Candle Soot Deposition and its Impacts on Restorers

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Introduction

The purpose of this paper is to define the phenomenon, causation, and impacts of soot deposition from ordinary candles.

Candle soot deposition is a phenomenon that is beginning to appear worldwide. A number of factors are causing this upsurge in occurrences, most notably the explosion in scented candle popularity. It is being investigated at a governmental level in Canada and Great Britain. It is causing severe damage to structures and furnishings when it appears, and due to the newness of the phenomenon, it is causing disagreements between its victims and the various contractors that service these buildings. HVAC contractors are the most vulnerable, since most of the soot is distributed by the HVAC system, and since the soot is generally associated with heat systems.

This researcher has personally investigated two candle soot losses; one in Georgia, the other in Tennessee. The total amount of these two losses alone was over $11,000.00. The case in Georgia was settled by this researcher with the homeowner to prevent litigation. The case in Tennessee was settled by the liability carrier for the candle manufacturer. In each case, the evidence pointing to candles as the culprit was overwhelming. There is a homeowner in Texas involved in litigation against both the candle manufacturer and the supplier of the candles. This case alleges property damage totaling over $100,000.00, due mostly to the estimated cost of replacing contaminated interior lined ducts that are built inside the walls of her home. It does not take long for it to appear either. In one test, burning four candles for three hours at a time for five days produced so much soot that the test had to be abandoned in that home for fear of causing too much damage.[1]

Obviously, this is a problem that is both serious and on the rise. It is just a matter of time before all restorers are faced with this situation, either by defending a claim of damage or investigating a "mysterious" smoke claim. This paper attempts to define the problem and present some reasons for its occurrence. It should be noted that, due to the newness of the phenomenon, very little published information is available. Most of the information in this paper was obtained through E mail or telephone dialogues. The best effort possible has been made to credit the sources of this information.

[1] Ron Bailey, P. E., Home Energy, January/February 1998

How a Candle Works

Candles have worked the same way since man first used tallow and a wick to make the first candle. Like all flame producing devices, the candle works by utilizing fuel, air, and a vehicle to combine the two in a controlled manner. In the case of the candle, the wax is the fuel, the air is simply the air surrounding the wick, and the combination vehicle is the wick.

Most candle waxes are a combination of large paraffins. A paraffin is chemically defined as any fully saturated hydrocarbon (all sites have a hydrogen on them).[2] In addition, additives are placed in the wax to allow proper burning characteristics, such as flame luminosity and scent, and to allow ease of manufacturing.

The wick is generally made of cotton. Some imported candles have been found to have lead in the wicks, allowing lead to deposit in homes they have been burned in. The homeowner in Texas mentioned earlier found definitely high lead levels in the areas around where her candles were burned. When the wick is lit, it burns long enough on its own to melt some of the wax at the base of the wick. This wax is absorbed up the wick by capillary action, and vaporizes when it gets close enough to the flame. This vaporized fuel then fuels the flame, which melts more wax at the base, which is absorbed by the wick. Eventually a pool of melted wax lies at the base of the wick, and the candle will burn until this wax pool is gone. The size of the wick determines how much wax can be introduced to the flame at a time. The larger the wick, the more fuel reaches the flame. Wick size is determined by two factors, length and thickness. The wick thickness is determined by the manufacturer, but the wick length must be controlled by the user. If a wick is not kept trimmed, it will allow too much fuel to reach the flame. Most manufacturers design their wicks for various candles to be kept at ¼" above the wax pool. The manufacturer recognizes that various wax mixes have different sooting tendencies, and design the wicks for each candle to match that wax. A properly designed candle controls the fuel supply by limiting the wick size to match the sooting tendency of the wax.[3]

Soot Formation in a Candle Flame-Chemistry

A candle flame is a diffusion flame, similar to a gas jet flame (like a butane lighter). The only real difference is that in a candle flame there is no forced flow of fuel. The fuel emission rate is controlled by the heat feedback to the wick.[4] Diffusion flames emit soot when the rate that soot is formed exceeds the rate that it is consumed in the

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[2] Dr. David L. Urban, NASA

[3] Ibid.

[4] Dr. David L. Urban, NASA

flame. The most interesting part of a flame is the luminous yellow zone that is responsible for most of the light emitted by a candle. This zone is also called the carbon zone, because it consists of carbonaceous soot particles. These are formed from decomposed hydrocarbons, which are rich in carbon because they have a relatively low hydrogen to carbon ratio.[5] The primary soot particles range in size from 10 to 200 nm and eventually cluster into chain aggregates. They are heated to incandescence by hot gasses and by the heat radiated from the reaction zone of the flame. As the particles rise through the yellow zone they are consumed by reaction with water and carbon dioxide to form carbon monoxide.[6] The threshold of soot formation represents the transition from the non-sooting to the sooting flame. The shape of the threshold of soot formation in a plot of mixture composition versus temperature looks like a peninsula.[7] The structure of the soot particle surface changes along the flame axis. At the beginning of the sooting zone, the surface of the soot particle is very smooth. These young soot particles look like an oily or greasy material. As the reaction time increases, the surface of the soot particle becomes structured, with a "fissured" surface.[8]

Soot formation occurs in the fuel rich side of the flame where there is little oxygen. During the soot formation process, acetylene radicals form and bond together to make soot. Basically, for diffusion flames, the sooting tendency will correlate with the carbon/hydrogen ratio.[9] Methane (CH4) burns very cleanly with a C/H ratio of 1:4. Propane (C3H8) produces some soot with a ratio of 3:8. Acetylene (C2H2) produces more soot with a ratio of 1:2.[10] The more hydrogens present in the fuel, the less soot is produced.

Since candle wax and fragrance oils are a hydrocarbon fuel, the soot that is produced is oily and can be characterized as "wet smoke."

Abnormal Soot Formation in Candles

There are several factors that can cause a candle to produce excess soot. Most unscented candles produce little soot. It is worth noting that most unscented candles are American made, and subject to stricter manufacturing controls. It was not until the surge in scented candle popularity that foreign manufacturers began to enter the market in large numbers.

Scented candles are the major culprits in the candle soot deposition phenomenon. This is due to a variety of factors. Most candle wax parrifins are more saturated

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[5] The Candle Cauldron, technical advisory message board.
[6] Ibid.
[7] Combustion Research Bulletin #97, CRB No. 97 November 1996-Technical Abstracts
[8] Ibid.
[9] Dr. David L. Urban, NASA
[10] Ibid.

hydrocarbons, and as such are solid at room temperature. Most fragrance oils are unsaturated hydrocarbons, typically liquid at room temperature. As noted previously, the lower the C/H ratio, the less soot is produced by the flame. Thus, waxes that have unsaturated fragrance oils mixed with them inherently produce more soot. The candle obtained by this researcher from the homeowner in Tennessee was labeled "Super Scented", and was obviously soft to the touch. It is likely that this candle has so much fragrance oil in it that it cannot burn cleanly. This is possibly due to the fact that liquid fragrance oils volatize at a temperature low enough that they become fuel directly from the wax pool. This throws off the fuel/air mix that has been designed into the wick, causing a flame that does not burn cleanly.

As noted before, the wick size plays the most important role in producing a flame that burns cleanly. The wick is the device that controls the amount of fuel that enters the flame. A wick that is too large will produce a rich fuel/air mix, while one that is too small produces a lean fuel air mix. Manufacturers control the amount of fuel reaching the flame by adjusting the thickness of the wick. Each wick is designed for a specific wax mixture. Unfortunately, there is another factor that affects the amount of fuel entering the flame: wick length. Manufacturers are powerless to control with any accuracy the length of the wick, because more wick is exposed as the candle burns down. They recommend to the consumer that the wick be kept trimmed to ¼", which allows them some accuracy in providing a clean fuel/air mix in the flame. The failing this researcher has noted in the recommendations to the consumer is that no mention is made as to WHY it is important to keep the wick trimmed. Many consumers in fact like the larger flame produced by a longer wick, and do not perceive the consequences of failing to follow these directions.

Some candle manufacturers add petroleum jelly or vegetable oil to their candles to prevent shrinkage in the molds, and to allow easy removal from the molds. These additives can constitute anywhere from 10%-50% of the additive mixture. At the higher percentages they can cause a candle to soot prodigiously.

Container candles are candles that are poured in glass containers. They are very popular, and are major contributors to the candle soot deposition problem. The theories for this are varied. Many of these candle types are imported, and that may be a root cause. Another theory is that as the candle burns lower, it becomes more difficult for oxygen to reach the flame, creating a richer fuel/air mix than the wick was designed for. Another theory is that the jar creates an unstable airflow to the flame, creating a mini-draft constantly to the flame. As will be discussed later, drafts are a major cause of excessive sooting for any candle. Yet another theory is that the jar increases the heat that the wax pool is exposed to, causing more fuel to vaporize than the wick was designed for. Whatever the reason, container candles are by all accounts a real contributor to this problem.

Mechanics of Soot Deposition

There are three major ways for these soot particles to deposit themselves. The first, impaction, is simply the repeated collision of these particles with other surfaces. In time, these surfaces become covered with the soot particles. A good example of this is a dark carpet stain under a closed bedroom door. As the return draws air from the room from under the door, soot particles supplied to the room via the supply duct are drawn under the door, where they are filtered by the carpet. Eventually a stain develops. This is the mechanism that causes damage to carpeting around floor registers, and to furniture skirts and drapery bottoms.

The second method is gravity. Particles of different sizes remain in the air for different lengths of time. Human hair, skin flakes, observable dust, and pollen (all ranging in size from less than 10 microns to 150 microns) require approximately five seconds to settle one meter.[11] Mite allergens, common spores, and bacteria, ranging in size from one micron (bacteria) to twenty microns (common spores) require five minutes to settle one meter.[12] Cat dander, tobacco smoke, organic fumes, and cell debris, ranging in size from .001 microns (cell debris) to .9 microns (cat dander), require ten hours to settle one meter.[13] Viruses, which are smaller than .01 micron, can require ten days to settle one meter.[14] Soot, or carbon black particulate, ranges in size from .03 to 3 microns, and can remain airborne for prolonged periods before settling.[15] Soot particles can be airborne almost indefinitely if enough air movement keeps them from settling. This allows large amounts of soot to accumulate inside a building.

The third method for soot deposition is attraction. Air coming out of the air handler at a high enough velocity and passing through a lined duct system can become electrically charged. The ACCA's Manual D for residential duct systems specifies a velocity of between 600 and 900 feet per minute (fpm). Measured velocities in houses having soot deposition problems has been as high as 4000 fpm, with numbers typically falling in the 1500-2000 fpm range.[16] The relative humidity of these homes has also been lower than 55%. This electrostatic charge is passed to particles moving through the duct. These particles will have a natural attraction for any surface that has an opposite charge. It is possible for particles, if caught in some turbulence within the air system, to become bi-polar, and possess both a positive and a negative charge. If this occurs, then the particles will clump together before adhering to a surface within the home.[17] An ACCA study conducted in Florida found that 28 of 29 homes with soot deposition problems had

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[11] Frank Vigil, January/February 1998 edition of Home Energy. In this article he credits John Spengler, Harvard School of Public Health, for these measurements.

[12] Ibid.

[13] Ibid.

[14] Ibid.

[15] Ibid.

[16] Ibid.

[17] Ibid.

both high velocity air moving through a duct system as well as localized turbulence within the system.[18]

Building Mechanics and Their Impact on Candle Soot Deposition Potentials

Certain dynamics of the building itself can have a great effect on the potential for soot deposition problems.

One of the biggest factors is air movement. It is widely accepted that a candle flame disturbed by air movement can create up to 300% more soot than the same flame in an undisturbed state. If a candle is allowed to burn for an extended period of time in a disturbed state, then a copious amount of soot can be produced. There are many things that can cause this air movement. The HVAC system can be a major contributor, especially if the candle is burned near a supply or return duct. The movement of individuals can play a large role. If a candle is burned where people are constantly walking by it, then it will be disturbed much of the time. A simple ceiling fan can move air in such a manner as to constantly disturb the flame to some degree. It is worth mentioning here that there seems to be a real correlation between minute Freon leaks and soot deposition. It seems that these leaks combine with soot and change it in such a manner that allows it to deposit in great quantities inside the home. There is an investigator in Florida who states that he has investigated as many as 9,000 homes in a three-state area with this problem. This researcher could not confirm this theory or locate this researcher, and this theory is greatly unconfirmed. Trane and York are both working with a lab in Oklahoma City to research this area.[19] Newer homes and older homes that have been extensively remodeled are much tighter than homes built in the past. Upgraded energy codes and new building techniques have produced homes where fresh air has to be actually introduced into the building. Aside from obvious health and IAQ standpoints, this plays a major role in soot deposition cases. The drastically fewer air exchanges produced in these homes tends to allow soot to become more concentrated, thus settling, impacting, and attracting on surfaces more readily. Many of these deposition victims will say, “My mother burns these same candles with no problems!” And they may be right. The difference will be in candle placement or in the number of air exchanges allowed by the different homes.

Another building factor that can play a major role is the variations of temperature found on the building material surfaces. Due to Brownian motion, soot particles move in every direction as they absorb energy from the surrounding air. Soot particles floating close to a cool surface tend to absorb more energy from the warmer surrounding air than from the cooler surface. As a result, the Brownian motion tends to drive the particle to

[18] Hank Rutkowski, P.E., ACCA Reference Bulletin #146, December, 1997
[19] Kelly Parker, P. E., Smart House Consultants, Oklahoma City OK

the cool surface. Obviously, if the entire surface was uniformly cooler than the surrounding air, then it would be uniformly covered by particles. If, however, a surface has differences in temperature relative to the surrounding air, then the particles would be deposited in a noticeable pattern. This phenomenon has been seen for years in the Restoration field as soot particles outline cooler wall studs or the heads of drywall fasteners. U.S Steel conducted a series of experiments in the early 1970's to investigate how "ghost marks" can occur in a home due to dust build up. They found that patterned particle deposition began on a surface when there was just a 3.3 degree F. difference in the surface temperature relative to other parts of the surface. If this temperature varied more than 8 degrees then severe discoloration occurred.[20]

Impacts on Restorers

There are several ways that this phenomenon can impact restorers. The first case that this researcher encountered involved a home that he restored after a fire. Naturally, when this "smoke" began to appear on the walls, floors, and furnishings, the contractor was held responsible. No amount of evidence could convince the homeowner, and after a year litigation against the contractor and the Insurance Company that initially paid the loss was imminent. The contractor made a claim against his liability insurance, who settled the matter. Obviously, since Restorers are constantly restoring buildings after fire losses, this liability exposure is real. All restorers would be well served to be as aware and knowledgeable on this subject as possible.

Another way that this situation impacts on Restorers is that they will be the ones called to investigate these "phantom" smoke claims as they arise. The adjuster will look at a smoke damage claim that has no apparent cause, and will then turn to a Restorer to attempt to explain the cause of loss. Every adjuster that this researcher spoke to said that they would provide at least some coverage in this situation, but that they would need to somehow document the cause of loss. Knowledgeable Restorers can be very valuable when this arises. Be assured, also, that it is only a matter of time before it does. Two factors are dramatically increasing the possibilities of this phenomenon occurring, the construction of newer, tighter homes, and the explosion of scented candles on the fragrance market. The first factor is well documented. Consumers and building codes are demanding tighter more energy efficient homes. As mentioned earlier, some types of construction require fresh air to be mechanically ducted into the home! As for the explosion of scented candles on the fragrance market, just look at the numbers. The scented candle market is serviced by a $2 billion dollar a year industry, and has been growing at a rate of 10%-15% since the early 1990's. The prediction is that this will continue for at least the next five years.[21] Many major companies are increasing their

[20] Energy Design Update, April 1995.
[21] Kim Frazier, ABCNEWS.com, Aug.7, 1998, from TheStreet.com.

investment in this market. Both SC Johnson Wax and Dial are attempting to bring scented candles to the grocery store and out of the specialty store.

The largest seller of candles worldwide is Blyth Industries, located in Greenwich, Conn., with sales of $687.5 million last year. Blyth has been very aggressive lately, buying up Hallmark's candle operations as well as Eclipse; an English company that makes scented floating candles. They have even bought Sterno Handy Fuels, the largest maker of chaffing fuels.[22]

The second largest manufacturer of scented candles is the Candle-Lite division of Lancaster Colony, located in Columbus, Ohio. Candle-Lite had gross sales in 1997 of $336.2 million.[23] Beyond these two, the industry is serviced by literally hundreds of other manufacturers, selling their products on a regional and only local level.

The trend for candle buying used to be very seasonal, but now consumers are buying candles to burn year-round. Susan Colley, owner of the Covington Candle boutique in New York, says "This used to be a seasonal business where 35% of our business was done around Christmas time. We are finding now that this is a year-round business now."[24]

Market research has revealed that consumers are shifting away from scented potpourris and are buying more scented candles. By 1995, scented candles were outselling potpourris two-to-one.[25] It's not that candles are stealing market share either. The candle market has grown that much. The beginning growth of the aromatherapy market will only tend to push candle sales higher.[26]

Another factor is the introduction of the do-it-yourself candle by Smith and Vandiver Company and by Scents and Fine Things, both regional manufacturers. These kits come with a glass jar, wax beads ready to melt, wicks and instructions.[27] What will happen when these do-it-yourselfers get creative with the mix? It's likely that Restorers will get to find out!

It can easily be seen by looking at these trends that candle soot deposition claims will only increase in the future. A knowledgeable Restorer will not only be able to help Adjusters find a cause for these losses, but will also be better able to protect himself and other contractors from claims arising from this situation.

As mentioned earlier, HVAC Contractors have been the ones initially blamed for this soot deposition. Homeowners mistakenly assume that this is an HVAC problem, probably due to two factors. First, HVAC contractors are probably the only contractors to regularly enter the home that can reasonably be associated with soot, usually after a winter furnace start up or an HVAC servicing. Second, the problem manifests itself

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[22] Ibid.
[23] Ibid.
[24] Ibid.
[25] Gil Y. Roth, Cover Story, September 1997.
[26] Ibid.
[27] Ibid.

initially around the HVAC supply registers, as this is the primary distribution mechanism for these tiny particles. So many of these complaints have occurred that the ACCA was prompted to issue a technical bulletin entitled "Soot Deposits in Residential Structures." In this bulletin it states:

> *Executive Summary*
> *This technical bulletin represents a preliminary discussion of the soot problems that are sporadically appearing in homes across the country. Investigations indicate that candle burning is the primary source of contamination, and they suggest that a specific set of circumstances must be present before a sooting event can be triggered. As explained below, these conditions are created when good construction techniques and equipment sizing practice are combined with poorly designed duct systems that feature fibrous materials. However, the mechanics of this conditional process have not been reduced to a set of multi-parameter equations that can be used to evaluate the likelihood of a sooting problem. This means that an estimated rate of consumption (pounds of candle material burned per hour) cannot be correlated with the probability of an event. Therefore, HVAC contractors cannot and should not guarantee that there will be no soot problems in candle burning homes.*[28]

There are many other causes of "ghosting" stains on walls and furnishings. Many of them are well known and documented, including soil filtration, fume fading, oily contaminates absorbed by olefin carpets, and outdoor sources such as traffic, industrial fumes, or simply dust from a nearby dirt road. It is important that these factors are taken into consideration in the investigation of a soot deposition claim. Keep in mind that a Homeowners claim that is paid on the basis of damage caused by candles has real subrogation potential. You would be doing your adjuster a disservice by allowing him to go out on a limb when you have not investigated all the possible reasons for this type of loss.

A cause of black soot deposition worth mentioning here is fiberglass attic insulation. In a case outlined in a recent edition of Cleaning and Restoration magazine, fiberglass attic insulation was entering the supply side of attic installed gas furnaces. This insulation was burning against the heat exchanger, and the resulting dark residue was depositing throughout the home.

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[28] Hank Rutkowski, P.E., ACCA Reference Bulletin #146, December, 1997.

A final factor worth mentioning is attributable to HVAC contractors, almost always in a commercial installation. Some commercial blowers are belt driven, and if the sheaves are not properly aligned then microscopic belt shavings are worn from the belts and can be introduced into the supply air. The commercial HVAC contractors that this researcher has spoken to about this situation agree that it can happen, but have not run across it themselves. Still, it is a viable possibility, and in a commercial situation it should be investigated.

Summary

Candle soot deposition is a relatively new phenomenon that is just now being investigated. The possibilities for damage to homes and furnishings are real, and can quickly become catastrophic. In some instances, noticeable soot damage can develop within a few hours of lighting the candles. Scented candles seem to be the main culprit, due to the addition of liquid fragrance oils to the wax mix. Candles work by mixing fuel and air in a combination device called a wick. A candle flame is a diffusion flame, similar to a butane lighter. The amount of fuel brought to the flame is controlled by the size of the wick. Manufacturers control the fuel flow by varying the thickness of the wick, and it is important that consumers keep candle wicks trimmed to ¼" above the wax pool so the fuel flow will remain accurate. Longer wicks introduce more fuel and make the mix too rich, creating excess soot. Other factors that can cause excessive sooting are wax additives and constant drafts disturbing the flame. With a few noted exceptions, this phenomenon seems to be caused by a combination of scented candles, tight home construction, and improperly designed HVAC systems that create too much velocity and interior turbulence. These factors create the candle soot residue, allow it to build up in the home, and charge the particles in a manner that clumps them together visibly and allows them to attach themselves to surfaces. Other methods of soot deposition on surfaces are impaction and gravity. Soot particles are very small, ranging in size from .03 microns to 3 microns, and can remain airborne for significant periods of time. Homes that are built tightly allow fewer air exchanges than others do, so the amount of candle soot within these homes can build up to high levels. With the increasing trends of building tight homes and consumers burning more scented candles, we can only expect the number of these situations to rise. Restorers can be beneficial in these situations by familiarizing themselves with this phenomenon and with the other possible causes of "ghost" marks. This knowledge can make them valuable to the adjuster and can also protect them if a liability situation arises regarding their own work.