of paper, leather or textiles have to be surfaced cleaned by water - a solid-liquid interface. When we use water or aqueous solutions we become aware of wetting features of water - spreading wetting, adhesional wetting and immersional wetting. Wetting causes other things to happen i.e., the heat of wetting and evaporation. We control wetting by changing materials water repellency or by making them more wettable by introducing wetting agents such as surfactants, detergents, etc. The use of water looks simple but it is very complex.

Water as a liquid

Water as a liquid may be involved as a solvent in which ionic compounds are dissolved, as a molecule in chemical reactions or as a dispersing media in colloids. All three of these activities can lead to deterioration of protein materials.

Water is able to dissolve soluble compounds because of its polar characteristic, which means that it has negative and positive poles, or a dipolar state. The electrons are not shared equally between the hydrogen and oxygen atoms because the oxygen has a greater attraction for electrons, thus gaining a slight excess of negative charge, giving the dipolar nature of the molecule. Because of this unequal charge water is said to be a polar molecule giving it solvent power.

In pure water a few molecules will dissociate and form high energy hydronium ions. Hydronium ions are also formed when an acid is dissolved in water. The hydronium ions are strongly

positive giving an acid (depending on their concentration) its strong electrolytic activity resulting in acid damage. Thus they are a major agent of deterioration. They are also formed in most photooxidation reactions.

Water in air

Water in air is water vapour. The amount of water in air depends on the air's temperature and atmospheric pressure and the water availability. The physical characteristics of water are water vapour pressure, movement and temperature. These are the driving force of diffusion. In a closed system such as a museum the water availability and movement are controlled by air conditioning not the whims of weather. The water vapour pressure is controlled by the chemicals in the water, the temperature and atmospheric pressure. We do not record the amount of water present in air, instead we record the relative humidity(RH) of air and control it as a preventative measure, but do not consider how much water is actually present in the air. RH is a measure of the % of the water vapour present in the air relative to the amount of water vapour the air can hold at that specific temperature and atmospheric pressure. Air at a specific temperature and a specific volume can hold a specific amount of water vapour. This amount of water in a specific volume of air is recorded as absolute humidity. We use RH as our guide but are we aware that air can hold the same amount of water at different temperatures and RHs, i.e. air at 24oC at 40%RH, 20oC at 50% RH and 17oC and 60%RH all have the same absolute humidity, and are we aware that air of the same RH but at different temperatures can have different absolute humidities, i.e., air at 50%RH, and 5oC contains about half the amount of absolute humidity as air at 50% RH and 20oC. Thus the RH is not a guide to the amount of water vapour present. We need to know as much as we can about water to make logical preventative decisions. Maybe we should be looking at absolute humidity? There are inexpensive psychrometric charts and RH converters commercially available.

The importance of the dew point and microenvironments

Dew point is another parameter we do not often measure. If there has been a dramatic drop in temperature or a sudden increase in available water in the air, it may become saturated to the point that it can not hold the water which now condenses as free water on surfaces that can not buffer the rapid change. The temperature and absolute humidity at which this occurs is called the dew point. A dramatic drop in temperature can occur in air passing over cold surfaces such as a cold wall or floor, these are microenvironments in which condensation can occur. I am convinced that the majority of surface fungal spots on supposedly dry materials, i.e., leather, textiles, gelatin films, etc., occur in such microenvironments due to condensation because the dew point was reached. Condensation can occur and the fungal structures can rapidly sequester the water into its biofilm which will support invisible limited growth even after the environment has returned to a normal state. Fluctuations of such environmental changes can allow the fungi to develop a visible fungal structure- the spot on the photographic film or on the paper support. Dew point can be calculated from psychrometric charts and there are also converters for RH readings. If there has been a weather or plumbing problem causing dramatic rapid RH changes,

knowing if a dew point has been reached is critical information for prevention of fungal activity. We should seek out and eliminate- if possible- microenvironments or at least monitor them.

Water in materials

When we have a temperature change and the amount of water changes in the air- where does the water go? Into or out of adsorptive materials. We record experimentally the amounts of water in materials as equilibrium moisture content(EMC) at a specific temperature and RH. Diffusion of water vapour in and out of materials occurs allowing an equilibrium to be reached, thus its name EMC.

We have generic charts which are a guide to the EMC of materials such as for gelatine films, commercial textiles and tanned leathers, but the material of each artifact is unique because of its environmental, manufacturing and use history. There is literature which points out the extensive variation due to manufacturing in photographic material. Just one example; over the environmental range of 30-60%RH at 20oC unhardened photographic gelatin has a range of 11%-14% EMC whereas a hardened gelatin emulsion has a range of 3%-9%EMC. Materials are also altered by their environmental history, for example if exposed to adverse drying environment, they may no longer be able to adsorb much moisture thus have a low EMC. Different materials may be prone to or resistant to deteriorate or fungal growth because of the different state and amounts of water in them. It would be nice if we had this information, it would help use determine those materials which are most vulnerability or stable. Surface moisture meters can give some information. Simply weighing an incoming object and recording the ambient RH and temperature during initial accessioning or documentation may be a valuable record in the future to determine its change in an environmental disaster or just long term storage. The movement of water in(adsorption) and out(desorption) of materials is recorded by isotherms and hysterical hysteresis. These are not straight-line graphs because the rate of adsorption and desorption of water is different due to their different thermophysical characteristics. In adsorption the heat of wetting generated allows it to occur faster than desorption which requires heat for evaporation. The relevance of this in conservation is that materials exposed to rapid temperature or RH changes, in the process of drying to the original RH and temperature, may have a higher moisture content than it had at that original RH and temperature. This extra moisture could make some materials vulnerable to fungal and insect activity. This only touches moisture in materials, there is extensive literature some of which is referenced at the end of this paper.

Often in the literature in determining the EMC, not just the amount of water that moves due to changes of RH is recorded but all the moisture in the materials. There are three types of water in organic porous materials, molecularly bound, multilayered (often called free water) and condensed water. The molecularly bound water is chemically bonded in the material molecules. It has a low vapour pressure and requires high heat to remove it, it does not move with normal temperature and RH changes and does not freeze.

Multilayer water is loosely bonded to surfaces of material molecules, on other water molecules and in small capillaries less than 50um in diameter. It does not freeze and depending on its location and bonding strength can move with temperature and RH changes. When we measure a weight change from one RH to another, it is the loss or gain of this water we measure. Some of this multilayer water is the water that is utilized by fungi and is involved in chemical reactions. Condensed water is the third type of water. It is the water from wetting not water vapor. It usually has a high vapour pressure thus evaporates rapidly with an increase in temperature or decrease in RH.

We are flying by the seat of our pants when using RH as a means to control of biodeterioration, but with luck. We have set an environmental goal in air conditioned museums and archives etc., of 20oC and 50% RH . In some special storage conditions a wide range of temperatures and RHs are used. Recommendations for the specific environmental parameters come from conservation scientist who have studied specific photographic materials to arrive at these specific parameters and their influence on the material EMC. Most materials will be protected, but there are some materials with inherent high EMC or water activity which could support fungal activity even if the RH is normal. We are aware of the EMC but are not yet able to measure it. If the building does not have environmental control or there has been an unusual RH or temperature change, we must to be aware of dew points and glass transition points and their potential to increase the EMC of material and its vulnerability to fungal activity. We must look for microenvironments in which these can occur and eliminate them or at least monitor them . Air movement is critical in eliminating many microenvironments.

The importance of the glass transition point and microenvironments

Photographic materials are made up of gelatin layers on substrates such as acetate, polyethylene films, paper, etc. All these materials will expand and contract-reversibly - with increase and decrease of water vapour as long as they have not reached the yield point and have extended their elastic ability. If this happens cracks, and delamination may occur. A conservative estimate for the yield point for many such polymeric materials is 0.4% extension. Gelatine films on glass slides stay adhered without elastic ability during RH changes but will be stressed by mechanical restraint.

Gelatin is a colloidal material and can be in the state of a solid, gel or solution. Gelatin films are in the solid state. During the developing process they are immersed in solutions which are adsorbed and the gelatin passes through the glass transition state and becomes a gel. As a gel the film is now permeable to the photographic chemicals required for developing . This same glass transition can occur at varying RH and temperature. The higher the temperature the lower the glass transition point, i.e. for a specific photographic gelatin it will occur at 22oC and 70-75%RH and also at 30oC and 65%RH. It occurs over the range of varying temperature and relative humidity and can be calculated from isolines available in the literature for that photographic gelatin. For preservation of these colloidal films, in the solid state their hard impermeable surfaces must be retained - it is lost when a gel. Thus the glass transition point is

another critical environmental parameter we should be measuring. Like the dew point it can occur across the temperature and RH spectrum, and occurs when there has been a dramatic environmental change or in hidden microenvironments.

Water vapour moves in and out of gelatin films, as is shown on by their adsorption and desorptive isotherms, but the water in the gelatin does not appear to be readily available to fungi. It is probably due to many reasons: the surface molecular packing of the tropocollagen fibrils with the protein molecule's hydrophobic side chains on the surface making an water impermeable surface layer; the hardening of the surface during the manufacturing and developing processes; and the strong bonding of the water in the internal mesh of tropocollagen fibrils and resultant low water activity of this multilayer water. Fungal growth that does occur on gelatin photographic materials is usually restricted to the surfaces and most likely started in surface condensed water or if the solid gelatin had been transformed to a gel. Thus if there has been a dramatic environmental change, one should determine if the dew point or the glass transition point has been reached to determine if there is a the potential for fungal activity. Pitting of photographic film surfaces under fungal colonies has been reported and it is most likely due to shrinking on drying of the slimy fungal biofilm and not necessarily loss of gelatin. It is obvious the major research is badly need on this subject.

Water activity

The strength of the bonds between water and polymers and other water molecules alters it waters volatility(water vapor pressure), and is called water activity. The term water activity(a_w) is used to describe its water vapour pressure relative to pure water, thus a_w 1-0, where a water activity of 1 is pure water. Besides the bonding to the polymeric materials, some multilayer water may form solutions with the chemicals inherent to the materials. The chemicals in materials come from deterioration, the manufacturing process, use, treatments, etc. Thus the water activity of the water in solutions is directly influenced by these chemicals. Each material will have its own moisture content and water activity according to its water bonding sites and inherent chemicals. We try to control biodeterioration by controlling RH when it's the water in materials that is critical. Fungi can only use water at a specific water activity in the range of 0.8-0.98. Materials can be almost saturated but if the water activity is not in this range the material will not support fungal activity. Water activity is critical in controlling fungal activity in the food industry, for example the soft dried fruits are full of water but also a sugar which lowers the water activity below 0.8. Understanding the water in materials is critical in understanding methods of biodeterioration control.

The water in fungi

Water is present in living fungal cells. The protoplasm contains circa 85% water content. This is the water of life and this amount has to be maintained for life. The fungi require external water for external digestion and to adsorb digested nutrient from the substrate, and at all times controlling that vital 85%. They have the ability to sequester water in to themselves and in their humectant biofilm of the slimy polysaccharide, beta glucans, which surrounds their hyphae. They are able to adsorb water against a diffusion gradient by metabolizing humectants such as

glycerol and sugars which hold the water internally or sequester water externally. Glycerol is produced by fungi and also insects when under water or heat stress. They are basically controlling the movement of the water by changing its water activity. When necessary they digest the biofilm or the glycerol to release its water for adsorption to maintain the water of life.

Fungal growth and biofilms

There are two stages of the life cycle of fungi that we must be aware of, the air borne conidia(spore) and the fungal colony which is the result of the conidia germination and its subsequent growth .

The critical aspect of conidia is its activation. There are many airborne conidia that have settled on all surfaces but only a few develop. Even if there appear to be suitable environmental parameters for fungal growth it may not occur. The main reason is that the conidia have not been activated. We know that seeds some times need to be frozen before they germinate and the pine seed in the forest need fire before they can germinate, freezing and heat are the activators for their germination. Conidia also need activators. Fungal activators breakdown the impermeability of the conidial cell wall allowing water to be adsorb. The loss of permeability can occur by the presence of fat solvents which dissolve the surface wax, wetting agents, by fluctuations of dry and wet or heat or dry conditions, etc.

Once the conidia is activated germination can occur. Germination and subsequent vegetative growth require conducive temperature, available water and nutrients. We have all seen graphs showing growth rates of fungi, grown in petri plates, showing the effects of temperature, water activity, nutrients, pH etc. In all tests there is maximum growth at some middle point and minimal growth at the extreme concentrations or temperatures. These graphs tell us is that there is an optimum point and less growth at the extremes. Controlling the growth rate is not enough we want to prevent any growth even that which occurs under the extreme parameters. The growth of fungi occurs from slightly below freezing temperatures, as long as there is still some unfrozen water, to around 37oC. There is a great degree of variation of temperature optimums between species. Some grow best at 25oC and some best at much lowers temperatures. Thus to give general parameters of growth is almost meaningless. The growth depends on the species and the state of water in the materials as well as the environmental parameters.

If materials are stored at low(4oC-refrigeration) temperatures, which is often done as a protection against fungal growth, growth will occur, but at a slow rate. Often these slow growing fungi are under stress and as a response produce black insoluble melanin in their hyphae which are attached to substrate fibers and are virtually impossible to remove.

Freezing the water in the cytoplasm of livable hyphae and germinating and hydrated conidia will kill them. Dry conidia, with a low water content, are resistant to freezing temperatures.

Controlling fungal growth rate by temperature may seem to be necessary but no growth should be the goal.

We also must realize that the surface environment of an emulsion or paper is not the salubrious environment of the petri plate- from which we get all the information on the vegetative growth of the fungi. In most cases the surface environment is an austere exposed environment. The growth that occurs is usually very limited. Most fungal activity in water damaged materials occurs when the materials are in the process of drying. This lag time may have something to do with conidial activation, but is more probably due to airborne surface contamination during the recovery process. There are stringent procedures, aseptic techniques, which can help prevent this contamination.

Fungi utilize simple sugars best and do poorly on solely proteinaceous materials. Usually their growth on proteinaceous material is because of other organic material present in the dust and free amino acids from the breakdown of the proteins, not the polymeric protein material itself. Fungi can be growing profusely on surfaces of leather or paper but do not utilize the polymeric proteins or cellulose.

A scenario of the growth of fungi on a photographic emulsion, and paper would be as follows. The conidia on the surface would be activated say by fluctuating relative humidities and is ready to adsorb nutrients and water. If the environment is conducive, that is appropriate temperature and water availability germination and subsequent growth could occur. The temperature range is broad but the availability of water would have to come from an environment change which would result in an increase in EMC of the material, reaching the condensation or glass transition point, all would increase the water availability.

The conidia will swell and germination will start. The hyphae grows out of the conidial germ tube and immediately lays down or covers itself with the slimy beta- glucans to stick itself to the substrate. The water soluble beta-glucans slime makes a microenvironment for the hyphae, in which water is drawn into and stored and enzymes are distributed.

This is the beginning of a biofilm- a film, composed of beta-glucans deposited on the surface of the material in which the fungi is attached and growth of hyphae and subsequent mycelium and conidia will develop. The purpose of explaining this is to make you aware that there is more than just fungal structures in a fungal infestation- there is also the slimy beta-glucans, the two make up a biofilm. In developing recovery treatments, both have to be considered.

The fungal allergen-beta -glucans

Beta-glucans are considered as to be the main allergen from fungi. They are considered to cause non specific inflammatory reactions and increase asthma severity and are indicated in the sick building syndrome. The antigenic characteristic of beta-glucans can be determined immunologically by the presence of antibodies IgE and IgG which are formed when beta-glucans enters an animal's immune system.

Beta-glucans is the main component: in the complex hyphal cell wall; and in the non-cellular, extracellular, hyphal mycofibrils; and the biofilm. It is a polymer which has the form of single or triple helix, or a random coil which may form cables or mycofibrils. The mycofibrils range from a few nanometers to cables which are less than 1µm in diameter. The large mycofibrils observed under scanning electron microscopy may be an artifact of the drying of the beta-glucans slime. The hyphal encrustments used for fungal species identification are most probably the mycofibrils in which chemicals crystals are embedded. Oxalic acid crystals has been shown to be present in wood fungi mycofibrils. Fibril formation is a common characteristic of drying colloidal solutions, which beta-glucans would be. Because of the size of the mycofibrils they must easily become airborne, but their presence in bioaerosols has not been analysed by microscopy because of their small size. Thus besides analyzing by microscopy the bioaerosol or surface samples for the total fungal structures(conidia, spores and hyphal fragments), chemical analysis for the total amount of the allergen/antigen beta-glucans should be undertaken. This would include all the beta-glucans present in the fungal structures and the mycofibrils and is a measure of the total fungal antigen load.

Biofilms are common to microorganisms. Bacterial biofilms are common in food processing, water filters, air washing screens, humidifiers, industrial washing processes, etc. Biofilms that include a mixture of microorganisms have been studied on stone heritage objects. A biofilm is present in the red brown coloration in old fungal fox spots. In the spot are a few fungal structures and an discolored area around and beyond the fungal structures. The cellulose fibers in the spot are covered with a thin surface film. The red brown colored material is the biofilm. These fungal fox spots contain very few fungal structures. The coloration may penetrate several pages without containing any fungal structures at all, suggesting the movement of a liquid, the slime. The conservation implications of this suggests that in recovery treatments of contemporary infestations if only surface fungal structures are removed the remaining biofilm may develop discolored spots over time, but research is needed. It has been reported to be extracted by hot detergent, trisbuffer and alkaline solutions. Could these be altered according to conservation standards and be used to remove the biofilms, if necessary? It is not known if the antigenic characteristic of beta-glucans in a fungal fox spot is lost on aging. The chemical nature in the discoloration in the biofilm of the fungal fox spots is still unknown but must relate to the presence of biofilm aging products, i.e., browning of sugars, amino-sugar melanoidins, lipo-protein aging products, etc.

Fungal odors and toxins

Microbial volatile organic chemicals(MVOC) are the odors of fungi. We do not know their health hazards but their presence has been attributed to some human discomfort. The production of these chemicals is under active research in monitoring and mycological research. The odors as well as the toxins are produced only under special growth conditions, thus their absence in monitoring does not mean that fungal growth is not present.

Mycotoxins are poisonous substances which are produced by a few fungal species. They are produced in the fungal structures which when breathed in or eaten cause a toxic response. One

such species is *Stachybotrys chartarum*, but the fungal structures, including conidia or ascospores, are not readily airborne because they adhered by its biofilm to the substrates it grows on, such as damp, alkaline, plaster, wall boards inside building's internal structures. Most conidial fungi produce conidia on aerial stems called conidiophores. Thus *S. chartarum* it is usually a building problem. It has been isolated from surfaces of paper but would not necessarily grow on these austere surfaces unless continuously wet. *Aspergillus fumigatus* is a pathogen which if inhaled may grow in the lungs causing the disease Aspergillosis. It only occurs in workers who are continuously exposed to the fungus species such as in flour or grain mills and composting centers.

Bioaerosol monitoring for ourselves and the artifacts

We must also consider ourselves in the equation of prevention. We must protect ourselves from any health hazards that may arise from the care of our heritage objects. We worry about fungal structures in the air we breathe while we work with artifacts and we worry about their potential to contaminate artifacts. We don't know how much is there or how much is too much. We don't have logical government regulation guides lines to know what concentration presents a health hazard. Threshold limits are presently being reviewed. Thus in dealing with mouldy materials all safety precautions should be taken.

In the meantime a logical approach is to undertake seasonal air quality monitoring and analysis for the fungal structures and beta-glucans in rooms of concern, i.e., storage rooms or other rooms which contain collections or will be used for collection recovery. Monitoring the air-its bioaerosol-will determine the normal background level of air borne fungal structures (conidia, spores, hyphae fragments) in the air of these rooms. This can then be used as a logical background reference in the event of a disaster such as water damage, to determine if there has been an increase in the air of fungal structures and also after a cleanup of a mouldy episode-recovery of the collection - that normality has been reached.

Outdoor air is commonly used as a background reference, but it is basically useless. Outdoor air and indoor air are normally quite different. Outdoor air is influenced by agriculture, industry, traffic, weather, etc. Indoor air is influenced by: air filters used of building or rooms; amplifiers(fungal colonies) such as on uncleaned mouldy materials brought in, food, in microenvironments such as near plumbing or in air ducts, etc. Thus the bioaerosol of indoor air of heritage collection will be different in rooms for preparation, storage and exhibit. It is obvious that samples of outdoor air and indoor air represent two quite different air profiles.

Outdoor air has traditionally been used as a background baseline reference because we do not have one for inside the buildings. This is a strange cultural constraint, there is no reason why we should not have background references inside buildings for specific room. I am recommending to museums and archives, to include in their general environmental monitoring program, four seasonal bioaerosol samples as well as surface samplings for fungal structures of specific indoor areas of concern. The reason for seasonal sampling is that there will be some outdoor air bioaerosol present which is influenced by seasonal changes. Areas of concern mean areas

without adequate environmental controls or areas which contain a collection prone to fungal infestation, or where microenvironments occur, etc.

In the analyses of the bioaerosol sample, determining the colony forming units (CFU) is not enough, this only shows the number of fungal structures which are viable and culturable and does not give the whole picture. The analysis of the samples should include, total spore count, hyphal fragments and viable CFU for analysis of the fungal structures, as well as analysis of the allergen beta-glucans for health hazard implications. Conservators will not be doing the analysis. It will be done by Industrial Hygienists or other professionals, but it is important that there is communication between the two so it is clear what information the conservators need about the museum environment.

This background baseline for fungal structures and beta-glucans can be put in a computer data bank which would be available for logical comparisons in the event of an infestation and can demonstrate a change and the degree of change from the norm. In the past monitoring has always occurred when a problem arises, this is obviously too late.

We monitor the RH and temperature of the air continuously why not four times a year for fungal structures and beta-glucans. There are simple and inexpensive methods for doing this already in the Industrial Hygienists repertoire. Let's use them. In prevention we must address the needs of the artifact but we must also make sure that the environment is not a health hazard for those caring for the artifacts.

Recovery thoughts

I am not a hands on conservator thus can not give any advice re treatments for objects. Also every object is unique and may require a special approach to recovery. The literature on the cleaning of dry infested objects shows that there are many methods used to remove fungal structures from, i.e., wet and dry mechanical removal using brushing, swabbing and conservation eraser and vacuuming using a zone collector or brushing. These methods will remove the fungal structures but how much is not known. Despite their common use there is little definitive research that proves their success. We can see the reduction of color when colored conidia are removed but we do not know how many, if any, are left behind. The majority have been removed and this seems adequate and logical because as soon as a cleaned object is placed in the air it becomes contaminated again. Mechanical removal of the fungal structures is important in reducing cross and future contamination of artifacts and a health hazard. Killing the fungi in situ does not eliminate the health hazard- fungal structures whether dead or alive are allergenic and must be removed- but it does prevent cross contamination.

Besides the fungal structures there is the biofilm. Just vacuuming will not remove this from the substrate, it will have to be solubilized before removal.

Besides dealing with small infestations on a few objects we are sometimes faced with massive clean ups after floods, plumbing accidents etc. The recovery steps will be according to that

specific situation but the best approach is to try to dry the wet materials in situ and as fast as possible. Cold storage only prolongs the problem- biding time-, after cold storage comes drying. Freeze-drying is often used, it has the advantage of drying the materials without dimensional changes and prevents paper sticking and fungal activity. The parameters used will kill the viable fungal structures. It is reported to remove bound water but there is no definitive research that shows this. A normal regain after the freeze-dry treatment does not mean that bound water has not been lost. Research is needed. There is a large body of literature on recovery scenarios. Many show simple solutions to a complex problems as well as information about things not to do.

Final words

We have only touched on the subject of water, photographic materials and fungi, and realized that we know very little and that there is need for research and interdisciplinary interpretations. We have looked at the water molecule itself and realize it is not an innocent molecule. It in it self can cause deterioration by its high energy hydronium ions and it can initiate chemical reactions. Besides its chemical activity it is essential in the physical stability of molecules and colloidal materials such as gelatin.

We have looked at water in the air and realize that we rarely monitor it. We monitor the relative amount that air is holding but not a real amount, the absolute humidity. We are aware that changing RH and temperature changes the absolute humidity but we don't measure it. We can easily calculate it from psychrometric charts and conversion tables. It is the water in the air that moves in and out of materials and is our concern re material stability and fungal activity. When there has been a dramatic change in the absolute humidity there are two things we must be concerned about. Has the dew point of air been reached and condensation occurred on surfaces or have materials increased in EMC or reached its gel state making it vulnerable to fungal activity. Empirical evidence suggests that many fungal infestation occur due to surface condensation.

In our buildings we are using 50% RH and 20oC as an environmental goal. We are lucky that most materials of artifacts have a sufficiently low EMC at these parameters to prevent fungal growth. We may be able to enhance this control by air circulation. There is a body of literature which shows how effective this is. We must be vigilant and look for microenvironments that maintain their own environmental parameters in the big room. In many cases the small fungal problems occur in these microenvironments i.e., adjacent to cold walls, under impermeable materials, near metal surfaces, in the bottom drawer next to a cold floor, etc

When the temperature is reduced the holding capacity of the air is reduce and there is more water in the air than it can hold and this extra water goes into the materials and increases its EMC. Extensive research on photographic gelatin has helped us understand this. Isotherms have shown this happens and isolines have illustrated how we can maintain a constant EMC over the range of -20oC to 80oc and RH 10%RH - 80%RH. The extensive research on photographic gelatin suggests there may not be a problem as long as we prevent reaching the glass transition point

which occurs when the solid becomes a gel. The main problem is the great differences in manufactured films and emulsions and their responses.

We realize that only some water in materials moves in and out with environmental changes and that some of this water is the water that supports fungal activity. Fungi have to maintain a cell concentration of circa 85% water content. Fungi use water from materials and the water they have stored in their biofilm for life. The water that is used by fungi has a specific water vapour pressure which is measured as water activity. It is the difference of its vapour pressure as a ratio to that of pure water. Lowering the water activity of water in foods is commonly done in the food industry to prevent fungal activity- may be we could use this feature as a preventative measure.

We realize that fungal growth occurs over a wide range of environmental parameters(pH, temperature, nutrients, water availability etc.) We know that there are optimums for growth and think that controlling these may help to control fungal activity. But our goal is to prevent any growth even that limited growth that occurs at the extremes. The majority of small fungal colonies on photographic film and emulsions are a result of fungi growing at these extremes and show only limited growth.

We are now aware that besides the fungal structures that there is a biofilm in the fungal infestation. We know that the fungal structures and the biofilm, both contain the fungal allergen beta-glucans. For prevention we should be monitoring the bioaerosol of the air and surface contaminants in areas of concern where artifacts are present and we breath the air. The analysis of the bioaerosol should include the total fungal structures, the viable culturable fungal structures as CFU, as well as the analysis of beta-glucans. Results from the former will let us know about problems for the artifacts and the beta-glucans level problems for us.

We have established recovery methods for surface removal of fungal structures but do not know how much we remove. It seems illogical to try to achieve complete removal because as soon as objects are cleaned they become contaminated from normal airborne fungal structures. Recovery treatments use mainly mechanical removal of fungal structures, should we be looking at removal of the biofilm as well?

Water is certainly a fascinating subject and extremely important in our pursuit of care of artifacts. There is a lot to think about. We are doing the best job we can with the knowledge we have. We realize we still need more information.

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