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BREAKING THE MOLD

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by Hal Alper

1.

A high school in Illinois is forced to close due to an infestation of mold. A Texas courtroom awards a family 32 million dollars against an insurer for mishandling a burst pipe claim. The house is covered with black rot mold (Stachybotrys) and must be destroyed. Lou Ferrigno (the "Incredible Hulk" for heavens sake!) is pictured on CNN evacuating his home due to mold infestation and complaining bitterly over the lack of his insurers responsiveness to the initial condition caused by the burst water pipe.

Environmental lawyers are holding weekend long seminars on mold litigation. Mold litigation and remediation is the new growth industry (Mold is Gold). Many states are developing regulations or have passed legislation applicable to fungal growth in indoor environments (New York, Texas, Massachusetts, California and others). Representative John Conyers (Democrat, Michigan) and 15 co-sponsors have introduced the Toxic Mold Safety and Protection Act in late June (H.R. 1540). What is going on here?!

2.

First of all mold, mildew, yeast, mushroom, rust are all names for fungi. Some terms such as yeast indicate a particular state of fungus and other terms do not have a clear technical distinction as is the case between mold and mildew. In this article we will often refer to the various states of fungus as affects indoor air quality as mold. Fungus belongs to the kingdom Mycota. A kingdom is a fundamental grouping of living organisms based on similarities in reproduction and other evolutionary factors. The other major kingdoms include plants, animals, protists and monera. For a long time fungi were considered as plants without chlorophyll but this is not accurate. Fungi have traits in common with plants and animals. Fungi are eukaryotes (possessing a distinct nucleus and nuclear membrane) which separates them from bacteria, as this is a trait common to higher life forms such as plants and animals. Fungi reproduce by spore production with basic cell wall structures which is a strictly plant like trait .On the other hand fungi are heterotrophic and contain no chlorophyll in common with animals. In fact both animals and fungi utilize enzymes (catalase and lignase in case of fungi) to degrade and absorb food materials, the difference being that animals perform this task internally whereas fungi decompose food stuffs externally and then absorb the nutrients.

Kingdom Mycota is composed of the following phyla

- Phylum Zygomycota: tube fungi, including some rusts, bread molds, water molds, and others
- Phylum Ascomycota: sac fungi, including yeasts, powdery mildews, cup fungi, blue and green molds, some bread molds, and others
- Phylum Basidiomycota: club fungi, including most mushrooms, toadstools, bracket fungi, smuts, and rusts

Of these, the major indoor and outdoor contributors to spores are the Ascomycetes and Basidiomycetes. Some examples are: Cladosporium, Penicillium, Aspergillus, Stachybotrys, Candida, Acremonium, Histoplasma, Chrysosporium, Trichothecium, Alternaria, Nigrospora etc.

The life cycle of fungus is alien to most of us. It is fairly complex and versatile. Fungi can reproduce sexually and asexually producing haploid (produced by mitosis)and diploid (produced by meiosis) spores . The fungus can enter a vegetative state where it primarily obtains and digests food but will often enter a reproductive state when food is depleted. This reproductive state produces spores. There are two basic types of spores, namely dry spores as in Aspergillus and slimy spores as in Stachybotrys. Although this is not an evolutionary distinction it is an important distinction in regard to filter media performance. Some basic terms applied to fungus are as follows:

- Hyphae: a filamentous cellular unit of a fungus
- Mycelium: a collection of hyphae
- Yeast: a unicellular growth phase of a fungus

Besides food, moisture, temperature, oxygen, pH and light can affect the state of fungus. The right combination of the above factors can cause the spore to change from its inactive to active form in the life cycle of the fungus. This process is known as spore germination. Some fungal spores must contact liquid to germinate. Other spores require in excess of 70% relative humidity for germination and yet other spores can germinate at extremely low relative humidity. Generally speaking fungal growth occurs best in warm and wet environments. The most effective way to prevent growth is by keeping material dry. Viable spores can germinate and produce hyphae when appropriate environmental conditions exist. If these conditions are sustained a robust mycelium develops. Once the material is colonized in this way the organism can usually endure severe environmental conditions and can still survive. The type of fungus present can be indicative of the extent of moisture damage. Primary fungal colonizers such as Penicillium require a low water activity constant ($aW<0.8$, aW is a normalized factor from 0-1 which is an indicator of the available moisture). Secondary colonizers such as Cladosporium cladosporiorides require an aW between 0.8-0.9. Tertiary colonizers such as Stachybotrys require an $aW >0.9$.

Fungus degrades cellulose and lignins in order to obtain its energy. Fungus plays an essential role in the carbon cycle by degrading grass, wood, paper and cardboard. To fungus many housing materials look like food. Humans probably first noticed fungus on the forest floor in the form of mushroom. Since then we have learned to use fungus in baking, brewing, manufacturing pharmaceuticals and in other ways. Until recent time toxic effects from fungus (mycotoxicosis) were primarily resultant from ingestion of poisonous mushrooms or by exposure to poison produced from mushroom extract (well documented in history and literature). Mycotoxins are produced by all fungi in order to ward off predation and competition. Mycotoxins can exist as endomycotoxins (not released from cell or cellular components) and as exotoxins, either volatile and released as a gas or non volatile and released as solid or liquid. Some mycotoxins are the most poisonous substances known. Additionally fungal spores can act as opportunistic pathogens and actually infect a person with fungus. Although fungal infections are rare they are very serious and often lethal. Some examples of such infections are Histoplasmosis (bird breeders disease) and Aspergilliosis which is one of the most frequently encountered fungal infections and often occurs in hospitals especially in burn wards. Airborne transmission of mycotoxins is accomplished through the formation of bioaerosols. Bioaerosols are simply buoyant airborne compounds, solutions, mixtures or solids of biological origin with close to neutral buoyancy in air. Spores, mycotoxins and endotoxins can become aerosolized by air movement, mechanical agitation or through physiochemical processes.

In recent times the primary route of entry for fungal infections and mycotoxicosis has changed from ingestion to inhalation (Stachybotrys atra also known as black rot fungus is blamed for the recent deaths of infants in Cleveland, Ohio). Some inhaled mycotoxins can be 10 times more toxic as compared to intravenous root of entry. What has happened to cause this change. Although the exact cause may be difficult to pinpoint two events were certainly contributing factors, these being the discovery of freon refrigerant by Thomas Midgley in the 1930's and the energy crisis of the 1970's. These two factors resulted in the tightening up of buildings using synthetic materials which sealed the structure and reduced air movement resulting in higher available moisture contents in the building materials, a condition favorable for fungal growth. Installation of air conditioning systems without properly considering microorganismal ecology and maintenance of hygiene compounded the problem. When human factors are included such as the fact that we spend more than 90% of our time indoor and the fact that many of us have compromised immune systems from diseases, medications and environmental insult and add to this the emergence of new and pathogenic organisms it becomes evident that our relationship with fungus is taking on a new urgency.

3.

What is the extent of the problem and what can be done about it. In recent times much work has been done in the characterization and quantification of fungi and mycotoxins. Some interesting recent studies are as follows:

- Airborne levels of culturable molds were samples in a 167 randomly selected school rooms in Indiana. Culturable mold levels were low with basidiomycetes, penicillium, cladosporium and yeasts were found to be the most prevalent. Indoor levels were significantly lower than outdoor levels. This is usually a good indicator as to where there is a problem or not. Interestingly significantly higher mold levels were observed in rooms which were climate controlled as compared to rooms which did not have operating ventilation systems. Mold levels in particular rooms were found to be high.

- The biodiversity and concentration of the airborne fungi were monitored over a six month period in the special care unit of a hospital. Sampling was performing in a hallway adjacent to a bone marrow transplantation unit. 98 fungal species were identified including Aspergillus fumigatus as well as 48 other species reported as potential pathogens. Neither the degree of fungal air contamination nor the species composition inside the unit differed from that in the corridor.
- 12026 indoor and outdoor samples were taken in 1717 buildings between 1996 and 1998. In all cases culturable air borne fungal concentrations in indoor air were lower than outdoor air. The fungal levels were highest in fall and summer and lowest in winter and spring. Highest fungal levels were found in the southwest, southeast and the west. The most common species were Cladosporium, Penicillium, nonsporulating fungi, Aspergillus and Stachbotrys chartarum although these accounted for only 6% of the total.
- The capability of air filters to retain airborne outdoor microorganisms was examined in field experiments in two heating, ventilating and air conditioning (HVAC) systems. At the beginning of the 15-month investigation period, the first filter stages of both HVAC systems were equipped with new unused filters. The number of airborne bacteria and molds before and behind the filters were determined simultaenously in 14 days-intervals. Under relatively dry (relative humidity 60-80%) and warm (> 12 deg C) outdoor air conditions air filters led to a marked reduction of airborne microorganism concentration (bacteria by approx 70% and molds by approx 80%). However during long periods of relative humidity (> 80%) a proliferation of bacteria and mold on air filters with subsequent release into the filtered air occurred. These microorganisms were mainly smaller than 1.1 micron therefore being a part of the respirable fraction.

Discussion:

What does all this mean? It is clear that bioaerosols of pathogens including those created by fungi are difficult to avoid and can be very detrimental to human health. The order of precedence for infectious diseases is as follows with 5 being the highest

1. plants
2. animals- fungi
3. protozoans
4. bacteria
5. virus

whereas the order of risk from bioaerosols is in the following order of importance

1. virus
2. animals
3. plants and protozoans
4. bacteria
5. fungi

This is not to say that there are not significant bioaerosol threats from other kingdoms. Legionella is known to form in cooling towers and hot water systems and industrial operations such as machining creates significant anthropomorphic bioaerosol hazards. The extremely complex lifecycle of fungi makes it very difficult to determine whether a toxic condition exists. Many fungal species including those known to be extremely toxic and pathogenic seem to coexist peacefully with us. On the other hand if conditions are right the same fungi can create bioaerosols which can kill us. Certainly a good rule of thumb to adhere to in order to determine the existence of a problem are fungal and mycotoxin counts inside and outside of the dwelling and the species composition of the air. If counts are higher inside than outside and or if the species composition of the air is different inside than outside then you probably have a problem.

It is clear that certain enclosed environments containing high concentration of people and quite possibly some people with compromised immune response must do a better job of providing reliable air quality. Two examples that come to mind are hospitals and airlines. In regard to hospitals it was acceptable in the not too distant past to essentially take no measures in regard to keeping surfaces pathogen free. In present day hospitals quite a few measures are taken to eliminate surface pathogens as sources of disease. These measures include sterilization, use of biocides such as chlorhexadiene and the use of disposable items. Based on the German hospital study as cited above it appears that measures for providing pathogen free hospital air and the hospital air itself is from a 100 years ago. Approx 50% of hospital deaths are caused by infections acquired during one's hospital stay. Aspergilliosis is a major concern for burn victims. The infection is transmitted through the air. All cases of tuberculosis transmission are traceable to airborne aerosols resulting from human activities such as talking. Hospitals must take much greater measures to ensure that the building is not a source of fungal spores and pathogens. Filtration of introduced spores and pathogens must also be improved. The same general principles applied to airlines especially in regard to utilization of filtration systems which are easily cleaned and do not support growth of pathogens.

Regarding prevention and remediation it is disturbing that air filters and air filtration devices appear to provide a comfortable habitat for fungi especially in high humidity conditions. Recirculation of air without immobilization of spores and toxins probably does more harm than good. In general dust suppression, control of moisture, good ventilation and speed drying of clean surfaces are recommended.

Remediation of mold is becoming a hot area. Remediation of mold looks like it will become the next asbestos. Currently there are a variety of recommended procedures for remediation including use of oxidizers, fungicides and bactericides and shielding compounds which seal the antimicrobial agents within the treated surface. Much work remains to be done regarding determination of an effective means for eliminating mold. It is uncertain whether cleaning procedures improve or exacerbate the problem. In the meantime the best course of action is to eliminate any conditions favorable for the growth of the most toxic fungi. Fortunately most of these are secondary or tertiary colonizers and require a fair amount of moisture for spore germination.

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