Common Engineering Mistakes in the Analysis of Aquarium Fires

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Fires caused by the proximity of electrical equipment to a large aquarium are very common. We discuss several engineering fallacies. We used data from 50 real-life investigation, and we obtained commercial products, ran tests, and analyzed cases reported. (1) Heaters are routinely blamed, but our tests show that they never cause a fire, even if the water level around them drops too low. (2) Arcing (high voltage) is often blamed for fires caused by a short circuit (low voltage), clearly a self-contradicting argument. (3) Moisture collecting in light fixtures and in power taps remain the actual causes of most aquarium fires, but confinement of any electrical hardware only increases the likelihood of a fire ignition. Confinement can include but is not limited to (i) placing electrical power sources in a cabinet beneath the aquarium, (ii) placing electrical components into a closet near the aquarium, or (iii) placing them very close to each other. (4) Using electrical appliances not rated for a moisture rich environment (i.e. NOT rated for use with an aquarium) is the cause of most aquarium fires, and this is not the fault of specially rated aquarium appliances.

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Introduction

Previously, we wrote about our investigation of aquarium fires [1]. Home aquariums of 25 gallons or more have a high probability of catching fire. A quick check of the internet shows many dozens of cases of house fires blamed on a large home aquarium [2, 3]. In [1], we showed that the most likely causes of an aquarium fire in the home were lighting fixtures/bulbs and power taps (aka power strips, terminal strips, surge strips, surge power strips). In another paper [4], we explored the problems with power taps when used in a moist or wet environment.

Power taps are available everywhere – Home Depot, Walmart, drug stores, hardware stores, and a host of other places; they can also be ordered online. Our only caution [1, 4] was that they should be rated to be used in a moisture rich environment. Fires normally start by moisture depositing on the power tap and creating a bridge of salt or dirt between the output voltage (generally 120 VAC) and ground (or neutral). The salt bridge builds up over time, and as it does, more current is shunted by it. The reason that the fire starts is that when current reaches a value of approximately 5 amps, it makes the plastic hot enough to ignite – most plastics ignite at approximately 700 degrees F. A circuit breaker or fuse in the home generally will NOT trip the circuit off unless the current reaches 15 or 20 amps.

Lighting fixtures have the same problem as power taps. A bridge of salt/dirt settles out of the moist air across the lamp's load. A current of about 5 amps can melt and then burn plastic parts and insulation in the vicinity.

One troubling discovery from our investigation is that some light fixtures and power taps are advertised as "safe in a moist or damp environment", but they are not. Their remains have been recovered by us at several fire scenes. But this is not the focus of our present work, and so we leave it as a caution without further discussion.

Problem Statement

We have investigated approximately a dozen aquarium fires in the past several years. We find what we consider "junk science" being used to back claims of how the fire started in each case. One of the most common ways to analyze a case quickly and with no real scientific basis is to blame the heater(s) used to keep the water in the tank warm. The assumption is that the heater is a high current device specifically made to create heat, and somehow this heat is the cause of the fire. Less likely culprits include water filters and other appliances that are made to be submersed into the water. Our tests on heaters and other appliances from a fire scene invariably show that these devices cannot be the cause of the fire. In order to gain UL approval, these devices have their electrical components well shielded from water.

Since heaters were the primary suspect in all of the cases investigated, we acquired a dozen heaters and tested them in a controlled laboratory environment. We do not cite specific manufacturers in this paper, since our results are the same for all of the major heater makers. We do concede that a dozen samples may be too limited, but the repeatability of our tests for 12 heaters convinces us that heaters are not the cause of aquarium fires, and clearly more testing needs to be done to vindicate the integrity of each individual heater by every heater manufacturer.

The 12 types of heater can be broken down into 2 groups – (1) 200 watts with a plastic over aluminum housing, cylindrical with dimensions of approximately 12 inches long by 1 inch in diameter and (2) 100 watts, glass body, approximately 10 inches by ¾ inches. For each type of heater, there is a bi-metallic control to attenuate the voltage (120 VAC RMS) by cycling it on/off in a predictable manner. Typical pictures of some of two of our heaters are shown in Figures 1 and 2.

Figure 1: Glass body heater, 10 inches long, is capable of delivering 100 watts.

Figure 2: Plastic covered aluminum body, 12 inches long, is capable of delivering 200 watts of heat.

Analysis

The heaters were each placed into a 25 gallon aquarium and set at their maximum heat output. They all reached a steady-state within a half hour or less. As expected, the smaller heaters barely raised the tank temperature by a few degrees, while the larger heater did better. However, since we were investigating the effects of each heater by itself, we did NOT run more than one heater in the test aquarium at any time. Over a period of days, we kept enough water in the tank to completely submerge the heating element, and thus there was no noticeable damage in any of the heaters.

We then reduced the water coverage by one inch. There was no change in our results. Reducing this again showed no change. We did not catalog any new observations until we reached a point where we were only submerging about 50% of the heater element. At that point, the exposed portion of the heater was noticeably hot to the touch. With less coverage, the exposed portion of each heater grew, and this portion grew quite hot. By contrast, the portion of the heater that remained in the water was merely warm, as it had been when each heater was fully submerged. Even when only one inch of the heater was submerged in water, the water's high specific heat capacity was strong enough to absorb most of the heat and carry it off into the water. The exposed portion of the heater was hot and radiated heat into the air, but the heater never broke.

As a final destructive test, the heaters were placed in air, i.e. they had zero percent of their body submerged in water. Each heater grew very hot, but continued to operate. After an average of 6 hours, the heaters with the glass housing stopped working. There was NO fire and no broken glass. There was a break in the heater element – either in the heater wire itself or in its contact to the bi-metallic control or to its contact to the power source. The heater elements and controls appear discolored from the heat, but there was no evidence of arcing, despite the fact that the conditions were favorable for arcing, i.e. a large electric field generated across broken contact points. There was no evidence of short-circuiting. None of the glass-body heaters had a short, but rather there were "opens" created by each break and measureable by an ohmmeter.

After 6 hours the heaters with the plastic/aluminum bodies continued to work. We conclude from this that they were more ruggedly built to withstand large temperatures.

In our investigations of real-life fires, the heaters were often blamed as the cause by investigators who were not well versed in the science of thermodynamics. But we found that the heaters cannot cause an aquarium fire. Yet there was a fire. What caused the fire, if not the heater? The same suspects as we reported earlier [1]: moisture collecting in appliances not designed for a moisture rich environment, with emphasis placed on power taps and lighting fixtures, and with this problem augmented by placing these appliances in a confined space (cabinet with doors on it or a nearby closet).

But our results lead to a troubling question. For our investigation of real-life fires where an aquarium is present, the heaters are frequently damaged. Many times there is no damage seen in the heater, but many times also there is breakage and/or arcing. In fact, some heaters have been retrieved from a fire scene as a small pile of black charred pieces.

Conclusions

We conclude that the fire started external to the heater in each of our investigations. In some cases, the water surrounding the heater shielded the heater from damage, and it was relatively un-damaged. In other cases, the heater received the brunt of the external flame, and it cracked and charred. If the connection of the heater to the electric power remained intact, breakage can occur in the heating element, and this would produce a strong enough electric field to induce arcing. But our results are in line with published results that indicate that arcing in a heater are caused by an EXTERNAL flame [5]. Our results indicate that a true heater fire (with several started by us in a lab setting) does NOT include arcing. Arcing occurs if the electric field propelling the electricity is strong enough to cause electricity to jump from conductor to conductor across an insulator (air in this case). The electric field varies directly as the voltage, which is constant at 120 VAC RMS or 170 volts peak value. A small break can have a separation of a millimeter or less, and this would give an electric field of 170,000 volts/m or more, more than enough for an arcing event. Arcing can be used to start a fire, but only on condition that the voltage source is large (1000 volt range) and it is applied to a resistive load that is high impedance, low current [6, 7], and this is exactly opposite to what we find in an aquarium heater which is low voltage (120) and high current (one or more amps). Aquarium fires with arcing on the heater are a very good proof that the heater was NOT the cause of the fire.

There is one good thing about an electrical fire caused by an aquarium. In all of the 50 real-life cases we reviewed, the water in the aquarium wound up putting out the fire. Collateral damage, of course, included smoke damage, some fire damage, and a great deal of flooding damage to the house. No loss of life or limb was found in any of our case studies.

References

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