CIRCUIT BREAKER MYTHS

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introduction

The circuit breaker is the basic means by which wiring is protected from both a short circuit and overload damage. Circuit breakers have replaced the fuses of yesteryear, and are desirable for both consistent performance and also for the fact that they can be reset.

A short circuit is different from an overload. NFPA 70E defines an overload as:

> *"Operation of equipment in excess of normal full-load rating or of a conductor in excess of rated ampacity that, when it persists for a sufficient length of time, would cause damage or dangerous overheating. A fault such as a short circuit or ground fault, is not an overload."*

Practically speaking, plugging twenty 150 watt light fixtures (3000 watts total) onto a 14 AWG branch circuit is an overload—we have a current of 25 amperes flowing in cabling rated at 15 amps. Shorting the hot lead to the neutral lead on this same branch circuit will cause hundreds of amps to flow—this is a short circuit, and is often accompanied by arcing and the splattering of molten metal.

The basic circuit breaker used in both residential and light commercial applications is called the T-M or Thermal Magnetic Circuit Breaker. Another term that is sometimes used is the MCCB, or Molded Case Circuit Breaker. The T-M circuit breaker has two independent trip mechanisms: thermal and magnetic. The former reacts to overloads and causes the breaker to trip, while the latter responds to short circuit fault currents.

the myths

There are several myths associated with circuit breaker operation. In this article, it is our intent to discuss each one, and explain physically the reason that each myth is just that. These myths are as follows:

1. T-M circuit breakers trip upon reaching rated current
2. T-M breakers trip immediately
3. A tripped breaker always means an electrical event has occurred
4. Breakers protect appliances and appliance cords
5. Breakers protect persons from electrical shock
6. Climate and ambient conditions have no effect on trip times
7. Circuit breakers prevent arcing
8. Circuit breakers can be used as on/off switches.

basic breaker operation and design

In order to debunk the myths it is important to understand the basic operation and design of the trip mechanisms in a circuit breaker. The thermal portion of the circuit breaker works by use of a bi-metallic strip which causes a spring-loaded latch to release and trip the breaker. The deflection of the bi-metallic strip depends on the temperature, thus the breaker has a trip temperature and it is the heat generated within the breaker that causes the temperature to rise, the faster the heat rise, the faster the breaker reaches temperature and trips. Heat is directly proportional to the power (watts), which is proportional to the square of the current ($P=I^2 \times R$)

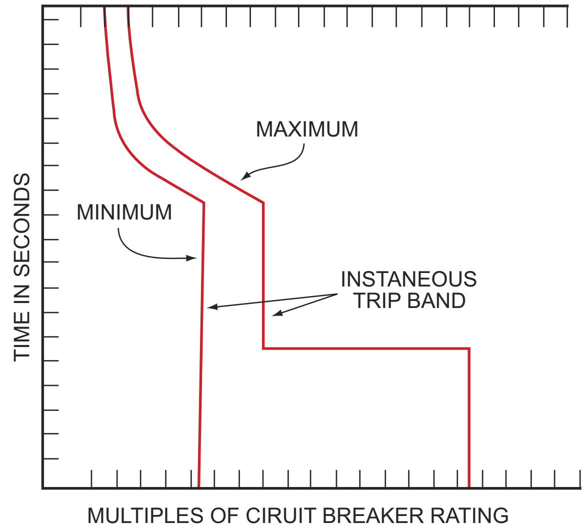
TABLE 1

BREAKER RATING (Amperes)	ALLOWABLE TRIP TIME (Minutes at 200% rating)
0-30	2
31-50	4
51-100	6
101-150	8
151-225	10
226-400	12
401-600	14
601-800	18
801-1000	20
1001-1200	24
1201-1600	26
1601-2000	28
>2000	30

The first (and most common) misconception is that a breaker trips when its nameplate rating is exceeded. One fire text has stated (incorrectly) that a circuit breaker will trip in several minutes with a small increase in current over its rating[1]. Actually, a 20 amp breaker must trip at a sustained current of 27 amperes (135 percent) at less than one hour, and at 40 amperes (200 percent of wire rating) in less than 120 seconds—far different from what the cited text implies. These two trip points (135 percent and 200 percent) are defined in NEMA Standard AB-1, MCCBs and Molded Case Switches[2]. TABLE 1 lists the 200 percent allowable trip times for different size (amperage) circuit breakers. MCCBs have characteristic 'curves' published by their respective manufacturers. A sample of such a curve appears in FIGURE 1. Knowing the amount of current flow, as a multiple of the breaker rating, allows one to determine the minimum and maximum trip times. Usually, the allowed times (per the manufacturer's curves) are shorter than what the NEMA spec allows.

A circuit breaker is designed to open (trip) before the energy passing through it creates enough heat in the branch circuit wiring to cause damage to the wiring. As an example, a type #12 AWG NM-B

FIGURE 1: ILLUSTRATION OF CIRCUIT BREAKER TRIP CURVE



with 40 amperes (flowing on it will not cause substantive overheating in the 2 minutes allowed for the breaker to trip. The caveats here are that the wiring being protected is *branch circuit wiring* **and** the breaker and branch circuit wiring are appropriately sized. A residential circuit breaker is not intended to protect load wiring such as extension cords or appliance line cords that may be subjected to overloads. For example, if we assume that an extension cord is rated at 10 amperes (#18 AWG) and is carrying a load of 25 amperes while connected to a branch circuit wire that is protected by a 20 ampere T-M breaker, the 20 ampere breaker may never trip. At the same time, the extension cord is grossly overloaded, and will become damaged. Similarly, a 40 ampere breaker protecting 15 ampere branch circuit wiring (#14 AWG type NM, as an example) **will** allow damage to occur during sustained overloads, because the breaker is inappropriately sized.

The response of a conventional T-M circuit breaker is affected by the temperature of its surroundings. This means that a breaker at an ambient temperature of 110 degrees F (thermally) will trip much faster than the same breaker will in an atmosphere of 20 degrees F. TABLE 2 shows data from a Square D circuit breaker rated at 30 amperes at different temperatures. When sufficient heat is generated in the bimetallic thermostat the breaker opens. In this case, the test current was 60 amperes.

TABLE 2

TEMPERATURE (°F)	TIME (S)
20	30
36	27.9
47	26
56	24.5
69	21

The magnetic portion of a circuit breaker is sometimes called the instantaneous trip portion. Rather than having an inverse current/time relationship, the magnetic trip level is characterized by the rate of change of the current flowing (di/dt) that is, the faster the increase in current, the faster the magnetic trip time. Once the instantaneous trip level is exceeded, there is a sufficiently strong magnetic field to cause the breaker to trip. Unlike the thermal trip mechanism there is no intentionally induced delay. Furthermore, the magnetic trip level is not affected by heat, such that ambient temperatures have no effect on performance. Another difference between the magnetic and thermal functions is that NEMA AB-1 does not specify a required magnetic trip level. Rather, each manufacturer is free to specify at what range of current the breaker will react to a perceived short circuit.

One might be quick to compare circuit breakers to fuses, however; there are several salient differences between the two. Fuses are non renewable, while circuit breakers can be reset. If a fuse blows and someone does not have a 'like' replacement readily available, on more than one occasion fuses have been replaced with larger size fuses—this is obviously a fire hazard. In addition, fuses are very easy to 'bypass'; copper tubing, as an example, easily fits in a cartridge fuse holder and provides no overload protection.

relocatable power taps

Relocatable power taps, more often called power strips, all have circuit breakers present. In general, these breakers are thermal breakers, and have no magnetic trip level. They are intended to prevent damage to wiring caused by having to many appliances plugged in (i.e., too great a load), and are usually rated at 15 amperes. We mention these breakers because they are common, and yet they are very different from the T-M breaker used as a part of branch circuit wiring.

T-M measurements

Given that there are two separate trip mechanisms in a circuit breaker, we have heard the following question posed numerous times in the past, as follows:

> "If we test the thermal portion of a breaker, will that ensure that the magnetic portion of a breaker is properly functioning?"

The answer is *"No, the two internal mechanisms operate independently."* The reason that the question is asked is because it is much easier to test the thermal portion of a breaker than the magnetic portion. To demonstrate the independent operation, we obtained a number of T-M circuit breakers of varying sizes and various manufacturers. We tested both the thermal characteristics (all at 75 degrees F, nominal), and then tested the magnetic trip levels.

Testing was done on a custom test set, using a computer to both simulate fault currents and measure actual currents and time. Using IEEE488 protocol and operating under Agilent VEE software the computer controlled a programmable power supply (Agilent 6813A) which in turn supplied power to a high current transformer (Unitrek 600 Ampere) in which the output was connected to the breaker being tested. Current values were measured across the breaker via a digital volt meter (Agilent 34401A) and fed back to the computer in order to maintain a constant current. FIGURE 2 is a diagram of the test setup.

For the thermal characteristics, a 200 percent test current was supplied to each of the breakers (i.e., 30, 40, or 60 amperes for the 15, 20, and 30 amp breakers, respectively) and maintained until the breaker tripped. Current was continually monitored and adjusted (via software) to ensure a constant load current. The same transformer was then used for the instantaneous or magnetic trip levels testing for the breakers. The power supply was programmed to send a pulse train of

FIGURE 2: SCHEMATIC OF CIRCUIT BREAKER TESTING DEVICE

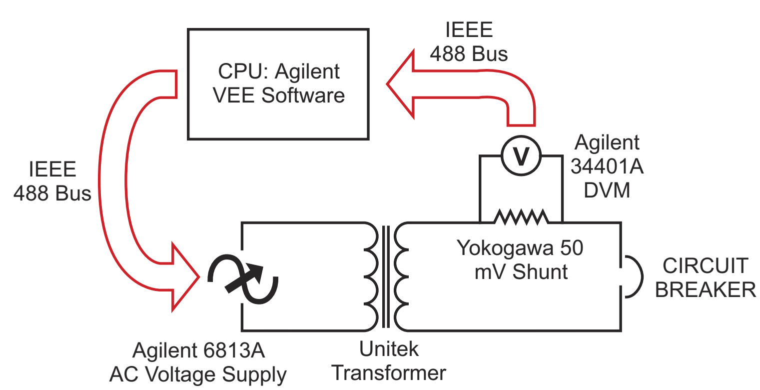


FIGURE 3: MAGNETIC TRIP LEVEL vs THERMAL TRIP TIME FOR 15 AMP BRAKER

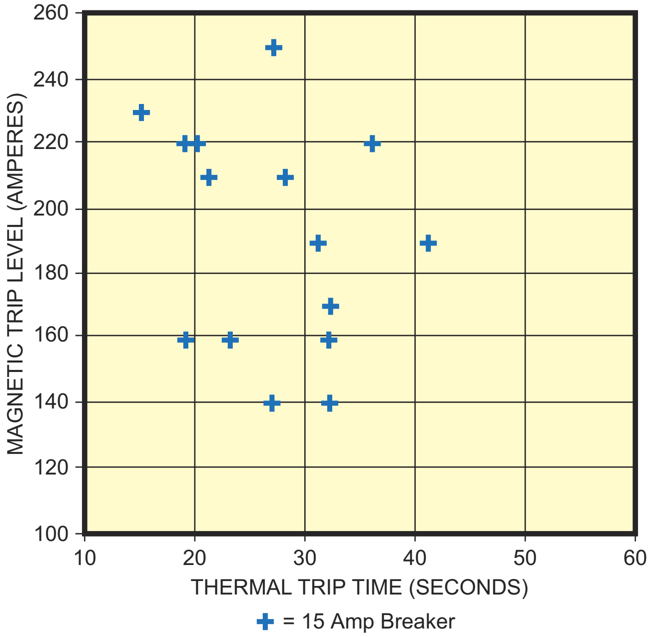


FIGURE 4: MAGNETIC TRIP LEVEL vs THERMAL TRIP TIME FOR 20 AMP BRAKER

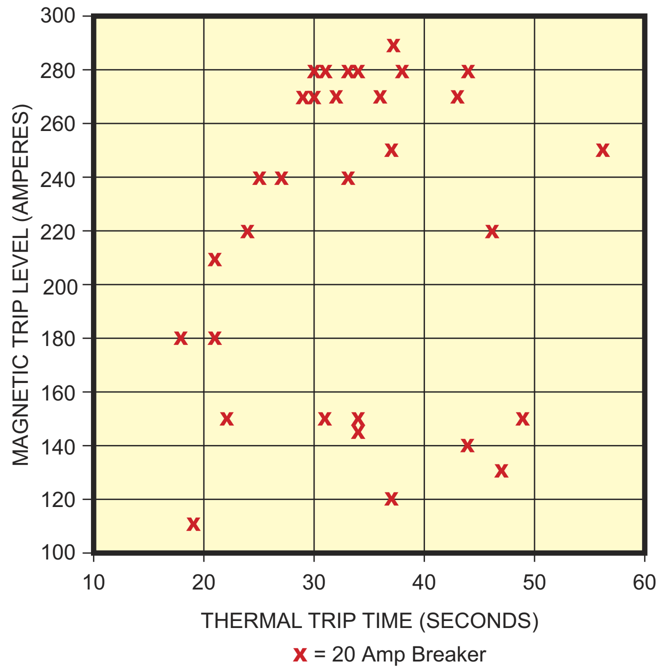
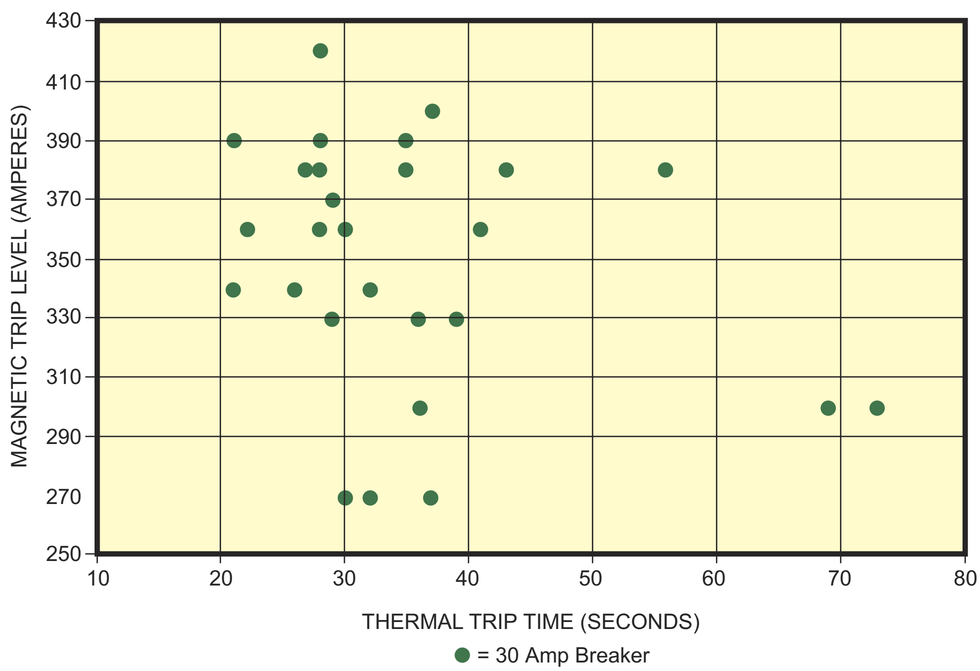


FIGURE 5: MAGNETIC TRIP LEVEL vs THERMAL TRIP TIME FOR 30 AMP BRAKER



6 constant current pulses (60 Hz sine waves, starting at zero degrees) followed by 10 seconds of wait time. Then, the current level was stepped up (increased) by 5 ampere increments and 6 more pulses were again applied. The wait time was introduced in order to ensure that the thermal portion of the breaker did not react and cause the breaker to trip.

FIGURES 3, 4, and 5 show the thermal characteristics (trip time) for each breaker as the independent variable, and the trip level (instantaneous) in amperes given as the dependent variable. As is readily apparent, there is no correlation between thermal trip times and instantaneous trip levels.

discussion

Circuit breaker performance is one data point our lab often assesses in investigating a fire. Having said that, we have been able to identify only three fires in 24 years where we felt that breaker performance was a significant factor in a loss. Two of these losses are now described:

(1) A homeowner had done wiring on a porch light, accidentally shorting the hot lead to the ground. The type NM cable, when shorted, allowed about 90 amperes to flow on the hot and return on the ground conductor. The light switch to the porch light was turned on, and a resulting fire ensued. The hot conductor (black lead of the NM) was "sleeved" along its length in the breaker box. *(Sleeving is a condition*

in which there is damaged insulation on a conductor caused by excess current flow. A wire that is sleeved will have insulation that is charred, bubbly, and has started to deform.) The fire broke out in the attic, along the same run of NM. The breaker serving the NM would not thermally trip when tested in the lab. FIGURES 6 and 7 depict the breaker and a portion of the load wiring. The breaker is a dual breaker, and only one of the poles (the one serving the porch light) shows evidence of the overload.

(2) A new house had its electric meter installed less than one hour prior to a fire being discovered. A 20 ampere breaker fed a length of type NM (12 AWG) that served a bedroom and ran through the attic space. Fire broke out in the attic. In the breaker box, the hot lead of the type NM was severely charred, while the conductors serving other breakers had no thermal damage. The exact fault in the attic was never identified. Regardless of the initial cause of the fault, however, the breaker never cleared the fault. Lab testing confirmed that the breaker would never trip.

A defective breaker, in and of itself, does not cause a fire. There also has to be a fault condition (either overload or short circuit, that the breaker should have cleared in a timely fashion) so as to cause a fire. In our investigations of breakers, the telltale sign indicating such a failure is an overheated branch circuit conductor (which we have referred to earlier as 'sleeved'), surrounded by conductors that are intact. If, however, the fire has thermally attacked and damaged the breaker panel, it will be very difficult to establish that a breaker was malfunctioning, unless one can find a 'solo' overheated wire in another part of the building that has not sustained fire/thermal damage.

The NEC requires that electrical components be used per their listing (2002 NEC Article 110-3b)[3]. We have successfully argued that this includes the installation of circuit breakers. As an example, a 20 ampere MCCB with an instantaneous trip level of 180 amperes was used to power an office cubicle located ~ 270 feet from the breaker panel. The feed consisted of #12 THHN, 3 conductors. On such a long run the resistance of the wire has considerable effects. In this case, with a bolted fault (solid short), the current level was measured at the cubicle as being ~ 130 amperes. It is clear that this level of short circuit would never cause the instantaneous trip feature of the breaker to be activated. Regrettably, a gentleman was electrically shocked by the cubicle, when the hot conductor energized the cubicle's frame. The duration of shock was increased because of the breaker's inability to rapidly clear the fault. The fault was eventually cleared by the thermal portion of the breaker, which in the opinion of the neurologist, had a substantial effect on the man's injuries. Had the branch circuit wiring been appropriately sized, the breaker could have cleared the fault much faster. The smaller wire (#12) and the long distance prevented sufficient fault current to flow so as to allow the instantaneous trip function to clear the fault. (Note: While a 20 ampere breaker is appropriate for protecting #12 wiring, the excess length of the branch circuit run dictates a larger wire size)

One of the properties of breakers with thermal trip mechanisms is that they can be tripped from the heat of a fire—even with no load. Years ago, a fire occurred in a trash can in an office, brought on by the careless disposal of smoking materials. The breaker panel for the building was also in the same office, and its steel door protected the breakers from direct flame impingement. One investigator noted that all of the breakers were tripped, and concluded (erroneously) that a large electrical event occurred, bringing on the fire. The reader is also referred to the previous article by one of the authors, wherein ambient temperatures and their effect on breakers is discussed[4].

Even though we have seen breaker malfunctions on very few occasions, our advice is to collect the breaker(s) at a fire scene, if it is supplying power to a suspect appliance or branch circuit wiring. Moreover, we also ask that several inches of load wire be collected from the panel. In this way, one could look at the conductor and determine if it is appropriately sized, and also if it has received damage from excess current values. Given that it is easy to inadvertently move a breaker handle during an investigation, we also routinely photograph and then mark (with a paint marker) the position of all breakers prior to opening a breaker panel to inspect it internally.

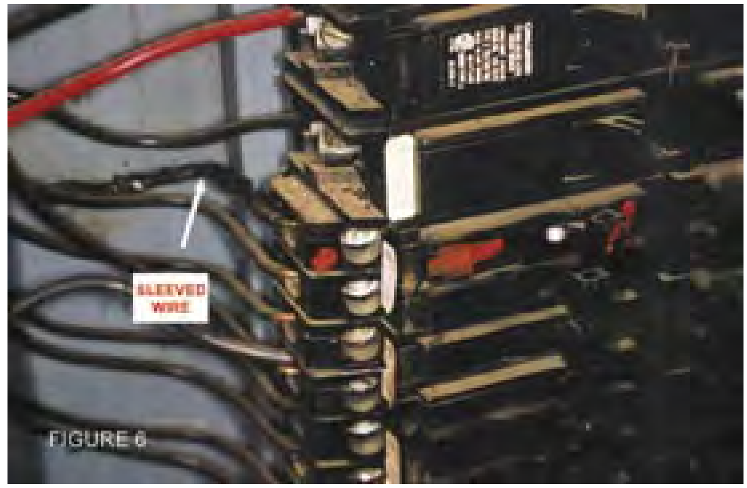


FIGURE 6

FIGURE 7

myths dispelled

Having discussed basic breaker operation and having demonstrated the independence of the thermal and magnetic mechanisms it is now easy to step through the myths and the physical reason(s) that each one is fiction.

1. T-M breakers trip upon reaching the rated current.

T-M breakers trip according to a trip curve, which includes both 135 percent and 200 percent trip times. At 135 percent of rated current, the breaker must trip in 1 hour or less. The trip curve is non linear as loads approach the breaker ratings (FIGURE 1), therefore, at even 5 percent above trip rating, there is no guarantee that the breaker will ever trip.

2. T-M circuit breakers always trip immediately.

These breakers trip thermally in seconds to minutes (depending on current level), per the published trip curve, in overload situations. In short circuit situations, trip times can be several cycles.

3. A tripped breaker always means an electrical event has occurred.

A T-M breaker reacts to overloads or short circuits. Current produced by the overload causes the breaker to heat internally and then trip. An external fire that places enough thermal energy into the breaker can also cause the breaker to trip.

4. Breakers protect appliances and appliance cords

T-M breakers used in buildings are rated for the size of the branch circuit. Often times the appliance wiring being fed by the branch circuit is smaller, thus has the same level of current flowing in it as in the branch circuit. Since the wire is smaller it has a higher resistance and will create substantially more heat in this cord that could cause failure of the cord.

5. Breakers protect persons from electrical shock.

A 15 ampere breaker, as an example, will trip in less than 2 minutes when 30 amperes is flowing. Electrical shock can occur with current in the .010 to .030 ampere range, with cardiac function being altered in less than 1 second. T-M breakers are not sensitive to currents this small.

6. Climate and ambient conditions have no effect on trip times.

T-M breakers work (in part) by the generation of heat internally. In a cold atmosphere, breakers will trip slower from overload situation; just the opposite is true in a warm atmosphere.

7. Circuit breakers prevent arcing.

T-M circuit breakers can react to the currents associated with arcing, but will not prevent the arcing. A short between a hot and a neutral in branch circuit wiring can easily allow several hundred amperes to flow, with resultant arcing. The T-M breaker will then trip in several cycles (depending on breaker rating and amount of current), but the arcing will have already occurred.

8. Circuit breakers can be used as on/off switches.

T-M breakers are complex mechanical devices, not meant for tens-of-thousands of operational cycles. However, there is one class of T-M breaker that can be used as an on/off switch, and this breaker will always be labeled as SWD (switching duty). SWD breakers are often used to control fluorescent lighting in offices and factories.

conclusions

The intent of this article is to dispel some of the myths regarding circuit breakers, as well as give examples of how a circuit breaker is intended to function. What we have seen is as follows:

1—A circuit breaker is only intended to protect branch circuit wiring

2—A circuit breaker has two separate mechanisms, thermal and magnetic

3—There is no correlation between thermal and magnetic performance for a given breaker

4—A breaker does not trip necessarily once its rating is marginally exceeded, nor does it trip immediately

5—Thermal portions of breakers are affected by ambient temperatures

6—A breaker is not intended to prevent electrical shock

7—A breaker does not prevent arcing

8—Circuit breakers are not to be used as on/off switches.

9—Breakers can trip from external heat

We are hopeful that our readers can use this information as part of their investigation into fires that possibly have electrical aspects.

REFERENCES

[1] *IAAI/NFPA User's Manual for NFPA 921*, 2001. Page 77.
[2] NEMA AB-1, MCCBs and Molded Case Switches.
[3] *NFPA 70, National Electrical Code*, 2002.
[4] Goodson, M.E., *Circuit Breaker Performance in Depressed Temperatures*, *Fire & Arson Investigator*, July 2001.

ABOUT THE AUTHORS—

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CIRCUIT BREAKER PERFORMANCE IN DEPRESSED TEMPERATURES

MARK E. GOODSON *PE*, TONY PERRYMAN AND KEN MC KINNEY, DENTON, TEXAS—Circuit breakers are the main devices by which wiring within residences and commercial buildings is protected from electrical faults. Typically, a circuit breaker panel (or several) will be installed with various size breakers to protect the electrical loads in a building. The size of each breaker (current rating) will depend upon the load connected to it; duplex outlets and lighting loads will usually have 15 or 20 ampere circuit breaker ratings, while larger loads (furnaces, AC units, ovens, clothes dryers) will have breakers rated at 30 amperes or more.

The function of a circuit breaker is to remove current should a short circuit or overcurrent condition develop. Inherent in the design of residential (and many commercial) breakers is the presence of two separate operating mechanisms: a thermal trip mechanism for overcurrent situations, and a magnetic trip mechanism to protect against short circuits. An overcurrent situation is defined as current flow in excess of the breaker rating; if the current flow is substantially greater than what the load wire is rated for, the current can generate enough heat to damage the insulation on conductors. Theoretically, this situation can exist for a 20 ampere breaker whenever a 12 AWG copper wire is carrying more than 20 amperes. In actuality, the 20 ampere rating is quite conservative and damage will usually not occur until currents of 50 or 60 amperes are flowing in the same wire. One way to create an overcurrent situation is to place a large load on a branch circuit in a controlled fashion; as an example, running thirty 100 watt light bulbs on a 20 ampere circuit is an overload. In this instance 25 amperes would be flowing, rather than the (theoretical) maximum of 20 amperes. The thermal portion of a conventional circuit breaker would be expected to respond to this type of problem. Table 1, taken from NEMA publication AB1, lists common breaker sizes and the appropriate wire sizes that these breakers are tested with[1]. The National Electric Code similarly prescribes breaker sizes based on the ampacity of a conductor protected by a breaker[2].

... 25 amperes would be flowing, rather than the maximum of 20 amperes. The thermal portion of a conventional circuit breaker would be expected to respond to this type of problem.

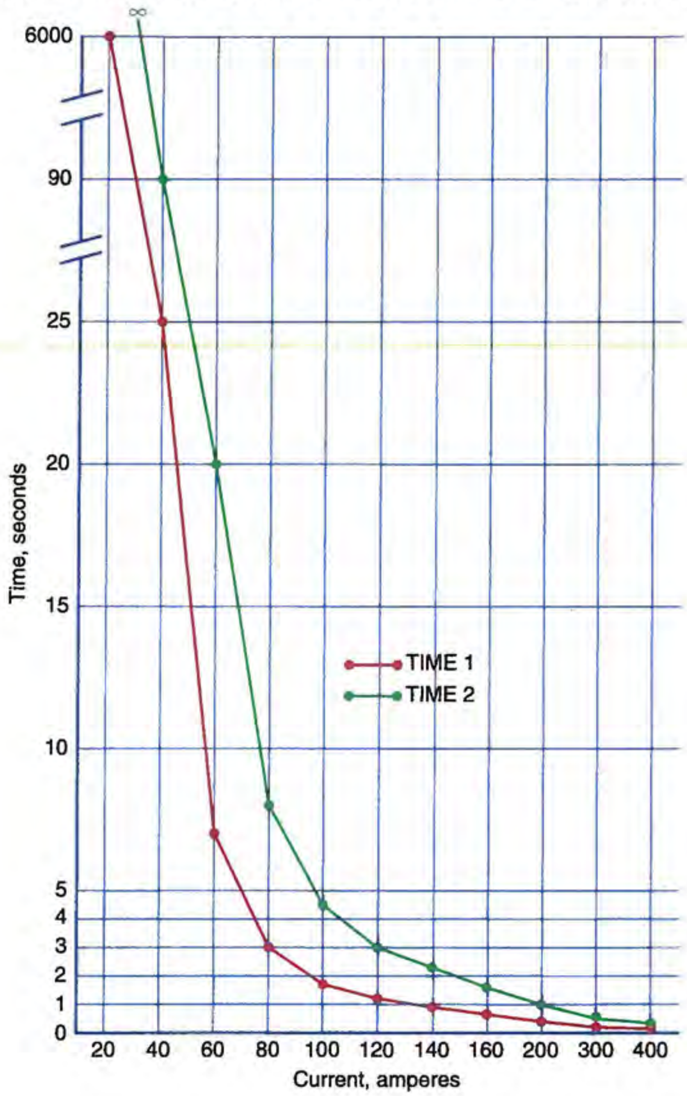
TABLE 1
MINIMUM WIRE SIZE FOR CIRCUIT BREAKERS*

BREAKER RATING (AMPERES)	LOAD WIRE SIZE COPPER, AWG (60° C WIRE)	LOAD WIRE SIZE COPPER AWG (75° C WIRE)
15	14	14
20	12	12
25	10	10
30	10	10
40	8	8
50	6	8
60	4	6
70	4	4
80	3	4
90	2	3
100	1	3
110	1	2
125	0	1
150	-	0
175	-	00
200	-	000

* SOURCE: NEMA AB-1, TABLE 4-6

A short circuit is different than an overload, and is associated with large amounts of current and a literal electrical fault. If a cable feeding a motor were to short out, the voltage would be expected to drop due to the short, and the current could easily reach several hundred or even several thousand amperes. As the current immediately increases rap idly, the magnetic portion of the circuit breaker responds and causes it to open.

FIGURE 1
TIME, CURRENT CURVES FOR 20 AMPERE BREAKER



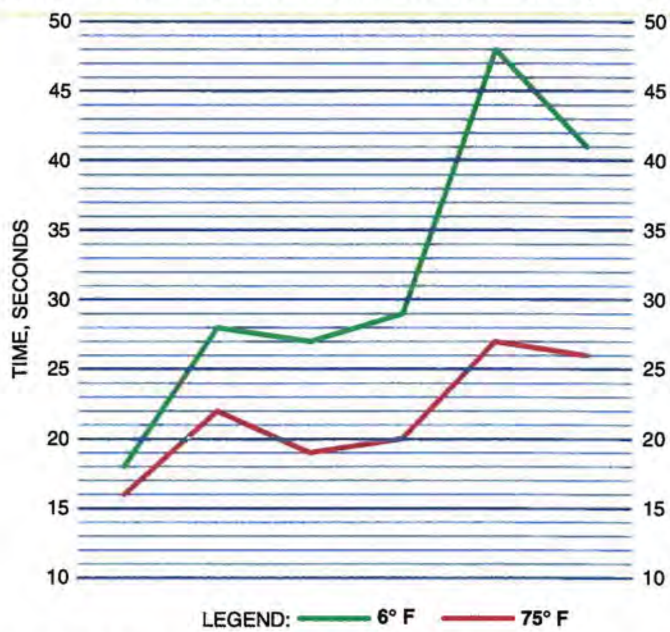
The typical circuit breaker has a set of performance 'curves' associated with it. These curves describe an inversely proportional time-current relationship for a given breaker. This relationship indicates that the greater the current overload, the faster the response time will be. This inverse time relationship applies only to the thermal portion of the breaker. The magnetic portion of the breaker will not trip appreciably faster when greater amounts of current flow. Figure 1 shows the inverse-time relationship of a typical 20 ampere breaker. It is a common misconception for residential breakers that they trip for current levels immediately above their rating; i.e., a 21 ampere load will cause a 20 ampere breaker to trip. The curves show, however, that this 20 ampere breaker will require between 25 and 90 seconds to operate at the 40 ampere (2x) level. Similarly, at the 60 ampere level, the trip time for the same 20 ampere breaker is between 7 and 20 seconds. The fastest trip time is seen at a current level of greater than 400 amperes. It is at this point that the magnetic portion of the breaker takes over, responding to a short circuit condition before the thermal portion of the breaker can take effect. As an example, a fault of 600 amperes on the same 12 AWG wire would cause the breaker to trip in less than .12 seconds.

Effects of Atmosphere

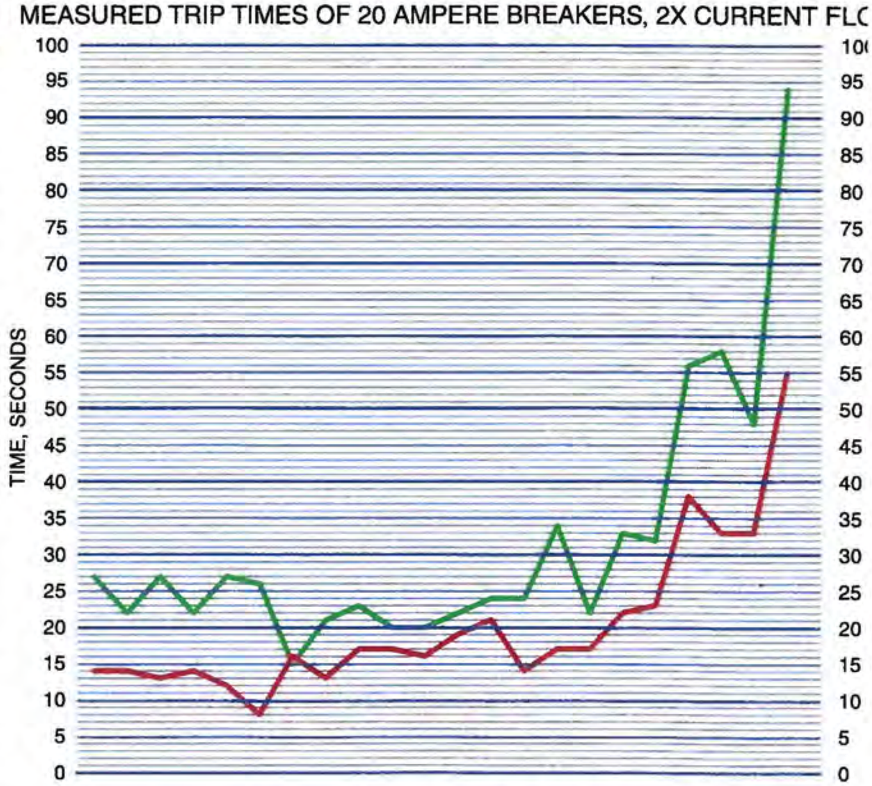
Research was carried out by the writers to determine the effects that depressed temperatures have on circuit breaker performance, and in particular the thermally actuated portion of the circuit breaker. The operation of this thermal portion of the circuit breaker centers around a bimetallic strip which deflects due to the heat generated in an overcurrent condition. This heat generation occurs in accordance with the usual formula for power, *Power (watts) = Current (amperes) ^2 x Resistance (ohms)*, where the amperes is the current flow through the breaker and the resistance is the resistance in that portion of the breaker which is designed to heat up and cause tripping. When heat is generated within the breaker, the speed (time) in which the breaker will respond and trip is a function of the level of current, the resistance, and the atmosphere.

TABLE 2

MEASURED TRIP TIMES OF 15 AMPERE BREAKERS, 2X CURRENT FL(



MEASURED TRIP TIMES OF 20 AMPERE BREAKERS, 2X CURRENT FL(



When the term 'atmosphere' is used in this article, it is primarily referring to the ambient temperature of the mounting location of the breaker, in most cases other factors in the environment (humidity, wind velocity) can be disregarded due to the lesser role they play in heat dissipation. NEMA standards regarding molded case circuit breakers state that the ambient air temperature shall not fall below 23 degrees Fahrenheit or above 104 degrees Fahrenheit; outside this range, the manufacturer is to be consulted[3]. This is a critical temperature spectrum, due to the fact that circuit breakers are calibrated for optimal performance in this temperature range. Placement of circuit breakers in an environment colder than 23 degrees Fahrenheit theoretically can allow a circuit breaker's performance to be retarded by the colder temperatures. Many readers have seen circuit breaker boxes placed in garages or even outside of houses. In a hot summer, the excess temperatures are a problem because they create nuisance tripping on the thermal mechanism of the breaker. In the winter, the question has to be asked: can a wire overheat in a house from an overcurrent situation because the circuit breaker, mounted outside, failed to trip when exposed to depressed temperatures? If the answer to this question is YES, then we have a situation where a fire could develop.

The writers conducted a series of tests on a total of 30 circuit breakers rated at 15 and 20 amperes, all in atmospheres less than 23 degrees Fahrenheit. Table 2 shows the results of these tests. In general, breakers which responded with mean or average trip times of 20 seconds at the 2x current level at 75 degrees Fahrenheit then had trip times that averaged 32 seconds at temperatures of about 6 degrees. These tests show that breaker trip time is retarded by the presence of the cold atmosphere, as would be expected. In these tests, however, the trip times were still below the 120 second trip time allowed per NEMA AB1[4].

Discussion

In any discussion of time-current relationships of a circuit breaker, one must always understand that the surrounding atmosphere will have an effect upon the response time of the thermal portion of the circuit breaker. Through the testing of circuit breakers at depressed temperatures described earlier, it was concluded that the trip time of the circuit breaker will only increase by approximately 65 percent under the given test conditions. The testing confirms that there is a relationship between trip time and ambient temperature. The colder that the outside temperature is, the longer a given circuit breaker will take to trip in an overload situation. At some point, a temperature will be reached where the circuit breaker will not respond to an overcurrent condition. Simply put, the air will be so cold that the heat generated internally by the resistance in the bimetal will all dissipate to the air before the breaker trips. The circuit breaker manufacturers recognize this, and recommend the derating of any circuit breaker used outside of the manufacturer's temperature specifications; one manufacturer, Square D, recommends derating any of their thermal breakers that are used outside of temperatures between 14 and 75 degrees Fahrenheit[5].

As to under what circumstances a fire might break out, consider the following situation:

A residence was being constructed in winter in a town where the nightly temperature was -17 degrees F. The house was well insulated, and in fact, was almost finished. Painters were warming one room of the house with 5 1500 watt resistance type heaters in order to encourage the stain in this room to dry. The house was still receiving its electrical power from a 'T pole' (temporary pole) located about 40 ft. from the house; on this T pole, a circuit breaker rated at 20 amps was located, and was the breaker being used for the duplex outlets in the room. The painters had spliced the #12 run from the T pole to the #12 'home run' circuit for this room.

Outside the house, the #12 wire run that ran from the T pole to the house was in good condition after the fire, with no evidence of overcurrent. In the house, a small fire occurred within the wall space where the #12 wiring was located. The fire was confined to several adjacent stud spaces, and died from a lack of oxygen. The wall spaces were heavily packed with thermal insulation.

The fire event in this case was brought on by an overloaded circuit carrying a load current of ~62 amperes on a wire rated at 20 amperes. Compounding the problem was that the wiring in the wall space was well insulated, trapping heat from the wire. When this same wire was tested in free air, it rose to a temperature of ~ 130 degrees Celsius; when heavily insulated by thermal insulation (fiberglass), the electrical insulation failed from overheating at the same current level. A further factor in the fire was the fact that the breaker was outside; testing revealed that the circuit breaker would never trip in an atmosphere of -17 degrees Fahrenheit when a load current of 62 amperes was flowing.

The above example represents a comedy of errors in which (fortunately) no one was injured. But it demonstrates the underlying idea behind this paper—***circuit breakers must be used in the same atmosphere as the load wiring they protect.*** If they are not, trouble will occur. In a hot atmosphere, the breaker will often trip in nuisance fashion. In cold atmospheres, they will trip in a retarded manner or not at all.

When investigating a fire where breaker function and placement are in question, the parameters that one must define are load (amperage), wire size, thermal rating of the insulation on the wiring, and atmosphere for both wiring and the breaker. Many of the factors can be determined at the scene, while a check with a local newspaper or the weather service (NOAA) can be used to establish temperatures. Once these variables are known, it is possible to simulate a fire scene using an environmental chamber, the same circuit breaker (if it is undamaged), and the same type of wiring and appropriate loading means (load banks, power supplies, etc.). Shown in Table 3 are the maximum trip times for 200 percent current tests described in NEMA AB1. Testing should be carried out to determine both trip times in the cold atmosphere as well as the temperature rise of the load wiring. If at the fire scene the wire was surrounded by thermal insulation, then the experiment should use the same type and thickness of insulation. If the actual breaker was damaged by fire, then it is necessary to test a number of breakers of the same rating and manufacturer; similarly, the appropriate curves from the manufacturer should also be referred to.

TABLE 3

ALLOWABLE TRIP TIMES FOR BREAKERS, 2X CURRENT FLOW*

BREAKER RATING (AMPERES)	TRIP TIME IN SECONDS (MAXIMUM)
0-30	120
31-50	240
51-100	360
101-150	480
151-225	600

* SOURCE: NEMA AB-1, TABLE 4-2

The NEMA data shown in Table 3 is useful, but only to a point. If we assume that a breaker that is required to trip in 120 seconds actually takes 5 minutes to trip at a 2x current level, certainly that breaker has failed. That does not imply, however, that this will cause a fire. Only actual testing of the breaker in combination with identical wiring in the same atmosphere can establish if a fire will occur.

Summation

The thermal portion of conventional circuit breakers is indeed affected by temperature. If a breaker is placed in an abnormally hot atmosphere, nuisance tripping can occur. In cold atmospheres, the breaker response times will be retarded, such that conditions for a fire occurring may be created. The NEC rating of conductors is extremely conservative, such that even if a breaker is substantially slowed in its trip time for an overload condition, a fire will usually not occur. It is only in rare conditions that a fire will occur. One would require both extremely cold temperatures for the breaker atmosphere, a large overload (perhaps 3x or greater), and wiring that is usually situated so as to trap heat. As with all fires, its is advisable to try and duplicate the fire scenario before reaching the conclusion that indeed this scenario occurred. ●

References

1.) National Electric Manufacturers Association, NEMA AB 1, Molded Case Circuit Breakers and Molded Case Switches, page 19, 1994.

2.) National Fire Protection Association, National Electric Code 1996, 1996.

3.) NEMA, ibid, page 8.

4.) Ibid, page 15.

5.) Square D Company, Thermal-Magnetic / Magnetic Only Molded Case Circuit Breakers, page 11, 1991.

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DORAN FIRST TO EARN FREE MEMBERSHIP

Congratulations to Robert J. Doran II of Winter Park, Fla., the first IAAI member to earn a free membership for 2002. A member of the board of directors since 1999, Doran signed up five new recruits for IAAI. He works for Engineering Fire Investigations (E.F.I.). "Doran sold the new recruits on the benefits of belonging to the IAAI. You can earn a free membership, too. Talk to your fellow firefighters, law enforcement officials and investigators. Tell them about the advantages, including support for testing and research projects related to fire investigation, a quarterly magazine and membership directory, representation in Washington D.C. and NFPA committees, plus the Certified Fire Investigator Program and the John Charles Wilson Scholarships for college students," says Alan Clark, IAAI Executive Director. For more information about IAAI, call 314-739-4224 or fax 314-739-4219. You and your recruits may also apply on-line at the IAAI website, www.firearson.org.

LIGHTNING INDUCED CSST FIRES

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ABSTRACT

Corrugated Stainless Steel Tubing (CSST) represents a relatively new technology for delivering fuel gas within a residential or commercial structure. The main benefit of CSST is brought about by a savings in installation time, relative to black pipe. However, the flexible thin walls of CSST also present a problem in terms of the propensity of CSST to fail when exposed to electrical insult, particularly lightning. We outline here the some of the theoretical basis for CSST failures caused by lightning, as well as investigative techniques to be used when examining a fire scene.

INTRODUCTION TO CSST

Corrugated Stainless Steel Tubing (CSST) is a relatively new building product, and is used to plumb structures for fuel gas in lieu of conventional black pipe. The advantages that are offered include a lack of connections and a lack of threading - in essence, it is a material that results in substantial labor savings (relative to black pipe). CSST is recognized by ANSI / IAS LC-1 -1997[1]. CSST consists of stainless steel corrugated tubing that is sheathed by a polymer conformal coating. Each manufacturer seems to have a proprietary system for achieving couplings / connections, but in general, the CSST (in that it conforms to ANSI LC-1) can be thought of as a commodity.

The authors have investigated several fires wherein CSST has failed when damaged by lightning. We outline here the theoretical issues regarding CSST, as well as results of fires we have investigated.

CSST DEVELOPMENT

The introduction of CSST into the United States was brought about by a firm called Foster-Miller. This engineering firm developed CSST as an alternate to black pipe. Our own reading of various pieces of literature shows that the driving issue is one of economy[2]. However, we caution the reader to review the literature and draw his / her own conclusions. CSST is made by 6 manufacturers, and each manufacturer requires a potential installer to take a several hour installation course. The installation courses are required as part of ANSI LC-1, and are an attempt to insure only qualified installers make use of CSST[3]. This arrangement will likewise prevent CSST from being available at home improvement stores.

CSST was first recognized by the NFPA in the *Fuel Gas Code* (NFPA 54) in 1988[4]. The IAPMO finally approved CSST in 2003[5]. It is interesting to note that in 2000, the IAPMO rejected CSST for reasons of safety[6]. The Foster-Miller documentation submitted in 2000 to the IAPMO states that there had been 50 million feet of CSST installed without one reported failure[7]. Now that there have been numerous reported failures, IAPMO action on CSST will be of interest.

In analyzing CSST, it is important to note that we can find no evidence of testing for lightning resistance during product development. The NFPA has stated that when CSST was first considered in 1988, lightning was given no consideration[8].

CSST UTILIZATION

CSST is different from black pipe, in a number of ways. On a CSST system, gas enters a house at about 2 psi, and is dropped to ~ 7" WC by a regulator in the attic (we are assuming a natural gas system). The gas then enters a manifold and is distributed via 'home runs' to each separate appliance. Unlike black pipe, a CSST system requires one separate run for each appliance. (See Figure 1 for a typical manifold) As an example, a large furnace and 2 water heaters in a utility closet will require 3 separate CSST runs; with black pipe, the plumber may have just used 1 run of 1" pipe and then teed off in the utility room. The reality of this design is that now there is a tubing system carrying 2 psi of NG in part of the residence; in addition, the requirement of one home run per appliance increases dramatically the number of feet of piping in a building.

Figure 1: Manifold and regulator leads of CSST setup

CSST is sold in spools of hundreds of feet, and is cut to length in the field for each run. In this regard, CSST has no splices / joints behind walls that might fail. CSST can be identified by its bright yellow jacket. Test pressures are higher for CSST than black pipe, and the industry touts this as a selling point; we find this somewhat of a 'red herring'. We know of no need to increase the Factor of Safety (FS) for black pipe – pipe tested at 20 psi and carrying 7" WC has provided satisfactory services for years. CSST does offer an advantage over black pipe in terms of structural shifts; with black pipe systems, the accommodations for vibrations and / or structural shifts are handled by appliance connectors.

THEORETICAL CALCULATIONS

CSST is extremely thin, with walls typically less than 10 mils in thickness. This lack of mass, necessitated by the desire for easy routing of the tubing, has resulted in a material that is easily punched through by electricity. Once the tubing has been perforated, it is possible for the escaping gas to be ignited by the metallic by-products of the arcing process, by auto-ignition, or by adjacent open flames.

The theoretical energy level required to melt a specimen can be compared by using both heat capacity and melting temperature. The heat capacity is the amount of heat needed to raise the temperature of either sample one degree Celsius. Changing the temperature from an initial temperature to the melting temperature requires the heat capacity to equal:

$$q = C \cdot m \cdot \Delta T_m + m \cdot H_f \qquad [1]$$

where C is the specific heat, H_f is the heat of fusion, m is the mass of the specimen, and ΔT_m is the change in temperature from the initial temperature to the melting temperature.

Our own field data indicates that lightning damage to black pipe is sometimes so small that it is often only visible with microscopic analysis and limited to a small pit that does not leak; lightning strikes involving CSST create leaks that vary from pinhead size to almost ¼" 'orifices.' For comparison sake we show the heat capacity for equivalent sized holes in specimens of black iron, CSST, aluminum, and copper tubing. Table 1 lists the relevant properties for all four samples.

TABLE 1

Material	C (BTU/lb F)	T_m (^oF)	H_f BTU/lb	Density (lb/in^3)	Wall thickness (in)
CSST (304) ½" OD	0.119	2589	128.7	0.285	0.008
Black Iron Pipe ½" OD	0.116	2575	122.7	0.284	0.12
Aluminum Tubing ½" OD	0.21	1166	167.3	0.098	0.035
Copper Tubing ½" OD	0.092	1981	88.05	0.323	0.04

For an equivalent 100 mil diameter hole, we can derive theoretical values for heat capacity based on the aforementioned equation.

Figure 2 is a plot of the respective values for each material. It is clear from

Figure 2 that the amount of energy to create a 100 mil diameter hole is much larger for black iron pipe then for any of the other three specimens. Thus we can now see why the thickness of the pipe plays such a critical role. In fact for this particular case, the amount of energy for a conventional ½" black pipe will require ~15 times the energy that would be required to similarly melt CSST, ~10 times the energy for aluminum, and ~5 times the energy for copper.

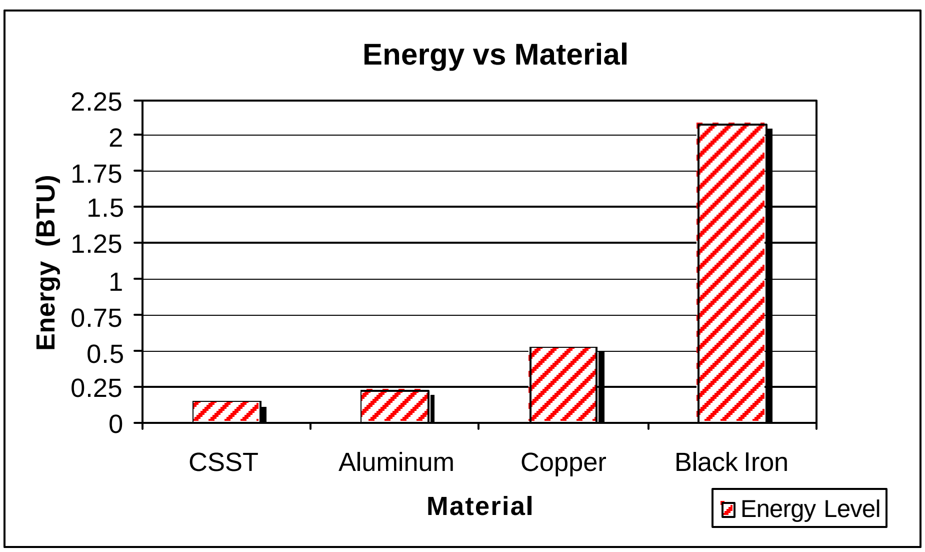


Figure 2: Comparison of heat capacity for 100 mil diameter hole in CSST, Aluminum Copper & Black Iron

LIGHTNING CHARACTERISTICS

How 'strong' is lightning? The data from Uman indicates that lightning strikes vary in current (amperes) from 10,000 to 20,000 peak (typical) to 200,000 amperes peak (maximum)[9]. Uman also lists the 'bottom' end of lightning strokes as having peak currents of 1,000 to 5,000 amperes[10]. Mechanical damage caused by heating is a function of current squared multiplied by time. Thus, the current is the dominant factor in creating the melting of the gas tubing.

FIRE INVESTIGATION

As of October 2004, we have encountered 4 fires in which we believe that lightning damaged CSST. We describe two of these fires here.

Fire 1

The fire occurred in the wood framed chimney space that had a metal chimney insert. CSST ran through the chimney space to feed the gas igniter. Four perforations were found in the CSST, ranging in size from a pinhole to a hole about 125 mils along its major axis. A STRIKE FAX lightning report showed that 4 hits within 0.1 mile of the house were recorded[11]. Figure 3 shows 2 adjacent holes that were created in the CSST.

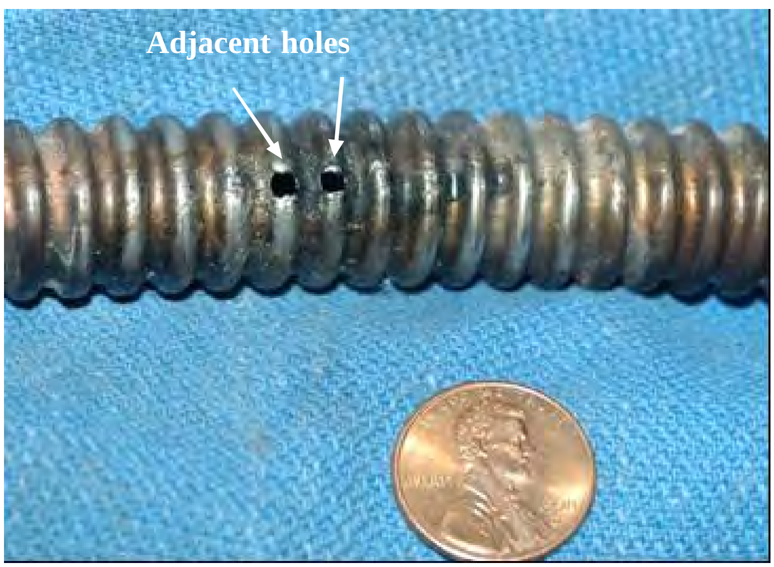


Figure 3: Adjacent perforated holes in CSST from Fire 1

Fire 2

The fire occurred in an expensive house (construction not finished) with a value in excess of 6 figures. The house was a 2 story house, and plumbed with approximately 95% black pipe. Two runs of CSST, each serving a fireplace, comprised the CSST piping in the house. A perforation with its major axis measuring approximately 200 mils was found in one run of the CSST (Figure 4). An interview with a neighbor confirmed that the audible and visual components of the strike were sensed simultaneously. A positive lightning report was obtained, showing 11 strikes within 0.5 mile. Regrettably, the house was razed before the investigation was complete. Figure 5 shows the failed CSST run to the fireplace.

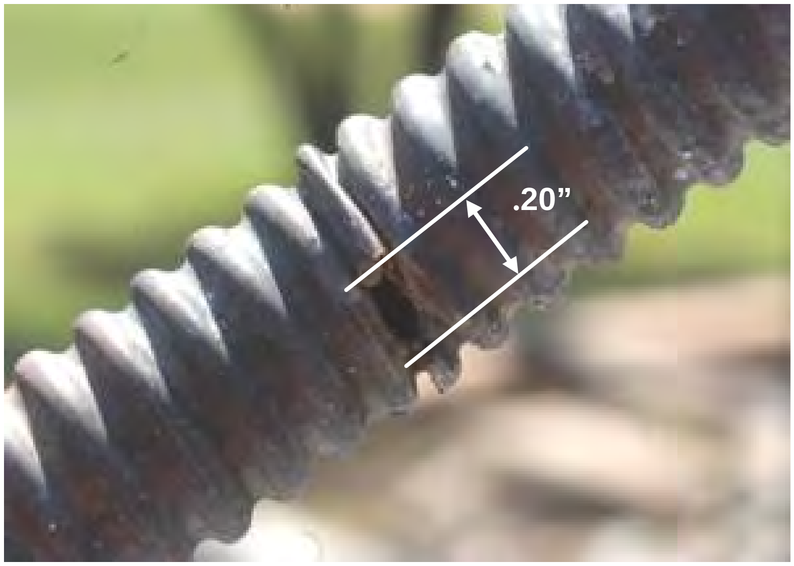


Figure 4: Perforated CSST pipe from Fire 2

Figure 5: CSST tied to Black Iron pipe from fireplace

DISCUSSION

It would be easy to list our findings as just ‘peculiarities’ and ‘vagaries of Mother Nature.’ Indeed, one of the CSST designers has stated that the phenomenon seems to be isolated to Frisco, Texas[12]. However, a recent article in the *Journal of Light Construction* outlines similar findings of an engineering firm in the Midwestern US[13]. In a recent presentation the authors gave to a fire investigators group, we found other fire investigators who have had similar fires in their jurisdictions.

The 'Frisco' experience is noteworthy, and was in fact the impetus for our research. In short, the Frisco (Texas) Fire Department noted a relationship between lightning and CSST fires. They thereafter sought to ban CSST in. A report generated by the City of Frisco states that the continued use of CSST would not be prudent[14]. In a newspaper article in the *Dallas Morning News,* a fair reading would show that the resistance to the ban was brought about for reasons of economy[15]. We would, however, urge the reader to obtain this article and draw his or her own conclusions.

As part of our research, we interviewed the Fire Department officials in Arlington, Texas. At the time of our research, the FD in Arlington was aware of 4 fires in their jurisdiction where lightning caused CSST failures[16]. We also reviewed a report issued by Donan Engineering, where again multiple fires were described that involved lightning and CSST. These extent of the fires reviewed were located in the Midwestern United States[17].

One of the underlying issues with CSST is that it is part of the grounding system. Purists will argue that that gas piping is not to be used as a ground, and they are correct[18]. In reality, however, the gas piping system is *per se* part of the grounding system, and this is recognized by the *National Electric Code* (NEC)[19]. Per the *Fuel Gas Code,* metallic gas piping is to be bonded to ground[20].

For reasons of electric shock prevention (and also elimination of sparks associated with static electricity), it is desirable to have all exposed metal within a structure bonded so that there are no differences of potential. Here, however, lies one area where applying DC circuit theory (or even 60 Hertz steady state phasor theory) has limitations. Lightning energy is known to have fast wavefronts. Testing of devices for transient responses has typically involved an 8/20 uSec pulse, as defined by the IEEE[21]. Another variation is the 10/350 uS pulse, as recommended by the IEC[22]. While the reaction of large wires and irregular surfaces is predictable at 60 Hertz, the fast wave fronts associated with lightning may cause substantial problems with CSST, given its corrugated surface. Moreover, new house construction we have observed has shown very tight bends and routing of CSST immediately adjacent to large grounded surfaces. Testing of CSST under actual installed conditions using transient waveforms may well show further limitations that conventional bonding and grounding cannot accommodate.

CURRENT TRENDS

One manufacturer (Omegaflex) has recognized the problems that lightning poses for CSST. In response, Omegaflex has developed a jacketing material (the yellow polymer coating) that contains conductive materials; the role of the conductor is to dissipate the charge over larger areas of metal, thereby reducing current density and increasing chances for survival. Witnessed tests of the new material were described in the July 2004 *Journal of Light Construction*[23]. The reports indicate a much greater tolerance for lightning.

Correspondence received from Foster-Miller indicates that Franklin lightning rod systems will protect CSST from lightning insult[24]. However, we have not seen CSST-equipped houses being outfitted with lightning rods. The same correspondence also shows that the CSST industry is becoming aware of the problem, and will propose fixes to the other Codes (ie , NEC or Fuel Gas Code); no mention was made of fixes to the standard LC1. A further item that should be mentioned is that Foster-Miller believes that the problem does not exist in Florida, even though Florida is prone to substantial lightning activity; Foster-Miller attributes this difference to greater adherence to lightning-related Code provisions (bonding, grounding)[25].

INVESTIGATING CSST FIRES

Investigation of a fire caused by CSST and lightning is a straight forward process. One of the characteristics of CSST that makes this a simple investigation is the high melting point. Stainless steel is not prone to melt during a fire. If a hole is found in CSST, there is a good chance that the hole is from electrical current. One would need to reasonably eliminate other sources of the leak, to include eutectic melting (alloying) and mechanical damage. Microscopic work would be necessary to insure that the orifice was created by an arcing condition. As with copper wire, one is looking for sharp delineations between fused and non-fused areas. If there appear to be other metals present at the arc site, one should conduct EDX (Energy Dispersive XRay) to see if the metal being examined is stainless, or if it has other metals present (such as Cu, Zn, Al, Sn). If copper is present, one might reasonably attribute the problem to an ongoing fire attacking both the CSST and nearby NM electrical wiring – when the NM faulted to the CSST, a perforation was created. Figure 6 shows a photo taken under a scanning electron microscope (SEM) of a section of CSST that failed when touched by an energized 120 VAC copper wire.

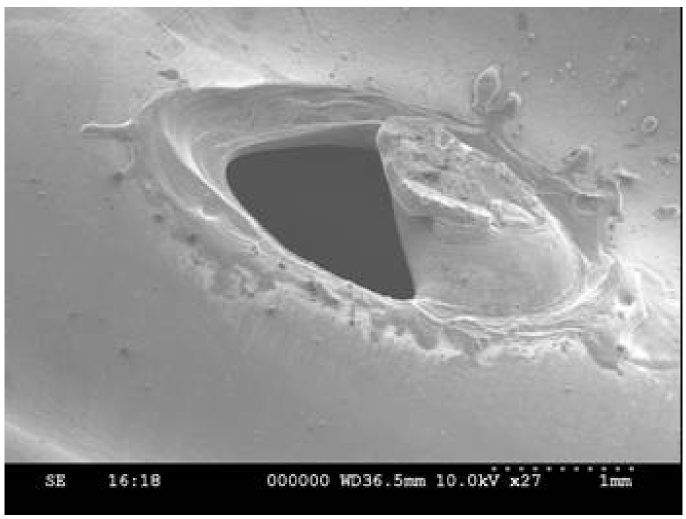


Figure 6: Hole caused by energized 120 VAC copper wire

To find holes, we recommend an instrumented leak test at ~ 7" WC air. One end of the CSST should be plugged, and each hole sequentially plugged (modeling clay seems to work the best) until the CSST no longer leaks. One of the holes we found in CSST was in an area of tubing where the polymer coating had no pyrolysis (See Figure 7). Also, Figure 8 is a microscopic view of this small leak. As in any fire investigation, the leaks and subsequent flame development must support the area of origin, or the leaks would appear to be of little consequence.

Figure 7: Photo of perforated CSST without pyrolysis

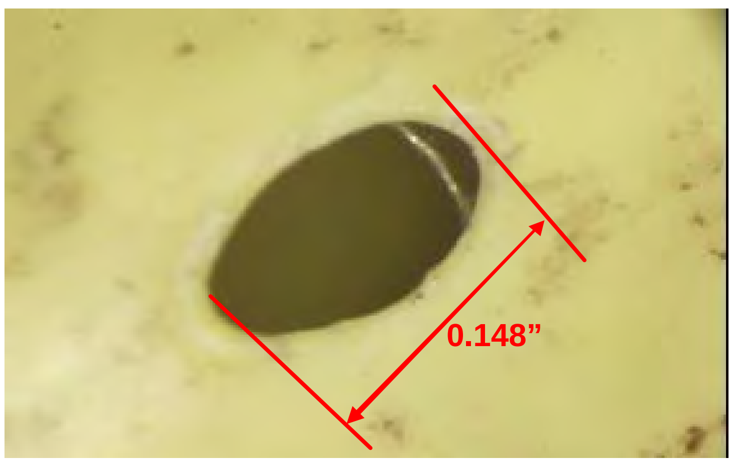


Figure 8: Microscopic View of Perforated CSST

The Frisco Fire Department Report lists escaping gas from the end connectors during lightning events as also being possible sources of ignition[26]. In a previous article written by one of the authors (MEG), this very phenomenon was described on appliance connectors[27]. The fact that a gas line fails at a connection is no surprise, in that gas lines are chosen for mechanical integrity at their junctions, and not necessarily electrical conductivity. Figure 9 shows the end of a failed appliance connector that has arced and caused a fire due to electrical current flow. We might expect to see similar manifestations with CSST at its connectors.

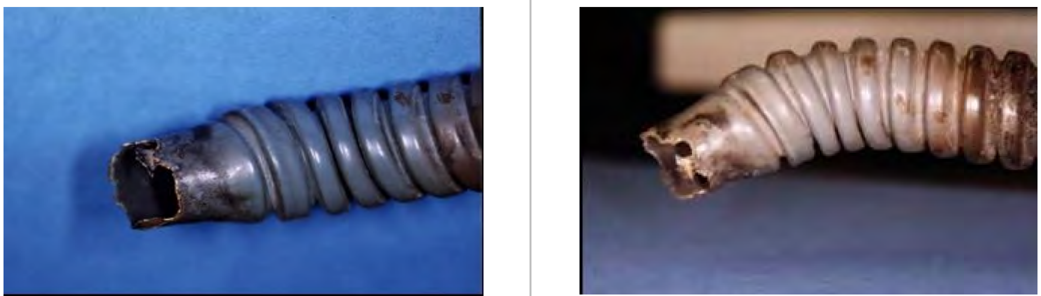


Figure 9: Bottom and side respective views of failed gas line from appliance connectors

In all of our investigations, we have obtained positive lightning reports via STRIKE FAX. The City of Frisco, in their investigation, also made use of STRIKE FAX reports. We must state, however, that in our opinion, the perforated gas line can normally stand on its own in terms of evidentiary value; we know of no other phenomenon that would create a clean arced hole other than lightning. If a copper wire arced to the stainless steel tubing, there should be copper remnants found. Likewise, the melting point of SS will not be reached in most fires. While the lightning reports are useful, we would add that they might add 'too much' information, if that is even possible. The reports list strike magnitude, polarity, distance, and time. If there are multiple strikes, there is a question of which strike is causative. Likewise, is it possible that one strike induced multiple perforations? We are not certain that these additional questions can be answered accurately, nor do we know to what extent these answers may be helpful. In the end, the CSST failed from lightning, or it did not – we have not been concerned as to which of multiple strikes brought on the failure.

In one of our fires, a field examination revealed the hole in the CSST. The STRIKE FAX sent thereafter to the O&C investigator was negative. And yet, a neighbor was a witness to the lightning. The request for a lightning report was re-submitted, and this time the report received was positive for lightning events at the location. In this fire, the physical evidence was very clear and helped to serve as the basis for a requesting a new lightning report.

We have not spoken of spoliation, but it is of course advisable that potential adverse parties be given notice of inspections if litigation is anticipated.

THE ULTIMATE QUESTION:

The ultimate question is whether or not CSST is safe as currently installed. We would offer initially that there is one similar product that reminds us of CSST. Aluminum wiring was approved by the NEC and by a recognized testing group – UL. Aluminum wiring was installed for reasons of economy, in that it was less expensive than copper. Aluminum wiring was also never adequately tested before being placed on the market. We later learned about creep, dissimilar thermal coefficients of expansion, and the insulating properties of oxidized aluminum. When adequate testing was conducted, it was realized that aluminum had numerous problems not posed by copper. Wiring on the inside of houses and business is now all copper, which does not pose the risks associated with aluminum,

In the case of CSST, we know of one manufacturer diligently trying to alter the product so as to prevent losses. We are also aware of the industry proposing changes to codes so as to make CSST less of a threat during lightning. These alterations, combined with mounting fire losses involving CSST and lightning, would suggest that it has deficiencies. The underlying issue, however, is whether or CSST is as safe as conventional black pipe. In this regard, reported fire losses indicate that it is not as safe as black pipe in regards to the issue of lightning. While we cannot state that black pipe will never fail from lightning, we have yet to see such a fire.

REFERENCES:

[1] ANSI, *"Standard for Corrugated Stainless Steel Tubing, LC-1" 1998.*

[2] Faloon, Kelly, "The CSST Battle is Over", Plumbing *and Mechanical*, February 2003, http//:www.pmmag.com.

[3] ANSI, op. cit., p

[4] NFPA, National *Fuel Gas Code Handbook*, International Approved Services, 1997, Section 2.6.3, p 52.

[5] IAPMO *Uniform Mechanical Code*, 2003

[6] IAPMO, *2000 Uniform Plumbing Code Changes Committee Recommendations* Las Vegas, NV May 3, 2000 Item 84 Section 1210.1.

[7] Ibid Section 1210.1.

[8] Lemoff, T., personal correspondence with City of Frisco, January 3, 2003.

[9] Uman, M. A., Lightning, Dover Publications, Inc New York, 1969. p 5

[10] Ibid, p 128.

[11] Vaisala Inc, Tuscon, Arizona, http://www.vaisala.com.

[12] Torbin, R., "*Preliminary Metallurgic Evaluation of Two Fuel Gas Piping Systems*", Review of Technical Report, Foster-Miller Inc.

[13] "Flexible Gas Piping Involved in Fires Caused by Lightning" *Journal of Light Construction*, May 2004.

[14] Frisco Fire Department, "House fires involving lightning strikes and flexible gas lines" Investigative Summary, FFD p 3.

[15] "Frisco Bans Pipes Used in New Homes" Dallas Morning News, April 3, 2003.

[16] Open Records Request, City of Arlington Fire Department.

[17] "The Effect of Lightning on CSST Gas Tubing Papers on Fire Cases", Fire and Arson Conference, Indianapolis, Indiana, August 16-18, 2004

[18] NFPA, *National Fuel Gas Code*, op. cit., Section 3.14b, p 98.

[19] NFPA National Electric Code (NEC), 2002, Section 250.2 fpn p 96.

[20] NFPA, *National Fuel Gas Code*, op. cit., Section 3.14b, p 99.

[21] IEEE/ANSI C62-41, IEEE, New York.

[22] IEC 61643-1.

[23] "New Lightning-Resistant Flexible Gas Line Shines During Demonstration", *Journal of Light Construction*, July 2004

[24] Torbin, R., personal correspondence, August 27, 2004.

[25] Ibid, August 27, 2004.

[26] Frisco Fire Department, op. cit., p 3

[27] Goodson, M. E. "Electrically Induced Gas Fires" *Fire Arson Investigator*, July 1999.

*Principal and Consulting Engineer, respectively

Polyurethane foam insulation systems represent an attempt to do away with some of the drawbacks of fiberglass batt insulation for ceilings and walls. The advantages of foam, relative to fiberglass, include lower labor costs, ease of handling, and less worry about inhalation of fiberglass by workers. Other attractive properties, per manufacturing data sheets, include reduced sound transmission, good fill around boxes and pipes, and a lack of urea formaldehyde that was present in some prior foam systems. These qualities, while admirable, are secondary in our mind to the important feature—*high R value.* (For the reader not familiar with energy management and heat transfer, the *R value* is defined as the *reciprocal of heat conductance—U*. Typical R values per inch thickness are: cellulose—3.7; fiberglass—3.3; polyicynene foams—3.6; and polyurethane foams—5.6[1]. A good "insulator" is by definition, a poor conductor of heat and will have a *high R value.*)

These foam systems, while serving as excellent thermal insulators, also have the potential for reducing the ampacity of type NM *(NM, per the National Electric Code, is Non Metallic, often generically referred to as "Romex")* cables, should the cables be thermally insulated with the foam. Tests were conducted by the authors to determine, if indeed, the ampacity of a wire was substantially reduced such that a fire situation could arise. Our findings are detailed here.

By way of background, the authors set out on this project after investigating a small fire caused by a light fixture in a newly built 17,000 S.F. mansion, under construction for 2 years. During the investigation, we noted that foam encased type NM in the residence was discolored and slightly charred in places, and yet the house had not been lived in. The manufacturer and distributor were contacted, and they denied there was a problem. The authors were told that the foam system had been tested by UL, and that there was no danger in using the foam. We were further told that no one ever uses 100 percent of the ampacity on wiring, and that even if the wire does fail, the foam will not allow a flame that might develop to be sustained.

Ampacity

The ampacity of a wire is actually its *amperage capacity*, as defined by the NEC. In general, cables sized at 14, 12, and 10, American Wire Gauge *(AWG)* and of NM construction[1] must be protected by overcurrent devices rated at 15, 20, and 30 amperes[2].

A characteristic of type NM cable, as with many electrical conductors, is that it can carry twice its rated current with no adverse short term effects. It is only when the cable carries 2.5 to 3 times its rating that a cable starts to become severely damaged. As an example, in open air (25°C) a 12 AWG cable of type NM can carry 40 amperes without significant overheating. At the 50 and 60 ampere level, however, we are reaching an area where sustained operation can cause significant damage and a possible fire. The damage starts with the melting of insulation, and can eventually lead to arcing.

In order to protect the cable, the NEC requires overcurrent devices. Commonly, these are circuit breakers. Contrary to anecdotal tales, a 20 ampere breaker does not trip when 20 amperes is marginally exceeded[3]. Rather, the breaker works in an inverse time—current fashion. As the current through a breaker increases, the breaker trip time decreases. Per UL 489 and NEMA AB-1, the following trip times are allowable for 15, 20, and 30 ampere breakers[4,5]:

TABLE1
Allowable trip time for 15, 20 & 30A breakers

CURRENT LEVEL	TRIP TIME MAXIMUM
135%	1 HOUR
200%	120 SECONDS

Thus, a 20 ampere breaker at 27 amperes must trip in 1 hour or less, and at 40 amperes it must trip in less than 120 seconds. Note that at the 24 ampere level (as an example), there is no requirement that the breaker ever trip in a normal, 25°C atmosphere[2]. From our discussions above, the 20 ampere cable will normally not be damaged until the current is at 50 or 60 amperes. Ergo, a 12 AWG cable that carries 24 amperes should never be damaged.

In regards to the NEC and overcurrent protection, the underlying theory is that a breaker (overcurrent device) must always trip before the temperature rating of a wire or cable is exceeded[6]. If the rating (often 75°C or 90°C) is not exceeded, the cable is presumed to be able to carry that current into infinity. Once the temperature rating is exceeded, there is a chance for a breakdown of the cable insulation, with resultant arcing and a possible fire. It is doubtful that a type NM cable will start to immediately degrade once the 75°C or 90°C threshold is exceeded. However, operation of the cable at temperatures sufficiently above the limits will erode the margins of safety built into the cable.

Testing

Much of the data we know about electrical cables is derived from work done at ambient temperatures, and with heat dissipation into free air. In a closed wall space with no insulation, this assumption is fairly valid. The question has to be raised, however, as to whether urethane foam thermal insulation systems seriously degrade ampacities of wires such that they can operate dangerously[3,4]. The foam insulation, when installed, clings to any cables that are present, forming a very intimate seal and preventing good heat dissipation.

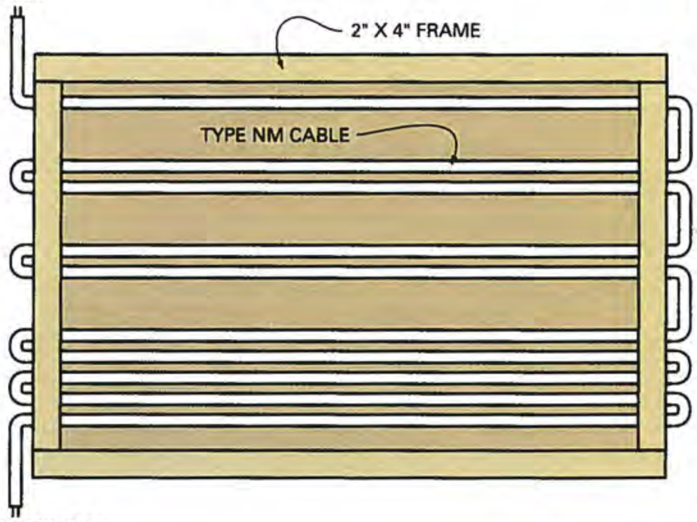
Initial testing by the authors was conducted on both #12 and #14 AWG type NM cables, in that these cables are the most commonly used. Test panels were constructed using standard framing lumber and

EFFECTS OF POLYURETHANE FOAM SYSTEMS ON WIRING AMPACITY

COAUTHORED BY MARK GOODSON, PE; TONY PERRYMAN, EIT; KELLY COLWELL, DENTON, TEXAS

1/4" plywood. The test cells used nominal 4" wall studs, and were each 4' in height and 30" in width. Testing was conducted at various current levels. We tested for both single and multiple wire runs (parallel cables tie wrapped together). Figure 1 shows a diagram of the test jigs that were used. Thermal insulation of an expanding foam type (polyurethane) was injected in all of the wall cavities and allowed to stabilize before testing. The type NM tested was rated at 90°C. Type K 30

FIGURE 1
Diagram of typical test jig



AWG thermocouples, feeding a Stanford Research 1630 scanner, were used to determine temperature on the outer jacket. Current was provided by a constant current power supply (DC). Using low voltage DC (8 volts maximum) allows the current levels to be precisely controlled. Because heat is a function of only current and resistance, heating effects between AC and DC are equal. Current entered a hot lead, ran to the other end of the fixture where hot and neutral were shorted, and then returned via neutral. Ambient temperature was 25°C for the testing. Photo 1 shows a test jig before insulation is injected.

PHOTO 1—Test panels were constructed using standard framing lumber and 1/4" plywood. Initial testing was conducted on both #12 and #14 AWG type NM cables. Photo shows a test jig before the insulation was injected.

The same experiment was repeated on 12 AWG wire loaded at the 24 ampere level, with 4" (nominal) batt insulation. These results are also charted.

Chart 1 shows the temperatures obtained on the conductors after 6 hours. The data also shows what temperatures were present when the cavities had no insulation present.

CHART 1
Temperature obtained on conductor after 6 hours

AWG	NUMBER OF RUNS	CURRENT LEVEL	INSULATED	MAXIMUM TEMP (°C)
14	1	15	YES	173
14	2	15	YES	245
14	3	15	YES	294
14	4	15	YES	332
14	1	18	YES	195
14	2	18	YES	308
14	3	18	YES	390
14	4	18	YES	417
12	1	20	YES	236
12	2	20	YES	267
12	3	20	YES	265*
12	4	20	YES	290
12	1	24	NO	114
12	2	24	NO	131
12	3	24	NO	141
12	4	24	NO	146
12	1	24	FIBERGLAS	131
12	2	24	FIBERGLAS	206
12	3	24	FIBERGLAS	211
12	4	24	FIBERGLAS	215

* Inspection revealed that the foam in expanding, pulled the thermocouple away from the outer jacket of the type NM.

Discussion

What is obvious from the testing that has been carried out is that the cables reach dangerous temperatures when covered with the foam. The more important observation, however, is that there is no overcurrent protection for these cables as they reach temperatures where they can be damaged. As noted earlier, overcurrent devices are to trip at the 135 percent level in 1 hour or less, and may never trip at the 120 percent level. The assumption in the NEC is that there is so much safety margin in the cable that sustained 120 percent current levels will never damage the cable; the effect of the foam has been to take away almost all of the safety margin. A second observation is that even at rated current, the cables are exceeding their temperature rating. Thus, wire rated at 20 amperes can no longer safely carry 20 amperes.

A report from UL Canada was produced by a manufacturer, and it shows that wiring does exceed its temperature rating when tested in single runs at rated current (20 amperes—12 AWG and 15 amperes—14 AWG)[7]. Steady state temperatures of between 93 and 95°C were reached for both the 14 and 12 AWG cables. No testing was outlined in this report at the 120 percent or 135 percent levels. The manufacturer's claim that the insulating system had been tested by UL was, in essence, true, but the document produced in no way formed the basis for a UL listing; rather, UL only performed temperature testing on thermally insulated wiring.

While it is true that (per the NEC) branch circuits are not to be overloaded[8], the installing electrician has no control over what appliances a homeowner plugs into an outlet. Two resistances heaters, each rated at 1500 watts, will place a load of 25 amperes on the same branch circuit. At the 25 ampere level, the circuit breaker protecting this branch circuit (rated 20 amperes) cannot be counted on to trip.

Photo 2 shows the 14 AWG test jig that carried multiple runs and which was energized at the 18 ampere (120 percent) level. As one goes from 1 to 4 runs, the level of damage increases. With 3 and 4 runs, there is substantial charring of the insulation on the cable. Following the testing outlined for this test jig, we separated hot from neutral and then powered up the three conductors in the standard hot/neutral/ground configuration, as if the cable were in normal use. When powered at 120 VAC, arcing immediately occurred on the damaged cable.

PHOTO 2—The 14 AWG test jig carried multiple runs at 120 percent level. After the 3rd and 4th runs, there was substantial charring of the insulation on the cable. When powered at 120 VAC, arcing immediately occurred on the damaged cable.

Twelve AWG wire will always be hotter than 14 AWG wire, given the same current ratios. With 12 AWG wire, a 20 ampere current will dissipate .66 watts per foot, while 14 AWG wire will produce .59 watts per foot at the 15 ampere level (assuming 20°C ambient).

A final observation made by the authors relates to the manner in which fires occur. Fires often occur because margins of safety are eroded. While it is true that wires should not be overloaded, they often are. When these overload conditions develop, we count on the circuit breaker to remove current before damage occurs. The foam systems we have tested reduce the safety margin that is inherent in type NM cables.

Brochures from the foam system manufacturer that was tested list the R value for the foam tested at 5.3. In our opinion, the key factor in terms of heat entrapment is not just the R value, but also the manner in which the foam clings intimately with the cable. We should also note that we did not test every combination of current, wire size, and insulation type. Once a cable began to exceed ~194°F (90°C), no further testing was conducted at higher current settings.

The manufacturer of the foam system we tested has told these authors that fire initiation because of the foam is not an issue, because the foam will not allow oxygen to get to the "area of origin." They similarly state that the foam will not support combustion. We have not investigated the foam in terms of combustion, smoke production, UL 94 characteristics, or oxygen index. The authors plan additional work to determine in what manner, if any, the foam does contribute to a fire causation scenario. Our opinion, however, is that it would be much better for the wiring to never fail, as opposed to having a failed wire cease the combustion process because the atmosphere is oxygen deprived.

We also note that the failing insulation has the potential to produce a "ground neutral" fault, which in and of itself is not an immediate fire hazard. The NEC does state that there are to be no bonds between ground and neutral at any point but the service connection[9]. Should the wiring overheat from the foam insulation system and cause the neutral and ground to become "bonded", this section of the NEC has been violated. If a floating neutral scenario then occurs, this damaged branch circuit will try and "balance" the load to a residence, possibly bringing about a fire.

Design issues

The authors have been asked to formulate ways of protecting type NM cables that are already installed and insulated in existing houses. The best way that we have developed to protect existing foam installations is to derate the breaker and to make sure that the breaker is a GFI breaker. On 12 AWG wire, we believe that 15 amperes is the more appropriate size, with GFI protection. As has been shown by one of the authors [MEG], GFIs can cut off current in cables with failing insulation before a fire can occur[10].

Arc Fault Circuit Interrupters (AFCIs) are now on the market, and they have the potential to cut off power during arcing scenarios. In that this technology is new and has not been tested by the authors, we can state that this is only a potential solution.—*(continued next page)*

—About the authors

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Summation

It is our opinion that insulating foams have the ability to seriously degrade type NM cables. The extent of degradation will depend upon the level of loading and the duration of that loading. What we can state with certainty is that the foam can trap heat sufficiently such that the cables will exceed their maximum operating temperature and the overcurrent protection will not respond. In this regard, the presence of foam makes it necessary for the electrician to substantially derate any cables that it encases.

Footnotes:

1. *Values vary among manufacturers, trade associations and also, with fiberglass and cellulose, depend on settling.*
2. *While some 20 ampere breakers may trip at the 24 ampere level, one cannot count on this when designing an electrical system. The only known qualities are those supplied by the time-current curves from the manufacturer.*
3. *The term "dangerously" is meant to mean that the wire temperature exceeds its insulation rating.*
4. *For the purist, the NEC ampacity tables are even higher for 90°C insulation (per Table 310-16), but Article 336 states that type NM shall be considered as 60°C wiring, and 310-16 also mandates the lower breaker sizes.*

References:

[1] NFPA, National Electric Code, Article 336, 1996
[2] ibid, table 310-16
[3] Siemens, ITE Molded Case Circuit Breakers, TD 4944, 1992
[4] UL, Standards for Safety UL 489 Molded Case Circuit Breakers, 1996
[5] NEMA, Molded Case Circuit Breakers AB-1, 1992
[6] McGraw Hill, *NEC Handbook 19th Edition*, Article 240-1, 1987
[7] UL Canada, Report 4180, 1998
[8] NFPA, ibid, Article 210
[9] NFPA, ibid, Article 250
[10] IAAI, *Fire and Arson Investigator*, "GFIs and Fire Investigations," Jan., 1999

KNOW YOUR CERTIFICATION!

Did you know that there are different types of certifications for fire investigators?

MICHAEL A. SCHLATMAN, CFI–There are several different types of certification for the fire investigator. They include: local, state, provincial, national, and international certifications. There are also different requirements to obtain each certification. To confuse the issue further, each certification is accredited by different agencies.

In the spirit of informing our members of the newly discovered certifications available, however not the most rigorous to obtain, we are providing the following information.

The CFI Committee located a website, www.e-technologycenter.com, which is reportedly a career institute located in Tennessee. They offer courses in real estate, computer technology and law enforcement.

If you choose the **"LAW 303 Course Fire and Arson Investigation"** it will take you to a screen where, for $99.95 plus $19.95 for shipping and handling you can "Get Certified." But don't think that's all you have to do, there is the required reading of a provided e-book *Fire and Arson Scene Evidence: A Guide For Public Safety Personnel.* Reportedly in that book are forms from NFPA 906. There is no mention of NFPA 921, testing, or any other requirements. Nor does the site indicate where the "certification" is recognized.

In contrast, the IAAI Certified Fire Investigator (CFI) Certification is the only one that is internationally recognized. Countries such as Canada, Australia, New Zealand, Georgia and South Africa are participating in the IAAI CFI Program.

In addition, the IAAI CFI Certification is the only one accredited by the National Board on Fire Service Professional Qualifications. That accreditation is awarded due to the CFI program's administration, compliance with the duty areas in NFPA 1033, the requirements for education, experience, expert testimony (or stringent testimony classes) and training before the examination can even be taken.

So when you choose to become a certified fire investigator, please make sure you consider the requirements, the agency awarding the accreditation and where it will be recognized.

In our view, your choice is limited!

Amazing how stupid people can be!

When his .38-caliber revolver failed to fire at its intended victim during a holdup in Long Beach, California, robber James Elliot did something that can only inspire wonder: He peered down the barrel and tried the trigger again. Happily for most concerned, this time it worked. (Natural selection at its best!)

The chef at a hotel in Switzerland lost a finger in a meat cutting machine and, after a little hopping around, submitted a claim to his insurance company. The company, suspecting negligence, sent out one of its men to have a look for himself. He tried the machine out and lost a finger. The chef's claim was approved. (Too bad they didn't send a lawyer!)

Mourners at the funeral of Anna Bochinsky in Moinesti, Rumania, were naturally somewhat taken aback when she abruptly leapt from her coffin as it was being carried to the grave. Before they could react to this unexpected outburst, the woman bounded into the nearest road, where she was run over and killed by a passing car. (At least the coffin didn't go to waste)

A man who shoveled snow for an hour to clear a space for his car during a blizzard in Chicago returned with his vehicle to find a woman had taken the space. Understandably, he shot her dead. (Chivalry is dead!)

After stopping for drinks at an illegal bar, a Zimbabwean bus driver found that the 20 mental patients he was supposed to be transporting from Harare to Bulawayo had escaped. Not wanting to admit his incompetence, the driver went to a nearby bus-stop and offered everyone in the queue a free ride. He then delivered the passengers to the mental hospital, telling the staff that the patients were very excitable and prone to bizarre fantasies. The deception wasn't discovered for 3 days. (And the escapees became politicians?)

In Minneapolis, USA, 28 year-old Derrick L. Richardson has been charged with third-degree murder of his much loved cousin, Ken E. Richardson. According to local police, Derrick had suggested to Ken that they play a game of Russian Roulette, but, having no revolver, instead put a semiautomatic pistol to his cousin's head. Apparently, he did not realize that one bullet always loads into the firing chamber of a semiautomatic. (Guns don't kill people, stupidity kills people!)

An American teenager was in the hospital recovering from serious head wounds received from an oncoming train. When asked about how he received the injuries, the lad told police that he was simply trying to see how close he could get his head to a moving train before he was hit. (DUH!)

ELECTRIC COOKTOP FIRES

> "... cooktops, from a fire standpoint, is such that misuse is much more likely that cause of a fire than is a malfunction."

BY MARK GOODSON, PE AND GLENN HARDIN, PE, DENTON, TEXAS—One of the cardinal rules about fire investigations is that an open mind must be kept. We must state, however, that we have a difficult time in being completely open when investigating fires believed to have been caused by electric cooktops. Our 'usual' pre- investigation advice to the client is to the effect that the unit was probably left unattended and thus caused the fire. We can also state that cooktops with conventional 'infinite' controls do not turn on by themselves. Outlined herein we show how cooktops work, as well as their modes of failure.

THEORY OF OPERATION

In analyzing a cooktop, one must first realize that this appliance is unlike most other cooking appliances. In a conventional oven, the temperature is set, a recipe followed, and baking takes place for a predetermined time. In this regard, an oven requires minimal attention from the user. A cooktop, however, often requires much supervision, in that the user is part of a 'control' and 'feedback' system. In its simplest form, cooking is merely a heat transfer issue—it is desirable to transfer sufficient heat flux Q to the mass of food such that the mass will rise in temperature to a desired point. The variables, however, include:

- Available heat from the burner
- Mass and shape of the vessel (pot or pan)
- Vessel material (copper, aluminum, steel, iron)
- Mass of food, as well as shape
- Heat capacity of food
- Amount of water present
- Cooktop burner surface material
- Rate of heat transfer from the burner.

When cooking, the user (chef) must consider all of these variables (with some dependent upon others), and adjust the burner heat output until the desired result is achieved. This is a very complex control system, with the user providing feedback. Taste, smell, and visual sensations received by the chef allow him/her to adjust the cooktop setting until the food is cooked properly—this is the feedback that is taking place. If the cooktop is unattended and the burner is on low, the food may never reach the right temperature—here, the feedback system can be considered 'open', but with 'gain' less than 1. The result is under cooked food. If the cooktop is unattended but the burner is too high, the food will burn—here, we have open loop (zero) feedback with gain greater than 1—such a system is 'unstable' (an engineering term) and results in disaster. For both the engineer and non-engineer, this long explanation is the reason that cooktop knobs (unlike an oven) do not have temperature settings present. Rather, the cooktop relies on feedback (user attention and control) in order to insure that the overall system works properly.

There are predominantly three types of electric cooktops in use—heater element, coiled heaters, and halogen lighting (we are ignoring the rare inductive type of cooktop). The heater element is simply a metal tubing (such as copper) that houses an insulator (typically Magnesium Oxide (MgO) and a resistance heating wire such as nichrome. General Electric invented this type of heating element, and it is often referred to as a 'Calrod;' we will refer to it as a 'sheathed heating element.' The pot or pan sits directly on these elements. These same types of sheathed heating elements are also used on electric water heaters, in dishwashers, and in hot tub heaters.

The next two types of cooktops often make use of a glass-ceramic (Ceran®) that is made by the Schott company. The glass-ceramic is very rugged, and is transparent to infrared energy. A coiled nichrome wire heater or a halogen lamp is placed beneath the glass-ceramic in each of the burner positions. When the element is powered, heat is transferred upwards to the pan, and heating takes place. The desirability of these Ceran® glass-ceramic types of cooktops comes from the flat surface they present—they are easier to clean.

Regardless of the type of heating element, however, all of them are typically controlled by what is known as an infinite control. The infinite control is a two pole thermostat, and is called 'infinite' because (in theory) there are an infinite number of settings between LOW and HIGH—it is strictly a matter of how finely one can adjust the control knob. Photo 1 shows a picture of the infinite control.

Photo 1—External view of infinite control.

The infinite control has two sets of contacts, one for each side of the 120/240 VAC system (we are assuming a 240 VAC cooktop). The infinite control has a detent system present, such that it must be pushed in order to rotate and turn ON. When turned on, one contact set is closed, applying one leg of 120 VAC to the heating element. The second set of contacts, however, are controlled by an internal bimetallic element, which causes the contact set to cycle off and on.

The ratio of ON time to (ON plus OFF time) is referred to as the 'duty cycle.' When multiplied by 100, we have the percentage duty cycle. In its lowest setting, the infinite control may have the burner on for 1 second, and off for 9. The percentage duty cycle is thus 10 percent. If the heating element is a 2200 watt element (as an example), the element is 'transformed' into a 220 watt element. At 100 percent duty cycle, the 2200 watt element will provide 2200 watts of power.

The on/off cycle is adjusted by changing the mechanical bias in the infinite control. The infinite control generates heat internally proportional to current flow. Photo 2 shows (by way of a thermogram) the internal heat generated by the infinite control. The heat is what causes the bimetallic element to cycle the control off and on. Photo 3 shows the two sets of contacts, with the 'fixed' contact being on the left hand side and the cycling contact being on the right hand side. With the control on fully HIGH, the cycling contact will not cycle but will be fully ON.

Photo 2—Thermogram of thermostat in the infinite control.

Photo 3—Internal view of infinite control showing contacts.

Wattages on the heating elements vary between about 1500 watts for small elements, and 2500 watts for large ones. Bosch has a cooktop that has five elements, as follows: 1200, 1500, 1700, 1900, and 2500.[1] The sum of all these wattages (8800 watts) would require about 37 amperes if each burner were fully ON.

Energy efficiency among various types of cooktops has been determined as follows:

Induction	90%
Halogen	58%
Electric	47%
Gas	49%[2]

The appliance industry has several standards that are useful. The reader is referred to the following:

UL 858—Household Electric Ranges
ASTM F1521—Standard Test Methods for Performance of Range Tops
BS EN 60335-1—Household and Similar Electrical Appliances—Safety.

There is also a 'black wall' test used in Europe, outlined in EN60335-2-6.[3] For this test, the wattage of a rear burner is increased by 24 percent over nominal by increasing the voltage to the element. Thereafter, the temperature is measured on a black wall located immediately behind the burner. Obviously, 'drop-in' type cooktops are of particular interest here, with the rear burners being key. Per this standard, a temperature rise of 150° K (270 R) is allowed on the black wall behind the cooktop.

Note that absent in our discussion of cooktops is the answer to the question, "How hot does it get?" While this seems to be a logical question, the answer is very dependent upon the 'loading' on the cooktop—what is present to take the heat from the burner. Because pots and pans are so varied, and likewise their contents, temperature measurements of an open burner are not very helpful.

EXAMINATION

We outline here failure modes and ways of diagnosing a cooktop fire.

1—PHANTOM OPERATION:

The 'usual' claim that we have heard is that the cooktop somehow turned itself ON. Mechanically, we have never seen this happen in analyzing about 80 electric cooktop fires or 'thermal events.' (A thermal event is what occurs when there is thermal damage and pyrolysis, but no true fire in the sense of flame being produced or self sustaining chemical reaction taking place) The controls on cooktops all have 'flats' on their shafts, such that it is easy to see if all the 4 controls 'line up' or if one (or several) are in the ON position. We make it a practice when examining a cooktop to first mark the shaft position of each control with a paint marker. If the control housings (thermoset plastic) are destroyed, it is still possible in many cases to find the flat and how it lines up. Another technique is to look at the contact faces—if the faces are well covered with soot, but have bare spots in the center, it appears as if the faces were touching and the controls ON.

We have on two occasions seen instances where unattended simmering was taking place, but a fire still resulted. In both of these cases, the 'cycling' contacted welded itself to its mate, resulting in a roughly 10 percent duty cycle jumping to 100 percent. These cases are easy to diagnose, but the manufacturer of the stove and/or control should be present when the control is disassembled. There is, of course, a human factors question present here—should the stove have been left unattended? The same question can be asked a different way: Is it reasonable for a person to put a large pot of stew on simmer for the day without having to constantly check on it to see if the control failed? Reasonable persons can disagree on these issues.

Occasionally, a cooktop is so badly damaged that the controls yield nothing meaningful when examined. At this point, it is necessary to examine the pairs of wires that run to each burner. The wires are covered with a high temperature fabric (glass) insulation. The insulation is very rugged, and not prone to failure in the same manner as common PVC is. If wiring on the load side of controls shows arcing, it is reasonable to assume that the wire was energized and thus the controls were ON. We have never seen this type of wiring fail from normal use and cause a fire by arcing. The reader will readily appreciate, however, that many cooktops are laden with grease in the control area, and thus such a fire is not out of the realm of possibilities.

In examining the phantom issue, the 'thermal event' is easy to analyze. For the thermal event, there is no self sustenance of an exothermic chemical reaction; rather, the heat continues to flow from the burner. Ergo, the destruction of combustibles will be seen to be a result of heat from the burner. A pot may melt, nearby control knobs may melt, or a cooking mitten may heat up and smolder; regardless, the damage will all point back to the burn as the heat source.

When a true fire takes place, analysis is much more difficult—did items (combustibles) degrade from heat from the fire or heat from the cooktop? In investigating the cooktop fire, one must identify the first combustible ignited. Identifying this first combustible may tell whether the problem is a result of human error (someone left a paper bag on the hot cooktop) or a control problem—the control stuck in the HIGH position and ignited a rear wall.

2—SHEATHED HEATING ELEMENT FAILURES:

In regards to sheathed heating element failures (Calrod type failures), we should note that we have never seen a sheathed heating element fail (melt) from a fire—this includes heating elements from cooktops, ovens, commercial coffee makers, and hot tubs. Conversely, every instance in which we have found a failed sheathed heating element we have found a fire or thermal event. (Note: we are specifically excluding here failures caused by corrosion, such as in a water heater) The MgO has a melting point of 4100° F, the NiCr has a melting point of 2552° F, and the copper sheath a melting point of 1980° F. These MPs are high enough that most fires will never cause the heating element any harm—after all, the heating elements were intended for high temperature generation. Photo 4 shows a portion of a failed sheathed type element—note the arcing that is present. When these elements fail, a fire is brought about by the spewing of molten products onto combustibles.

Photo 4—Failed sheath heating element.

3—HEAT TRANSFER FROM ADJACENT BURNERS:

The glass cooktops we have tested all show very localized heating. That is to say, a burner that is ON and serves the right rear burner position is not going to ignite a rag or cloth accidentally left on the right front burner. Photo 5 shows a thermogram of a cooktop with the left rear and right front burners on HIGH, and the other two burners OFF. It is obvious that there is little heat conduction to adjacent burner sights.

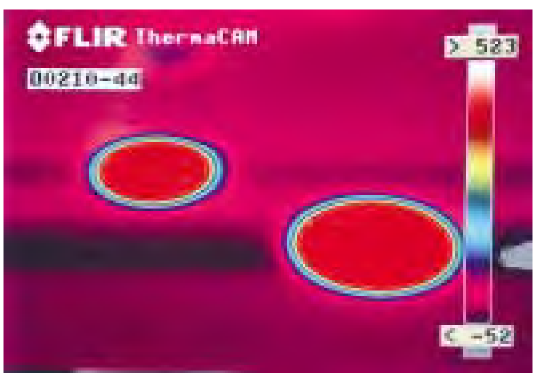

Photo 5—Thermogram of 2 burners on a glass cooktop, showing a lack of heat transfer to other burner locations.

4—FRACTURED GLASS:

The practical experience that we have had with Schott brand (Ceran®) glass-ceramic has been very positive. In cooktops we have used, we have never experienced a breakage problem. The glass is capable of effectively transmitting light, and must be impervious to fractures caused by differential expansion from spilling liquids. When a pot boils over, it is not acceptable for the glass cooktop to shatter. Similarly, it is rare that all 4 burners will be on and/or set at the same power setting, once again creating large heat differentials on the glass. Per the Schott website, thermal expansion of Ceran® type glass-ceramic (made by Schott) is almost zero. Likewise, the heat loss of Ceran® is also very low. All of these factors work together to establish that a fire caused by a shattering glass cooktop is a rare event. We have seen a 'thermal event' on only one occasion from Ceran® glass-ceramic. The cooktop was in use, and the glass shattered. The glass particles landed on an indoor/outdoor type of carpet, bringing about thermal degradation (melting and smoking) but no fire.

5—CONNECTIONS:

There should be no 'wire nutted' connections on a cooktop, other than at the incoming power connections. The presence of other connections possibly indicates repairs or modifications. Overheating connections are beyond the scope of this paper, but the experienced engineer should have little difficulty in diagnosing them.

SUMMATION

We have presented here the 'common' types of failures. Engineering examination of the controls will usually show that human error is involved with the fires or thermal events. The designs of these cooktops, from a fire standpoint, is such that misuse is much more likely that cause of a fire than is a malfunction. ●

REFERENCES

1.) Robert Bosch Appliances, NEM 930 36" 5 Burner, 2002. Brochure

2.) Cooktek, "What's Cooking," Spring 2002, Page 2

3.) EN60335-2-6, "Particular Requirements for Stationary Cooking Ranges,

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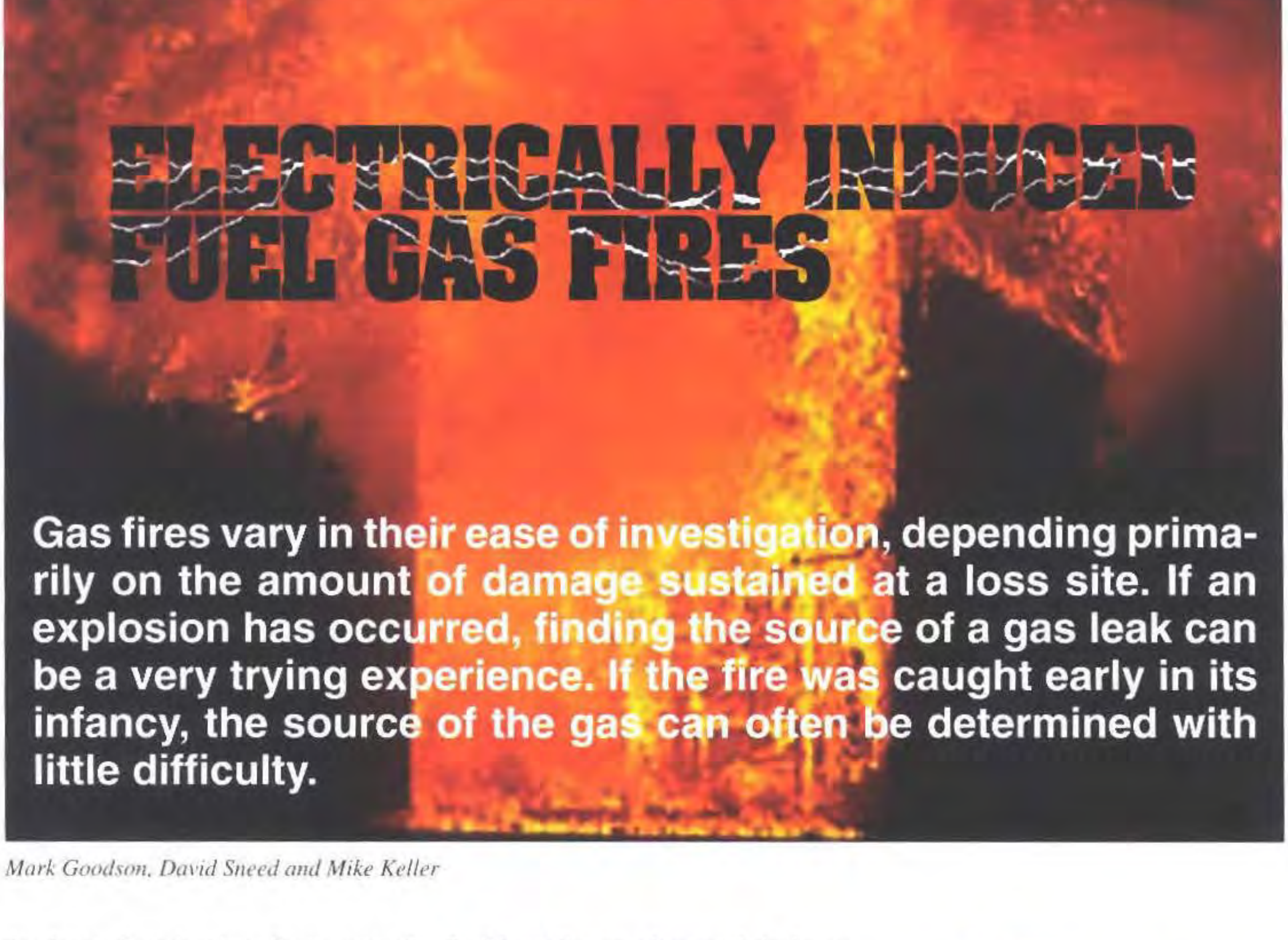

ELECTRICALLY INDUCED FUEL GAS FIRES

Gas fires vary in their ease of investigation, depending primarily on the amount of damage sustained at a loss site. If an explosion has occurred, finding the source of a gas leak can be a very trying experience. If the fire was caught early in its infancy, the source of the gas can often be determined with little difficulty.

Mark Goodson, David Sneed and Mike Keller

An electrically induced gas fire is a type of gas fire that occurs when electrical current passes through a gas appliance (natural or LP), with the current damaging the gas delivery system and brining about a fuel leak and resultant fire. This type of fire will always have associated with it some electrical fault that started the unfortunate sequence of events. The damages to gas pipes (and possibly gas appliances) associated with these types of fires are unique, and can be used as clues in investigating the fires. It should also be noted that the physical damages to appliances and piping can lead the investigator down the wrong road if the physical evidence is not understood. Described below are several fires that occurred when electrical activity brought about leaks in gas appliances and delivery systems.

Case 1.

This fire was diagnosed as a possible arson event by the original investigator . There were two separate points of origin, one being at the gas control valve on a water heater and the second being at the point where the flexible gas line mated to a steel nipple at a gas fired furnace. The investigator noted what appeared to be 'hacksaw' marks on the gas flex line to the furnace. Thus, the hacksaw marks and the multiple points of origin indicated a fire that was possibly brought on by criminal activity.

Photo 1. Microscopic view of what was originally believed to be a hacksaw mark.

A photomicrograph of the hacksaw mark is shown in Photo 1, while the flared end of the gas line to the water heater is shown in Photo 2. The hacksaw mark is actually a notch left in the flex line brought about when the line shorted against the metal case of the furnace. The flare fitting on the gas line has been almost completely disintegrated by electrical activity.

Photo 2. End of flexible gas line with most of the flare having melted due to electrical activity.

Investigation of the furnace shows it had a two conductor (i.e., ungrounded) male plug present for power; thus, the furnace used the gas piping system for its ground. Following the fire, the furnace was replaced because of the fire damage. Testing of the outside air conditioning condenser/compressor system showed that the compressor was faulted internally. In this fire, the sequence of events was as follows:

1. Failure of compressor, causing shorting of the windings to the frame of the compressor

2. The electrical current was carried via the copper refrigerant lines to the furnace

3. The current to the furnace traveled to the gas line on the furnace, creating a leak at the point where the gas line mates with a steel nipple

4. Some of the current now on the gas line system was also carried to the water heater, where the gas line at the water heater now failed and allowed gas to leak.

Case 2

This fire occurred in a heater closet in a residence. The fire was thought to have possible occurred because of some type tampering with the gas lines. The fire originated at a leak in the gas line at the point where the flexible gas line attached to the furnace. Photo 3 shows the end of the flared gas line, it shows almost complete erosion of the flare.

Photo 3. End of gas line with flare being destroyed by electrical activity

Examination of the outside air conditioning condenser unit shows that it was protected by two 30 ampere fuses, one of which was blown. This fuse was replaced during the investigation, and power was applied to the condenser. The new fuse blew immediately, with peak inrush current being measured at 380 amperes. Megger testing of the compressor showed a failure of the compressor inside, and one of the feed through for the windings on the hermetic compressor was found to be heavily damaged by excess electrical currents.

The sequence of events in this fire was virtually the same as in Case 1.

Case 3

This fire was once again a fire with two separate areas of origin. A utility crew had been trimming trees in a backyard, and limbs fell onto the triplex service drop feeding the house. The house was served with conventional 120/240 VAC. The service drop had pulled away from the meter base on the outside of the house because of the weight of the tree limbs. At the time the limbs fell, two separate fires broke out: one at the meter base, and one in the garage at the gas fueled water heater.

Examination of the meter base showed extensive melting of metal where one of the hot leads from the service drop had contacted it. This shorting and arcing was the cause of the fire at this location. The damage caused by the limbs had pulled the neutral off of the meter base, and the voltage now applied to the meter base by one of the hot leads energized the ground system in the residence. This ground system included the water heater and its gas lien. The flex gas line and its flared end are shown in Photo 3; as before, the electrical erosion of the flared end is extensive. Examination of the house showed that it did not have a cold water ground or ground rod; thus, the gas line served as the grounding system.

Photo 4. Side view of gal line in Photo 3, with the polymer coating still relatively intact because of protection provided by the brass nut.

Case 4

This fire occurred as an air conditioning repairman was working on an outdoor compressor unit. Power was applied to the compressor via a disconnect switch, and considerable popping was then heard in the attic. Shortly thereafter, a fire was observed in the attic, occurring at the gas fired furnace. Testing of the compressor after the fire showed that it had shorted out internally. Testing of the circuit breaker protecting the compressor showed that it had a faulty trip mechanism, and was very tardy in responding to an overload. Examination of the gas lines and regulator were carried out. The flared fitting on the gas line had sever arcing present. The gas control valve could not be examined, its die cast aluminum body having melted in the fire.

Discussion

These four fires demonstrate how electrical energy in a fault situation can travel along a gas line, creating a leak in the gas line and a resultant fire. The fires that occurred in these instances were all brought about because of electrical faults, and yet, none of these fires would normally be considered to be 'electrical' in nature. In the first fire, a cursory examination correctly showed multiple points of origin. With both the first and second fires, the damage to the furnaces/air handler units meant that the air conditioner compressors would not have been run until after the furnace damage was repaired; i.e., the actual faults in the compressors would not have been detected until after the investigation was complete and the structure repaired. This is of course a dangerous situation, because the occupants were not aware of the internal faulting at the compressor. Had the compressors not been examined after the fire, there is a real possibility that the fires would have once again occurred when the furnaces were replaced and power again applied.

The typical natural gas line is usually not thought of as a good ground. The metal components that make up a gas train are made from materials that are chosen for their ability to safely carry natural gas and the accompanying odorant. These metallic components are not known for their ability to carry electrical current. To further compound matters, it is not uncommon to find pipe joints treated with Teflon tape or plumber' putty; neither material is considered an electrical conductor.

The National Fuel Gas Code calls for the above ground gas piping system to be electrically continuous and also bonded to a grounding electrode (NFPA 54 3.14). The same section *prohibits* the use of the gas piping system as the grounding conductor or electrode. Section 5.6 of the same code requires the usual *NEC* adherence. The author's experiences indicate that the gas appliance that is not properly grounded is more susceptible to gas line arcing than is the properly grounded appliance. The exact amount of fault current, however, will depend upon the impedances of the several ground paths and the total fault current that is available. Air handlers for gas furnaces that are many years old seem to be the most prone. Typically, an inspection will show that the power for the blower motor on these older air handlers made use of a 2 conductor (i.e., non grounded) power cord.

A primary indicator that is found in these types of fires is the focal melting of the gas line at the connector. It is well known and appreciated that the flame that is fueled from a gas orifice does not normally make physical contact with the gas orifice; rather, there is some distance between the pressure, the size of the orifice, the available oxygen, and the mixing or turbulence. In short, the leaking gas is too rich to burn at the point of escape. In addition, gas that is under pressure will cause a very small amount of cooling to occur when the gas escapes from such a leak or orifice. Both of these factors indicate that a gas line would be least likely to melt at a connection if the melting were caused by the heat from the flame.

In the enclosed Photo 3, one can see that much of the polymer coating is still present on the gas line, and yet at the flare the brass has focal melting present. Testing of the polymer coating shows that it decomposes at temperatures of between 400 and 500 degrees F; brass requires temperatures of about 1700 degrees F before it will melt. Clearly, this type of damage cannot be from flame impingement. It is also noted that the brass flare is well protected from flame by the brass nut that definite lines of demarcation. In a distance of about 1/8", the heating of the arc will cause a transition to be made from melted brass to non-melted brass, and from no polymer coating (completely pyrolyzed) to an intact polymer coating. This rapid transition from extremely damaged (melted) brass to undamaged polymer is a very typical of an electric arc. Were the thermal damage caused by a flame, there would have been greater areas of heat stressing of the polymer coating.

In the cases described by the authors, the fire scene examination was usually straight forward and aided by the fact that fire destruction was not sever. Had the fire totally destroyed a building and its contents, the investigations would have been more difficult. Luckily, fires that destroy buildings usually leave externally pad-mounted air conditioning compressors intact. Checking of the windings for resistance and dielectric strength will help in diagnosing this type of fire. A blown fuse on a fused disconnect to a condensing unit is also an indicator of possible failure. Likewise, examination of the flared ends of the gas lines (inside the nuts) will also be helpful. The flared fitting should be relatively immune from actual melting from the fire unless the fire has reached temperatures in the 1700 degree F range. If the gas line is relatively unmelted, but the internal flare fitting is melted, one should suspect a fire brought on by arcing at the gas connection.

The authors have made no formal study of geographics regarding electrically induced gas fires, but common sense would indicate that this is more of regional phenomenon. One of the common causes of these types of fires is the electrical failure and breakdown of an air conditioning compressor. One would reasonably expect that such compressors would fail more often in hotter climates. Similarly, gas fueled fires will be more common in areas of the U.S. in which natural gas or LP gas are the prevalent sources of fuel for heating appliances.

Summation

The electrically induced gas fire is not particularly difficult to investigate *if* one appreciates the manner in which gas fittings are damaged by electrical current. These fires demonstrate the need for thorough examination of non-fire damaged equipment, such as air conditioning condenser units, after a fire. These types of fires can also mislead the investigator, given their possible multiple points of origin. Thorough electrical testing of the structure, documentation of the grounding system, and visual and microscopic examination of the gas fittings, can all be used in order to determine if this sequence of events is responsible for a fire's cause. ✧

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The advance of technology continues on, sometimes with unintended consequences. In the last several decades, we have seen a superior insulating material (asbestos) be banned because it was a carcinogen. Poly Chlorinated Biphenyls (PCBs) brought about excellent heat transfer characteristics to transformers, but now are an anathema. Aluminum wiring was thought to be a panacea, but we now know about the severity of aluminum oxide formation, cold flow (creep), and differences in thermal expansion coefficients. A gasoline additive known as MTBE was thought to improve the nation's air quality, but is now known to pollute the water supply. Ironically, each of these products was once revered because of their superior design qualities; now, each is better known for the manner in which they bring harm. It is with this backdrop that we examine the attributes of the electronic ballast, and why it is a product that fire investigators should pay attention to ...

Electronic Ballast Fires

Mark Goodson PE **Mark Hergenrether PE** **Aaron Stateson**

BACKGROUND

Fluorescent lamps are widely used in commercial and residential applications as a more efficient alternative to their incandescent counterparts. At the heart of a fluorescent fixture is the ballast. The ballast works to excite and regulate electrons from the gas inside the fluorescent lamp. The electrons form a plasma which releases photons that strike the phosphorescent coating on the inside of the lamp, thus producing visible light. Ballasts now come in two forms, "magnetic" which are formed much like a traditional copper/ferrous transformer, and "electronic" which are formed using solid state devices and fly-back circuitry.

For many decades, the magnetic ballast was the accepted way of energizing a fluorescent bulb. In a conventional fluorescent fixture (2X4' troffer), two magnetic ballasts allow the operation of four 40 watt (nominal) lamps. Figure 1 shows the schematic of a magnetic ballast wound for 2 lamp operation. This ballast is known as a Rapid Start ballast, and it is capable of firing the two lamps. Each lamp has two pins at each end, with an internal filament between the two pins often made of tungsten. These filaments are used to help start the lamp, and are rated at about 4 volts. Each filament consumes about 1.4 watts such that for a 4X4 (4 bulbs) troffer this is approximately 11 watts.

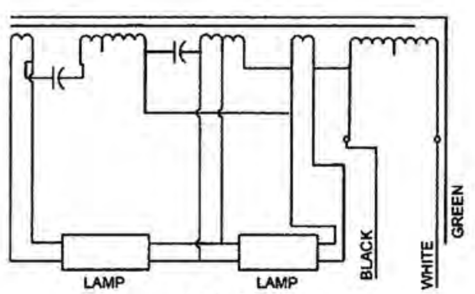


FIGURE 1

One design characteristic of a magnetic ballast is that it emits a humming sound as a result of line frequency (60 Hz). In a large office, where there can be many fixtures, this hum could be overwhelming. To reduce the hum level, the ballast is commonly potted with a mixture of sand and asphalt. This mass serves to dampen vibrations and quiet the ballast. As a downside, the asphalt can be ignited under the right conditions. To help prevent ballast fires, magnetic ballasts are thermally protected and are designated as Class P ballasts. Typically the thermal protectors are switches that open at ~ 105° C. The intent of the thermal protector is to prevent the ballast from reaching dangerous temperatures; however, the protection scheme does not always ensure the ballast can not start a fire. The ambitious reader will refer to a case styled *Truck v Magnetek* for a very good description of how a magnetic ballast is alleged to have started a fire.[1] This seminal case also addressed the issue of 'pyrophoric carbon', and was reported in a previous edition of *Fire and Arson Investigator*.[2]

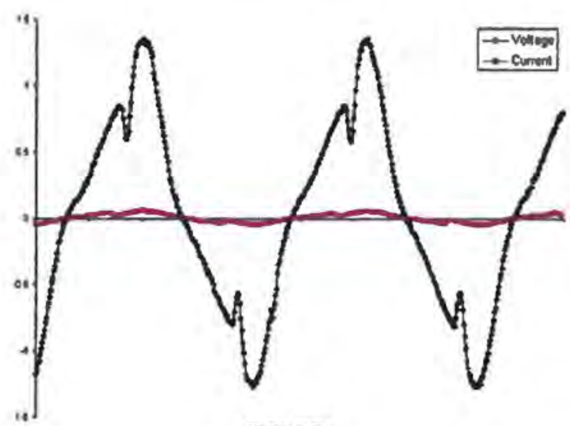


FIGURE 2

The introduction of the electronic ballast is an attempt to improve the overall efficacy of fluorescent lighting. In common parlance, efficacy is measured in Lumens per Watt where a lumen is light flux from the lamp and a watt is the power to the lamp. It is obvious that the electronic ballast is more efficient than is the magnetic ballast, because the former has no filaments that need to be powered. Internally, the electronic ballast converts single phase line voltage (120 or 277 VAC, 60 Hz) to a waveform that approaches 700 volts open circuit at a frequency between 25 and 40 KHz. Figure 2 shows an oscilloscope trace of the waveform to a type T8 lamp; the upper trace depicts voltage and the lower trace depicts current. Lamps driven by an electronic ballast do not require heated filaments in order to illuminate. The initial voltage is high enough to break down the gas and start and an arc inside the lamp. This mode of operation (without heater filaments) is known as 'instant start', as opposed to the aforementioned 'rapid start'.

In addition to a lighting system that does not need to make use of heating filaments, the electronic ballast uses a much higher frequency. This difference allows for a fixture to use much smaller electronic components (specifically the inductors) and one which does not require the fixture to be grounded for proper operation. (Note - per the NEC, the fixture is grounded for reasons of shock prevention. In comparison, the magnetic ballast also relies on the ground on the fixture to act as a capacitor plate to induce starting. The grounding is not necessary for starting of the bulbs driven by electronic ballasts.)

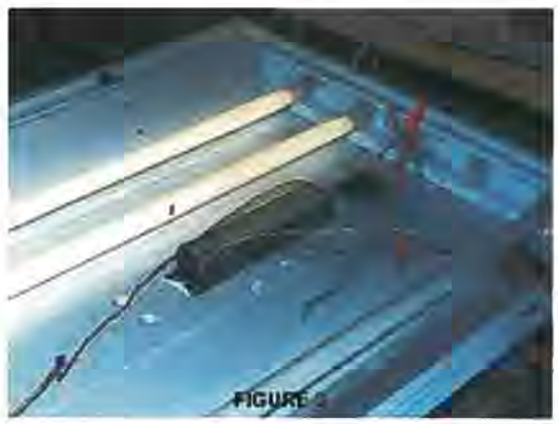
So far, the electronic ballast looks very promising in our analysis. It has greater efficiency, weighs less, and (due to a lack of heat production) should last longer than a conventional magnetic ballast. Furthermore, the electronic ballast requires much less potting compound (asphalt) and as such would appear to be much less of a fire risk.

THE HIDDEN DANGER:

The electronic ballast has one characteristic that we feel is important for the fire investigation community to be aware of. In our view, the ballast can bring on fires by means of poor electrical contact; this is of course no great revelation, in that electrical energy can often cause fires when there are voltage drops across poor contacts. What is different about the electronic ballast is that it can continue to illuminate the bulb properly while at the same time allowing a destructive arcing process to take place at the lampholder/pin interface. It is this ability to keep the bulb fully illuminated while a poor contact and arcing exists that is different from the conventional magnetic ballast. With a conventional magnetic ballast, should the pin(s) be misaligned, the bulb usually will not illuminate and often the second bulb will not illuminate, either. If the bulb is not illuminated, the user knows to climb a ladder and rotate the bulb such that good contact is established.

Unlike the rapid start feature of the magnetic ballast, the electronic ballast does not use the heater filaments. Instead it increases the start voltage to about 700 volts momentarily, so as to cause the bulb to start. Once the bulb has started, the ballast serves as a true 'ballast,' in that voltage drops and a relatively stable current level is maintained. Herein lies the first part of the hidden danger. When the ballast senses that the lamp has gone OFF such as if the bulb is misaligned, the ballast increases the voltage again in order to restart the lamp. Often this voltage is sufficient to allow arcing to occur between the lampholder's contacts and the lamp pin. If the voltage 'jumps' the gap, the bulb will illuminate.

A second factor in this scenario is related to the use of high frequency. For conventional AC line frequency (60 Hz), the arc extinguishes (quenches) 120 times per second, each time there is a zero crossing. As zero is crossed, the arc temporarily extinguishes and begins to cool. With the electronic ballast, however, the transition through zero is so quick (due to the high frequency) that the arc does not extinguish. In fact, the high frequency serves to stabilize the arc, allowing a continuous plasma. This characteristic of the electronic ballast helps sustain arcing between lamp pins and lampholder contacts. Figure 3 shows a 2 x 4 troffer, with the inner 2 bulbs illuminated.



LITERATURE SEARCH

A literature search was conducted, and the authors found a document authored by NEMA (National Electrical Manufacturer's Association) and published in 1998, entitled *Application Note: Wiring Equipment for T-8 lamps with Instant-Start Ballasts.*[3] The document recommended that BOTH pins be connected at each end of the lamp, even though both pins will be at the same potential. The document also proposed that as an alternative, a shunted lampholder be used. A shunted fluorescent lampholder has an internal connection that ensures that at each pin, the ballast fires both pins, rather than just one at each end. The document further recommends that contacts be repaired or replaced if pitting has occurred.

The electrical industry heeded the advice given in the above NEMA reference, and has produced bi-pin lampholders. As an example, Leviton literature lists a model 13653 for use with fluorescent lamps. However, if the lamp is to be driven by an electronic ballast, the correct part number is 23653, which states that it has internal shunt for connection to electronic ballasts.[4]

TESTING

In order to examine the potential for electronic ballast to start fires testing was performed. For the setup, the authors purchased 2 x 4' fluorescent troffers with universal electronic ballasts, capable of operating on both 120 and 277 VAC. The troffers were suspended, and the bulbs intentionally misaligned by slight manual rotation of the bulb. The arcing that occurred was immediately noticed. At times, the arcing would continue for several minutes, and at other times the arcing would cease until the bulb was again misaligned. The most fearful set of circumstances was brought on when the arcing had ceased for several hours, and then would begin again without manual intervention. Examination of the lampholders showed that they had been severely degraded by the arcing process. Figures 4 and 5 show the resultant lampholders.


FIGURE 4


FIGURE 5

"DAUBERT" CRITERION

Many of the readers of this article will certainly ask the question, 'Is this theory readily accepted, and has it been tested?' The answer to both questions is, 'Yes.' These questions (and their answers) help to meet the *Daubert* criterion, which includes several questions.[5] For our purposes, the following two *Daubert* points are referenced:

- Peer Review and Publication
- General Acceptance.

In a recent legal matter, subpoenas for the production of documents were served on two non-parties, Underwriter's Laboratories (UL) and NEMA. Both UL and NEMA begrudgingly produced responsive documents regarding electronic ballasts and fires. These entities also desired that the documents not be publicly distributed. However, their existence and content were aired in legal proceedings styled *Greenville ISD v Humphrey et al.*[6]

By way of background, there had been complaints made that caused UL to examine the issue of electronic ballasts *vis a vis* fire causation. NEMA, through its Lighting Section Task Force on Ballast / Luminaire Compatibility, contracted with UL to perform testing of ballasts and lampholders to determine if and what risk existed. In the past, UL had addressed similar issues in the development of UL 471, *Standard for Safety for Commercial Refrigerators and Freezers*. UL gave 3 options available to address the commercial refrigerator problem; as follows:

1. Use of a ballast with a circuit that shuts down should arcing occur, known as a type CC ballast
2. Provide independent support of the lamp so that it would not rely on the lampholder to secure it, or
3. Use lampholders that comply with IEC 60400.

Pursuant to the NEMA contract, UL performed a series of tests, and reported their findings to NEMA. The test methodologies were similar to those conducted by the authors in their own research. The background material and resultant testing are fully described in a report published by UL on August 25, 2005.

UL TESTING

Testimony in the *Greenville* case revealed that UL has extensively researched the problem at hand. The UL document produced to the jury describes the exact theoretical scenario as we have given: when a poor contact occurs, the voltage is increased to start the lamp, with resultant arcing between the lamp pin and the lampholder contacts.

UL tested 22 different types of lampholders, using 4 samples of each type, for a total of 88 different tests. The same ballast was used for each test. UL pre conditioned some of the lampholders for 168 hours at a temperature of 100° C, and the remainders were tested 'as received.'

UL personnel manually rotated the lamps while they were illuminated in order to induce arcing. The arcing was induced for ~ 5 minutes on each sample. Placed 12" below each lampholder was a bed of cotton.

Some of the more important results from the testing are as follows:

- Preconditioning had no discernible effect of production of fire
- Arcing caused charring, outgassing, and ignition of the lampholder
- Approximately 80% of samples had ignition within 2 minutes, some as early as 10 seconds
- Every sample had flaming ignition sufficient to ignite tissue paper placed above the lampholder.

The UL report states that their testing was severe, but displayed the arcing that may occur as a result of vibration, loose contacts, jarring, or corrosion.[7]

DISCUSSION

Although the testing we have carried out was some what rigid, the UL and NEMA documents, makes it clear that there is a issue with electronic ballasts and T8 lamps. The authors reiterate that a loose and overheating contact pair can often be considered a competent ignition source, depending on the resistance and the amount of current; however, there are salient differences between a 'normal' overheating contact and the lamp pin/lampholder interface associated with the electronic ballast. Described here are three characteristics of the electronic ballast circuitry which (as a group) bring about operating conditions that are much different than that of the magnetic ballast:

1. Voltage is ramped up in an Open Circuit (OC) condition enabling gaps created by loose connection to be jumped via arcing.
2. The high frequency (tens of KHz) helps to stabilize the arcing process
3. The lamp continues normal operation, unlike what would happen in a magnetic ballast

The latter of the aforementioned design characteristics also becomes a human factors issue. We are all familiar with poorly seated bulbs in troffers with magnetic ballasts. When a 'normal' bulb fails to ignite due to such a poor contact, we instinctively know of the problem and rectify it by rotating the lamp in order to restore the connection. With a lamp that stays illuminated it can be difficult to spot the signs of a poor connection.

FIGURE 6

A very pertinent question to all this examination relates to the first material ignited. The diffuser (lens cover) that is present on many lamp fixtures has no UL 94 rating. Testing of the diffuser shows that it both sustains combustion and drips molten (and flaming) plastic. Figure 6 shows combustion taking place on such an acrylic diffuser. Our own testing was done without a diffuser, and it achieved ignition of the lampholder on numerous occasions. We can easily envision a scenario where the ignition of the lampholder ignites the lens diffuser.

In our preparation of this article, we learned that there has been FAA Airworthiness Directives (AD) issued for essentially the same problem.[8] To wit, some Saab jets were using electronic ballasts to drive fluorescent lamps. The AD stated that cabins were receiving smoke and arcing was occurring between the lamp pins and lampholders. We think this scenario exemplifies the same problem that UL has been addressing, except with an airframe providing an environment that included vibration insult instead of a more conventional environment such as the air handler on an HVAC unit.

Based upon our own testing, the UL work, and the FAA's AD and underlying work, we feel that the lampholder/pin interface for fluorescent lighting systems with electronic ballasts can form a viable ignition source. Perhaps the more disturbing issue is that the lighting industry is well aware of the phenomenon, but has not seen fit to warn anyone that the danger exists.

INVESTIGATION

The investigator who is at a fire scene and who is suspect of this type of event should make every effort to find the lampholders and pins. If located, they should be carefully examined both visually and microscopically. Further examination via SEM (Scanning Electron Microscope) with EDX capabilities (Energy Dispersive X-ray) might be relevant to ensure the investigator that the phenomenon seen is truly some form of arcing, and not a result of binary eutectic melting (sometimes referred to as 'alloying').

Finding arced pins and contacts after a fire can be a challenging task, based on their size. Moreover, there has been very little written in the fire investigation community on this exact phenomenon. Two articles that come to mind include one published in *Fire Findings* and one that was authored by Dr. Zicherman.[9, 10]

DESIGN CHANGES

While the rigors of proper engineering design to prevent these fires are outside the scope of this paper, we will state that there are several avenues that need to be pursued. They include:

1. Using type CC ballast circuitry on all fixtures
2. Using lampholders fabricated from porcelain
3. Adding fire retardants to the lens diffuser
4. Using lampholders that use the pins for electrical contact only, while supporting the lamp tube independent of the electrical contacts.

SUMMATION

Indeed electronic fluorescent ballasts do have a hidden danger and we are of the opinion that this danger can lead to fire causation. Certainly, the seasoned investigator is aware of overheating contacts that can cause fires. Society's own practical experience has taught that if a fluorescent bulb is not lit, then try to re-seat it in its contacts. The operation of the electronic ballast is unusual in that it will continue to effectively illuminate a bulb while at the same time force arcing through poor contacts and cause overheating. As the progression of technology continues on, we cannot help but think back at the asbestos, PCB's, and MTBE's investigations of yesteryear and be reminded about what the philosopher Santayana once said: "He who ignores history is doomed to repeat it".[11] ●

References

1. *Truck Insurance Exchange v. MagneTek, Inc.* (No. 03-1026). U.S. Court of Appeals, Tenth Circuit, Appeal from the U.S. District Court for the District of Colorado, D.C. No. 00-RB-2218(CBS), Filed Feb. 25, 2004.
2. Babrauskas, V., *Truck Insurance v. MagneTek: Lessons to Be Learned Concerning Presentation of Scientific Information*, FIRE & ARSON INVESTIGATOR 55:2, 9-10 (Oct. 2004).
3. NEMA, *Application Note: Wiring Requirements for T-8 Lamps With Instant-Start Ballasts*, 1998.
4. Leviton Catalog Datasheets, *Fluorescent Lampholders, 2007.*
5. *Daubert v. Merrell Dow Pharmaceuticals*, 509 U.S. 579 (1993).
6. *Greenville ISD v Humphrey & Associates*, Inc,, Harrison. Walker and Harper, LP and Genlyte Thomas Group LLC, Cause # 68,461 in the 196th Judicial District. Hunt County, Texas.
7. UL, *Report on Research on Arcing in Fluorescent Lampholders Supplied by Electronic Instant Start Ballasts*, August 25, 2005.
8. FAA, AD 97-13-06 *Airworthiness Directive Saab Model 340B and Saab 2000 Series Airplanes.*
9. FIRE FINDINGS article
10. Zicherman, Joseph, *Fire Performance of Electrical Materials Used in Fluorescent Lighting Fixtures*, 2003, JOURNAL OF THE INTERNATIONAL ASSOCIATION OF ARSON INVESTIGATORS, Vol. 53 No 3.
11. Santayana, George, *Reason in Common Sense*, 1905.

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GFIs and Fire Investigation

Mark E. Goodson, P.E.

Ground Fault Interrupters (GFIs) have become common place over the last 20 years. The use of GFIs is now mandated in many parts of a residence, to include garages, bathrooms, kitchens, hot tubs, outside outlets, and swimming pools. The purpose of the GFI is to prevent deaths caused by exposure to electrical current.

The GFI is a relatively simple device. The amount of electrical current that flows through an energized conductor (phase or hot wire) is magnetically sensed within the GFI, as is the amount of current returning through the corresponding neutral wire. If the two currents are equal, the magnetic fields cancel each other out and the GFI allows power delivery. If the hot and neutral current differ by more than 6 mA, the GFI senses this imbalance and power is removed; i.e. the GFI trips. The assumption made is that a portion of the electrical current has been diverted to ground, as would be the case when someone was electrically shocked. The GFI will respond in a time period specified in the requirements of UL 943, *Standards for Ground Fault Circuit Interrupters*.

The formula specified by UL is

$$\text{Time} = (20/\text{Current})^{1.43},$$

where

Time is in Seconds, and
Current is the fault current in milliamperes.

This equation is suitable for the range of 6 mA to 264 mA. The latter figure, 264 mA, is the current assumed when a 500-ohm fault is placed across a nominal 120 volt line that has a 10% overvoltage condition present. The 500 ohm figure is presumed to be the lowest resistance that a human body would reasonably have when being exposed to a 120 VAC shock. Using the above equation, a GFI must respond according to the following table:

Fault current, mA	Maximum Trip Time, seconds
6	5.6
50	.27
100	.10
250	.027

It should be noted that even though the trip times are allowed to be up to several seconds (per the UL spec), in actuality most GFIs will typically trip much faster than the UL requirements. Trip times of 20 to 50 mS are very typical for even low level faults.

A second function of GFIs, which is not as well known, is to prevent 'double grounds' from occurring. In the United States, it is common for the neutral and ground connections to be bonded together at the circuit breaker panel, and at no other place downstream. Thus, the single grounding point at the main breaker panel insures that the grounding conductors throughout a building do not normally carry current; this assumption fails if there is a neutral to ground fault. To detect neutral to ground faults, some GFIs are designed to inject a small signal on the neutral wire and then to look for such a fault. While this type of fault (neutral to ground shorting) would usually not cause a fire, its existence can indicate that a cable has been physically damaged. By causing the GFI to trip, power has been removed from what is possibly a damaged cable.

While GFIs have their place in the prevention of electrical shock injuries, their presence must also be considered when investigating a fire. GFIs have the ability to both prevent fires and also to make some fire investigations more difficult. Described here are both theoretical predictions and actual lab results of the effects of GFIs on fire prevention and fire investigation.

FIRE PREVENTION

GFIs were not designed to prevent fires; rather, they were intended to prevent persons from being injured by electrical shock. Their ability to prevent fires is brought about because they can sense a low current grounding type of fault and thereafter remove power. Consider a standard piece of NM cable, which in a residence is often 14/2 or 12/2 AWG copper with a ground. The design of this cable is such that the ground conductor is placed between the hot and the neutral conductor. If the cable is damaged by rodents, mechanical abrasion, or poor installation, it is entirely possible that we can have two parallel conductors (hot and ground) that lie adjacent to one another that now are insulated by only an air gap. While it is certainly unsafe to have bare wires separated by a small distance and no insulation, there will normally be no arcing unless the wires physically touch one another (a line voltage of 120 VAC is assumed). If a semiconductive substance were to find its way to the adjacent damaged and bare conductors, this substance could bridge the gap between the hot and the ground wires, and electrical current would flow. This scenario could lead to a fire over time. If, however, a GFI is present, the GFI will remove current once the 6 mA threshold is exceeded. It is this ability to remove power at low fault currents that make the GFI useful. The 6 mA fault level is certainly much less than the current necessary to trip a standard Molded Case Circuit Breaker, MCCB. An MCCB would require 40 amperes of current (assuming a 20 amp breaker) to trip in 2 minutes or less, with 2 minutes being the maximum trip time allowed by UL / NEMA. The difference in wattage is .72 watts for the GFI versus 4800 watts for the MCCB. If we consider energy in Joules, and assume a 50 mS trip time for the GFI, and a 1 minute trip time for the MCCB, the energy allowed before removal of current is .036 joules (GFI) and 288,000 joules (MCCB). Clearly, the GFI can work to prevent a fire better than an MCCB *in some instances.* It is for this reason that some heat tape manufacturers recommend that their products be powered from GFI protected circuits.

The instances in which a GFI will not work to prevent a fire are those instances in which there is no ground fault. If we consider a typical 16 AWG stranded lamp cord with two separate conductors, hot and neutral, often there will not be a ground fault if the cable is damaged. If the cord is damaged such that the hot and neutral short one to another, arcing can result, with the amount of current leaving the hot wire the same as will return through the neutral wire. In this case, there is no current imbalance and the GFI will not respond. An exception to this would be if there were a grounded metal surface, and some of the current from the hot wire leaked to the ground path. If water were to leak between the exposed hot wire and the grounded surface, the GFI would trip. With some of the electrical current traveling through this grounded piece of metal, we would once again have a ground fault that the GFI can respond to.

The investigator should also note that some types of NM cable are round, rather than flat, and this has an effect on whether a GFI will or will not respond. With a flat cable, the ground wire is centered between the neutral and hot. Damage that occurs to the hot lead may also cause damage to the ground, thus eventually creating a ground fault and tripping the GFI. With round cable, the hot conductor is adjacent to both the hot and the neutral conductors. Damage that occurs to a hot wire may also damage a neutral *or* a ground wire (or both). The hot-neutral fault, as already explained, will not work to trip a GFI, because there is no current imbalance.

There are instances in which the rapid tripping of a GFI will not prevent an electrical fire, even though the GFI has detected and reacted to a ground fault. If two wires, hot and ground, touch such that arcing occurs, a readily flammable or explosive atmosphere can still be ignited by the arcing. The GFI will trip, and the MCCB may trip, depending upon the nature of the fault. Nevertheless, with the right atmosphere, the arcing can cause ignition even though the GFI will respond.

FIRE INVESTIGATION

When GFIs are present at a building and a fire occurs, their presence can impede a good understanding of the fire and its progression. One well-appreciated way of understanding fire spread is to examine the electrical arc damage to wiring in a building. As an example, consider a fire that occurs in a large house and which in fact reduces the house to several feet of debris with no walls standing. Examination of the electrical system remains shows every room to be serviced with 12 and 14 AWG type NM, which is now all bare secondary to the fire. Inspection of the many wire remains shows that there is arcing in a bedroom, and that the arcing is not present anywhere else in the electrical system. In an interview with the neighbor who first spotted the fire, it is learned that this neighbor saw smoke and then immediately turned off power to the house at the disconnect. This removal of power explains why there are numerous bare wires but very limited arcing. The location of the arcing gives us a very good idea of what part of a structure the fire started in. The arcing does not indicate that this electrical fault was the *cause* of the fire (it might be), but it does indicate that the fire first damaged the electrical system at this point, relative to the rest of the building. By studying electrical damage and breaker trip positions, one can often better appreciate the way in which a fire traveled in a building.

As an example of how GFI-protected wiring can affect a fire investigation, let us assume a fire that can be isolated to having started in a bathroom or an adjacent bedroom. It is our intent to use any evidence of electrical arcing to help determine the room where the fire started. Our scene work shows that the bedroom has two separate runs of type NM wiring present, each with arcing. Examination of the breaker panel shows that the both of the breakers serving the bedroom are tripped. In the bathroom, the wiring is examined and in no case is arcing found, even though the wiring is often bare secondary to the fire. The breaker is in the ON position. *Clearly the fire started in the bedroom, one concludes, based on the arc damage there and the lack of arcing on the bathroom wiring.* In fact, this assumption could be wrong.

When a fire is in progress, the heat will break down the insulation on wires. This pyrolysis will create carbon products, which serve as sources of leakage. In a fire, enough leakage will occur as the insulation breaks down so as to cause a GFI to trip. Modern day bathrooms are wired such that the wiring is protected by GFIs. In the above example, a possible reason that the wiring is bare in the bathroom (without arcing) and yet the breaker is not tripped is the presence of a GFI. The fire may have well started in the bathroom, penetrated the NM cable, and enough leakage current flowed to trip the GFI. The GFI thus tripped before arcing could occur in a manner such as to cause the circuit breaker to trip. The fire continued to spread, damaging the adjacent bedroom and creating the arcing observed there. If one neglects the action of the GFI, the wrong conclusion could be arrived at.

LAB TESTING

In order to experimentally show what effect a GFI will have on current flow between insulated conductors when their insulation breaks down as a result of an external flame, a series of tests was run. The tests all involved flat NM cable (copper), 12 / 2 AWG w/ ground. The cables were powered via 120 VAC, and then fed through a 20 ampere circuit breaker followed by a GFI receptacle. No load was supplied from the NM after it left the GFI. The tests made use of a propane torch for a heat source, with the heat applied to a section of the cable portion that was downstream from the GFI. Thus, the circuit breaker and / or the GFI would only respond when the fault current was occurring because of thermal damage to the cable (ie, hot to ground faulting). Current through the hot lead was monitored via a digital oscilloscope and a hall-effect type current probe placed on the hot lead.

In 15 separate tests, using flat NM cable, the GFI responded and tripped before physical contact and subsequent arcing between the hot and ground could occur. Thus, in every case, the GFI's action would have prevented arc damage from occurring to what was otherwise a normally energized wire. Radiographs (x-rays) were taken of each wire specimen after it had been tested, and distances between adjacent conductors were never closer than approximately 20 mils (.5 mm). This distance offers one explanation as to why there was no arcing; the wires never touched. In addition, before high current leakage paths and resultant arcing through the char could develop in the somewhat-pyrolyzed insulation, the power was removed by the GFI. Typical test results, as determined by the oscilloscope, showed that a propane fueled flame would cause a leakage current of 10 mA to flow at about 20 seconds after initial flame impingement, tripping the GFI.

DISCUSSION OF TEST RESULTS

The lab tests, as definitive as they were, must not be interpreted in a vacuum. In real life, wires are not damaged just by direct flame impingement. Wiring will be subjected to abrasion, heating (without flame impingement), and other forms of mechanical and possibly electrical stress. There will possibly be some fires in which GFI protected circuits are victims of a fire and in which arcing can and does occur. Factors other than mechanical ones that would have a bearing on hot to ground arcing on a GFI protected circuit include timing (at what point in the sine wave the fault occurs), the trip characteristics of the circuit breaker or fuse, and the type of insulation present on the wiring. Should a question arise as to how a GFI operated in a given fire, the investigator is advised to try and duplicate the electrical system, and to perform tests to determine how the GFI responds under fire and flame conditions.

SUMMATION

GFIs have benefits that go beyond prevention of electrical shocks - namely, they will prevent some fires. In particular, they can prevent some fires which are brought on by physical damage to energized cables. The geometry of the cable, the manner in which the cable is damaged, and the atmosphere in which a fault is located will all have bearings on whether or not a GFI will prevent a fire in a particular circumstance. GFIs also have some relevance to the way in which electrical fires are investigated. The investigator must always understand how a GFI works and its implications on a fire scene before determining what role, if any, that electrical wiring had or did not have in causing a fire.✧

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We're looking forward to hearing from you!

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GFIs and Fire Investigation

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HIDDEN DANGERS OF HALOGEN LIGHT FIXTURES

Co-authored by—Mark E. Goodson, PE; Kelly Colwell; Tony Perryman, EIT; Dave Sneed, CFI

The dangers or perils of halogen type light fixtures (to include torchiere type fixtures) have been well documented in the fire literature.[1,2] We present a "not so obvious" fire cause that can be associated with these fixtures. Testing of the halogen bulbs by both the writers and others has shown bulb temperatures between 1100 and 1200° F. The bulb temperature alone on conventional halogen bulbs is capable of causing the ignition of some combustible atmospheres, given the proper stoichiometry.

Testing of light fixtures used on construction sites (work lights) and for permanent mounting was carried out to document both temperature and any infiltration of substances. In addition, the contact surfaces of several fixtures were examined, showing the arcing that can develop at the electrical contacts, also serving as an ignition source. We outline here our findings.

BACKGROUND

Halogen light fixtures have become popular in the past 15 years as a means for producing bright light. The halogen atmosphere has the effect of insuring a longer filament light life. Prior to our work, there have been numerous papers written on the dangers of these fixtures. Manufacturers of these fixtures must now include metal screens as part of torchiere lamps so as to reduce combustion hazards from direct contact with flammable materials. In addition, a curved shield is now placed over the bulbs on the torchiere fixtures, to help reduce the hazards of a shattering bulb. On permanently mounted fixtures and on work lights, a glass shield has always been standard so as to provide protection against the hazard of a fragmenting bulb.

Our investigation was brought on after a painter was injured from an explosion and flash fire. The painter was using "volatiles" (lacquer and thinner), and had made use of a 500 watt halogen lamp fixture. The glass shield on the light fixture had been subject to over-spray to the point that it was no longer usable. Thus, the painter had removed the glass shield.

TESTING

Several new fixtures were purchased, in both a work light configuration and fixtures meant for permanent mounting. *(Photo 1)* We noted that the two "permanent" fixtures (rated at 150 and 500 watts) were not intrinsically tight or intrinsically rated. They are listed for use in wet locations, however. On the work light (rated 500 watts), there was a gasket around the glass shield and also around the switch compartment giving some appearance of being intrinsically safe. A pilot hole was drilled in the body, and air pressure applied. We noted that despite the gaskets, the work light is not airtight—air leaked out at the gaskets and at the switch cavity. Thus, none of the fixtures we examined were airtight, and all would be conducive to igniting atmospheres that are within limits of explosivity and which have auto ignition temperatures of approximately 1200° F. or less.

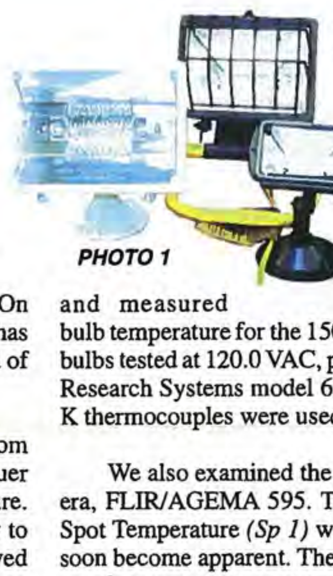

PHOTO 1

We measured the temperature of both of the 500 watt bulbs on the surface, and measured approximately 1266 and 1200° F. The bulb temperature for the 150 watt bulb was approximately 1200° F. (all bulbs tested at 120.0 VAC, provided by a HP 6813A source). A Stanford Research Systems model 630 thermocouple monitor and 30 awg type K thermocouples were used to measure the temperatures.

We also examined the 500 watt work light with an infrared camera, FLIR/AGEMA 595. The thermogram is shown as photo 2. The Spot Temperature *(Sp 1)* was measured at 318° F; its importance will soon become apparent. The second thermogram *(Photo 3)* shows bulb envelope temperature at two different points *(Sp 1 and Sp 2)*. The temperatures are 1239 and 1255° F, respectively. These temperatures are approximate measurements.

ANALYSIS

The first and most obvious conclusion is that halogen lamp fixtures can serve as competent ignition sources, given the right atmosphere. This statement is not said in a condemning fashion, but rather as a fact—the bulbs are inherently hot. While one does not ordinarily think of the bulb as causing ignition, the bulb is not much different than the "glow bar" that is now commonly used to ignite gas ovens. With the correct atmosphere, there can be a fire or explosion. Perhaps

(PHOTO 2)—Thermogram of a 500 watt work light. The Spot Temperature (Sp 1) was measured at 318° F.

(PHOTO 3)—Shows bulb envelope temperature at two different points, Sp 1—1239° F and Sp 2—1255° F.

an underlying issue is the "human factors" associated with these types of bulbs. Many people have routinely worked on cars or painted while using conventional (incandescent and fluorescent) fixtures and no hazard was noted. Given this background, the user may be very surprised to learn that the halogen fixture is capable of causing ignition of certain atmospheres. Our evaluation of numerous halogen fixtures shows that none of them are intrinsically safe.

An additional hazard, which is even more obscure, is that of arcing contacts. It is difficult to design an inexpensive, mass production light fixture where the electrical contact temperature for the bulbs will run several hundred degrees. In the thermogram, we noted a contact temperature of 318° F; which was also verified with a 30 AWG type K thermocouple. The gradient from bulb temperature (nominal 1255° F, to contact temperature 1255° F, is 932° F. This gradient is achieved in less than 1 inch. The high working temperature for the electrical contact, the gradient, and the high excursion temperature for the bulb envelope led us to suspect that the electrical contacts may be prone to arcing.

Photo 4 shows the copper splatter associated with a 300 watt fixture; the contact at the right end of the fixture was beginning to arc, spewing off molten copper. Photo 5 is a microscopic view of the end of a contact of a 500 watt fixture. As is obvious from these photos, the contacts can and do arc. While the arc by-products (splattering copper) will be contained by the glass shield, the arc is once again capable of igniting volatile atmospheres.

The readers have no doubt examined natural or propane gas explosions in residences, and the question is always asked—what could have ignited the mixture? The main issue is, of course, what leaked the gas? Ignition could have been brought on by a light switch, a pilot light, a relay on a TV, or the contacts of a thermostat or start relay on a refrigerator. Usually, we never know exactly what caused ignition, and in many cases, it does not matter. In one instance where we did come to the correct conclusion regarding ignition, a man smelled gas in his house and turned on the window AC unit to ventilate the house—he did not survive the resultant blast.

Given the measurements and documentation done as part of this study, a halogen light fixture has the propensity to ignite volatile atmospheres by way of actual heat or by arcing. Hence, these types of lights should never be used without the glass shield and they should not be used in volatile environments.

Given that these fixtures are not intrinsically safe, further research is necessary to determine if vapor infiltration could have occurred, so as to allow ignition. The best way to determine this is empirically. Every light fixture will have its own characteristics regarding "air changes" in and around the bulb. The gasket will be different among fixtures, as will be air currents in a room. Bulb temperature will even vary slightly with line voltage. Thus, having a lit bulb in an ignitable atmosphere may or may not cause ignition, depending on the characteristics of the fixture—testing must be carried out to prove or disprove the theory.

(PHOTO 4)—Shows a contact at the right end of a 300 watt fixture beginning to arc, spewing off molten copper.

(PHOTO 5)—Microscopic view of the end of a contact of a 500 watt fixture showing arc by-products.

SUMMATION

We have shown two modes whereby a normally operating halogen light can cause ignition of ignitable atmospheres. However, in these cases, there is no "catastrophic failure;" rather, the bulb and fixture are operating as intended. The halogen fixture in these cases is not operating defectively, but rather is just bringing about ignition to an atmosphere, through normal usage, that is prone to ignite. ●

References

1.) Lowe, Robert and Lowe, James, "Halogen Lamps II," Fire and Arson Investigator, April 2001.

2.) "Tips to Promote Halogen Light Safety," Canadian Association of Fire Investigators, March 1998.

LIGHTNING INDUCED CSST FIRES

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ABSTRACT

Corrugated Stainless Steel Tubing (CSST) represents a relatively new technology for delivering fuel gas within a residential or commercial structure. The main benefit of CSST is brought about by a savings in installation time, relative to black pipe. However, the flexible thin walls of CSST also present a problem in terms of the propensity of CSST to fail when exposed to electrical insult, particularly lightning. We outline here the some of the theoretical basis for CSST failures caused by lightning, as well as investigative techniques to be used when examining a fire scene.

INTRODUCTION TO CSST

Corrugated Stainless Steel Tubing (CSST) is a relatively new building product, and is used to plumb structures for fuel gas in lieu of conventional black pipe. The advantages that are offered include a lack of connections and a lack of threading - in essence, it is a material that results in substantial labor savings (relative to black pipe). CSST is recognized by ANSI / IAS LC-1 -1997[1]. CSST consists of stainless steel corrugated tubing that is sheathed by a polymer conformal coating. Each manufacturer seems to have a proprietary system for achieving couplings / connections, but in general, the CSST (in that it conforms to ANSI LC-1) can be thought of as a commodity.

The authors have investigated several fires wherein CSST has failed when damaged by lightning. We outline here the theoretical issues regarding CSST, as well as results of fires we have investigated.

CSST DEVELOPMENT

The introduction of CSST into the United States was brought about by a firm called Foster-Miller. This engineering firm developed CSST as an alternate to black pipe. Our own reading of various pieces of literature shows that the driving issue is one of economy[2]. However, we caution the reader to review the literature and draw his / her own conclusions. CSST is made by 6 manufacturers, and each manufacturer requires a potential installer to take a several hour installation course. The installation courses are required as part of ANSI LC-1, and are an attempt to insure only qualified installers make use of CSST[3]. This arrangement will likewise prevent CSST from being available at home improvement stores.

CSST was first recognized by the NFPA in the *Fuel Gas Code* (NFPA 54) in 1988[4]. The IAPMO finally approved CSST in 2003[5]. It is interesting to note that in 2000, the IAPMO rejected CSST for reasons of safety[6]. The Foster-Miller documentation submitted in 2000 to the IAPMO states that there had been 50 million feet of CSST installed without one reported failure[7]. Now that there have been numerous reported failures, IAPMO action on CSST will be of interest.

In analyzing CSST, it is important to note that we can find no evidence of testing for lightning resistance during product development. The NFPA has stated that when CSST was first considered in 1988, lightning was given no consideration[8].

CSST UTILIZATION

CSST is different from black pipe, in a number of ways. On a CSST system, gas enters a house at about 2 psi, and is dropped to ~ 7" WC by a regulator in the attic (we are assuming a natural gas system). The gas then enters a manifold and is distributed via 'home runs' to each separate appliance. Unlike black pipe, a CSST system requires one separate run for each appliance. (See Figure 1 for a typical manifold) As an example, a large furnace and 2 water heaters in a utility closet will require 3 separate CSST runs; with black pipe, the plumber may have just used 1 run of 1" pipe and then teed off in the utility room. The reality of this design is that now there is a tubing system carrying 2 psi of NG in part of the residence; in addition, the requirement of one home run per appliance increases dramatically the number of feet of piping in a building.

Figure 1: Manifold and regulator leads of CSST setup

CSST is sold in spools of hundreds of feet, and is cut to length in the field for each run. In this regard, CSST has no splices / joints behind walls that might fail. CSST can be identified by its bright yellow jacket. Test pressures are higher for CSST than black pipe, and the industry touts this as a selling point; we find this somewhat of a 'red herring'. We know of no need to increase the Factor of Safety (FS) for black pipe – pipe tested at 20 psi and carrying 7" WC has provided satisfactory services for years. CSST does offer an advantage over black pipe in terms of structural shifts; with black pipe systems, the accommodations for vibrations and / or structural shifts are handled by appliance connectors.

THEORETICAL CALCULATIONS

CSST is extremely thin, with walls typically less than 10 mils in thickness. This lack of mass, necessitated by the desire for easy routing of the tubing, has resulted in a material that is easily punched through by electricity. Once the tubing has been perforated, it is possible for the escaping gas to be ignited by the metallic by-products of the arcing process, by auto-ignition, or by adjacent open flames.

The theoretical energy level required to melt a specimen can be compared by using both heat capacity and melting temperature. The heat capacity is the amount of heat needed to raise the temperature of either sample one degree Celsius. Changing the temperature from an initial temperature to the melting temperature requires the heat capacity to equal:

$$q = C \cdot m \cdot \Delta T_m + m \cdot H_f \qquad [1]$$

where C is the specific heat, H_f is the heat of fusion, m is the mass of the specimen, and ΔT_m is the change in temperature from the initial temperature to the melting temperature.

Our own field data indicates that lightning damage to black pipe is sometimes so small that it is often only visible with microscopic analysis and limited to a small pit that does not leak; lightning strikes involving CSST create leaks that vary from pinhead size to almost ¼" 'orifices.' For comparison sake we show the heat capacity for equivalent sized holes in specimens of black iron, CSST, aluminum, and copper tubing. Table 1 lists the relevant properties for all four samples.

TABLE 1

Material	C (BTU/lb F)	T_m (^oF)	H_f BTU/lb	Density (lb/in^3)	Wall thickness (in)
CSST (304) ½" OD	0.119	2589	128.7	0.285	0.008
Black Iron Pipe ½" OD	0.116	2575	122.7	0.284	0.12
Aluminum Tubing ½" OD	0.21	1166	167.3	0.098	0.035
Copper Tubing ½" OD	0.092	1981	88.05	0.323	0.04

For an equivalent 100 mil diameter hole, we can derive theoretical values for heat capacity based on the aforementioned equation.

Figure 2 is a plot of the respective values for each material. It is clear from

Figure 2 that the amount of energy to create a 100 mil diameter hole is much larger for black iron pipe then for any of the other three specimens. Thus we can now see why the thickness of the pipe plays such a critical role. In fact for this particular case, the amount of energy for a conventional ½" black pipe will require ~15 times the energy that would be required to similarly melt CSST, ~10 times the energy for aluminum, and ~5 times the energy for copper.

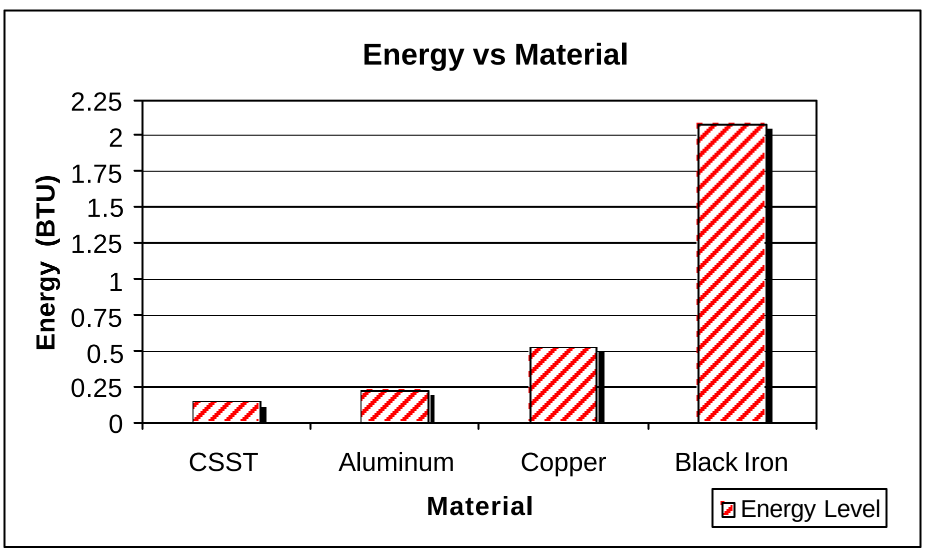

Figure 2: Comparison of heat capacity for 100 mil diameter hole in CSST, Aluminum Copper & Black Iron

LIGHTNING CHARACTERISTICS

How 'strong' is lightning? The data from Uman indicates that lightning strikes vary in current (amperes) from 10,000 to 20,000 peak (typical) to 200,000 amperes peak (maximum)[9]. Uman also lists the 'bottom' end of lightning strokes as having peak currents of 1,000 to 5,000 amperes[10]. Mechanical damage caused by heating is a function of current squared multiplied by time. Thus, the current is the dominant factor in creating the melting of the gas tubing.

FIRE INVESTIGATION

As of October 2004, we have encountered 4 fires in which we believe that lightning damaged CSST. We describe two of these fires here.

Fire 1

The fire occurred in the wood framed chimney space that had a metal chimney insert. CSST ran through the chimney space to feed the gas igniter. Four perforations were found in the CSST, ranging in size from a pinhole to a hole about 125 mils along its major axis. A STRIKE FAX lightning report showed that 4 hits within 0.1 mile of the house were recorded[11]. Figure 3 shows 2 adjacent holes that were created in the CSST.

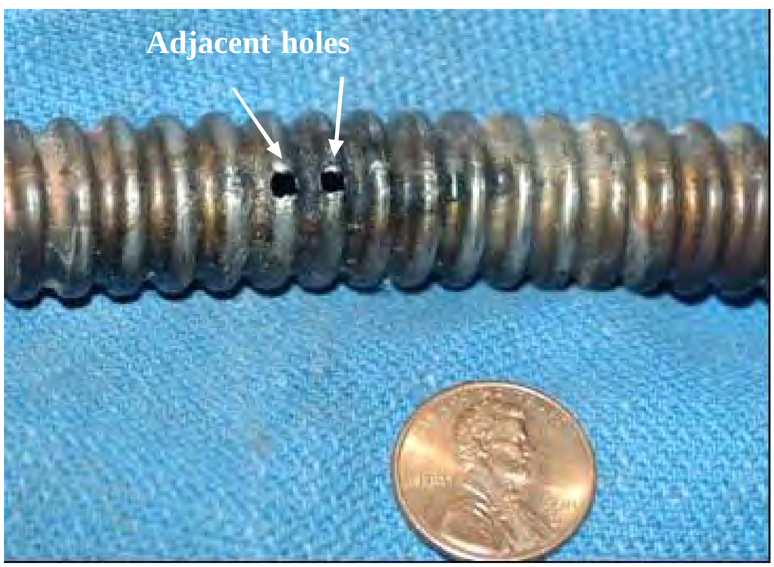

Figure 3: Adjacent perforated holes in CSST from Fire 1

Fire 2

The fire occurred in an expensive house (construction not finished) with a value in excess of 6 figures. The house was a 2 story house, and plumbed with approximately 95% black pipe. Two runs of CSST, each serving a fireplace, comprised the CSST piping in the house. A perforation with its major axis measuring approximately 200 mils was found in one run of the CSST (Figure 4). An interview with a neighbor confirmed that the audible and visual components of the strike were sensed simultaneously. A positive lightning report was obtained, showing 11 strikes within 0.5 mile. Regrettably, the house was razed before the investigation was complete. Figure 5 shows the failed CSST run to the fireplace.

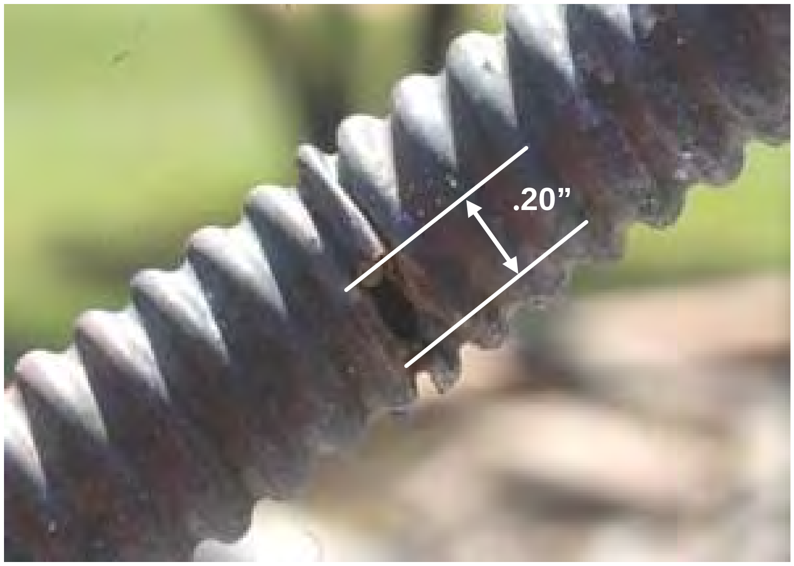

Figure 4: Perforated CSST pipe from Fire 2

Figure 5: CSST tied to Black Iron pipe from fireplace

DISCUSSION

It would be easy to list our findings as just ‘peculiarities’ and ‘vagaries of Mother Nature.’ Indeed, one of the CSST designers has stated that the phenomenon seems to be isolated to Frisco, Texas[12]. However, a recent article in the *Journal of Light Construction* outlines similar findings of an engineering firm in the Midwestern US[13]. In a recent presentation the authors gave to a fire investigators group, we found other fire investigators who have had similar fires in their jurisdictions.

The 'Frisco' experience is noteworthy, and was in fact the impetus for our research. In short, the Frisco (Texas) Fire Department noted a relationship between lightning and CSST fires. They thereafter sought to ban CSST in. A report generated by the City of Frisco states that the continued use of CSST would not be prudent[14]. In a newspaper article in the *Dallas Morning News,* a fair reading would show that the resistance to the ban was brought about for reasons of economy[15]. We would, however, urge the reader to obtain this article and draw his or her own conclusions.

As part of our research, we interviewed the Fire Department officials in Arlington, Texas. At the time of our research, the FD in Arlington was aware of 4 fires in their jurisdiction where lightning caused CSST failures[16]. We also reviewed a report issued by Donan Engineering, where again multiple fires were described that involved lightning and CSST. These extent of the fires reviewed were located in the Midwestern United States[17].

One of the underlying issues with CSST is that it is part of the grounding system. Purists will argue that that gas piping is not to be used as a ground, and they are correct[18]. In reality, however, the gas piping system is *per se* part of the grounding system, and this is recognized by the *National Electric Code* (NEC)[19]. Per the *Fuel Gas Code,* metallic gas piping is to be bonded to ground[20].

For reasons of electric shock prevention (and also elimination of sparks associated with static electricity), it is desirable to have all exposed metal within a structure bonded so that there are no differences of potential. Here, however, lies one area where applying DC circuit theory (or even 60 Hertz steady state phasor theory) has limitations. Lightning energy is known to have fast wavefronts. Testing of devices for transient responses has typically involved an 8/20 uSec pulse, as defined by the IEEE[21]. Another variation is the 10/350 uS pulse, as recommended by the IEC[22]. While the reaction of large wires and irregular surfaces is predictable at 60 Hertz, the fast wave fronts associated with lightning may cause substantial problems with CSST, given its corrugated surface. Moreover, new house construction we have observed has shown very tight bends and routing of CSST immediately adjacent to large grounded surfaces. Testing of CSST under actual installed conditions using transient waveforms may well show further limitations that conventional bonding and grounding cannot accommodate.

CURRENT TRENDS

One manufacturer (Omegaflex) has recognized the problems that lightning poses for CSST. In response, Omegaflex has developed a jacketing material (the yellow polymer coating) that contains conductive materials; the role of the conductor is to dissipate the charge over larger areas of metal, thereby reducing current density and increasing chances for survival. Witnessed tests of the new material were described in the July 2004 *Journal of Light Construction*[23]. The reports indicate a much greater tolerance for lightning.

Correspondence received from Foster-Miller indicates that Franklin lightning rod systems will protect CSST from lightning insult[24]. However, we have not seen CSST-equipped houses being outfitted with lightning rods. The same correspondence also shows that the CSST industry is becoming aware of the problem, and will propose fixes to the other Codes (ie , NEC or Fuel Gas Code); no mention was made of fixes to the standard LC1. A further item that should be mentioned is that Foster-Miller believes that the problem does not exist in Florida, even though Florida is prone to substantial lightning activity; Foster-Miller attributes this difference to greater adherence to lightning-related Code provisions (bonding, grounding)[25].

INVESTIGATING CSST FIRES

Investigation of a fire caused by CSST and lightning is a straight forward process. One of the characteristics of CSST that makes this a simple investigation is the high melting point. Stainless steel is not prone to melt during a fire. If a hole is found in CSST, there is a good chance that the hole is from electrical current. One would need to reasonably eliminate other sources of the leak, to include eutectic melting (alloying) and mechanical damage. Microscopic work would be necessary to insure that the orifice was created by an arcing condition. As with copper wire, one is looking for sharp delineations between fused and non-fused areas. If there appear to be other metals present at the arc site, one should conduct EDX (Energy Dispersive XRay) to see if the metal being examined is stainless, or if it has other metals present (such as Cu, Zn, Al, Sn). If copper is present, one might reasonably attribute the problem to an ongoing fire attacking both the CSST and nearby NM electrical wiring – when the NM faulted to the CSST, a perforation was created. Figure 6 shows a photo taken under a scanning electron microscope (SEM) of a section of CSST that failed when touched by an energized 120 VAC copper wire.

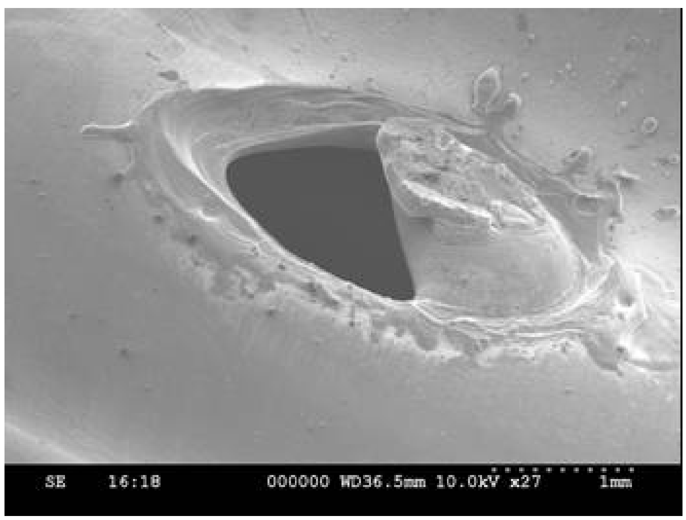

Figure 6: Hole caused by energized 120 VAC copper wire

To find holes, we recommend an instrumented leak test at ~ 7" WC air. One end of the CSST should be plugged, and each hole sequentially plugged (modeling clay seems to work the best) until the CSST no longer leaks. One of the holes we found in CSST was in an area of tubing where the polymer coating had no pyrolysis (See Figure 7). Also, Figure 8 is a microscopic view of this small leak. As in any fire investigation, the leaks and subsequent flame development must support the area of origin, or the leaks would appear to be of little consequence.

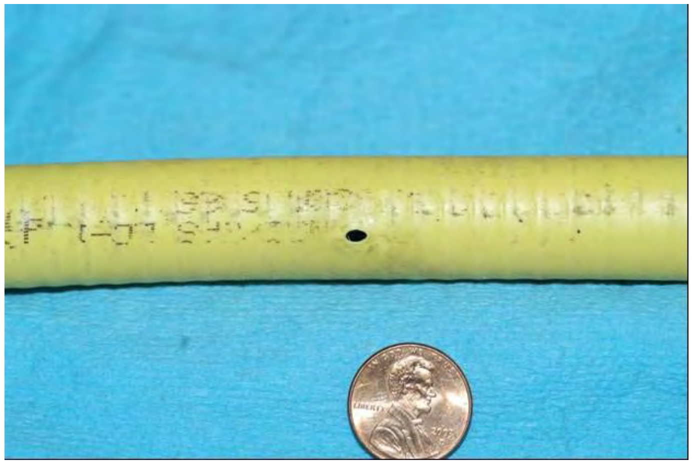

Figure 7: Photo of perforated CSST without pyrolysis

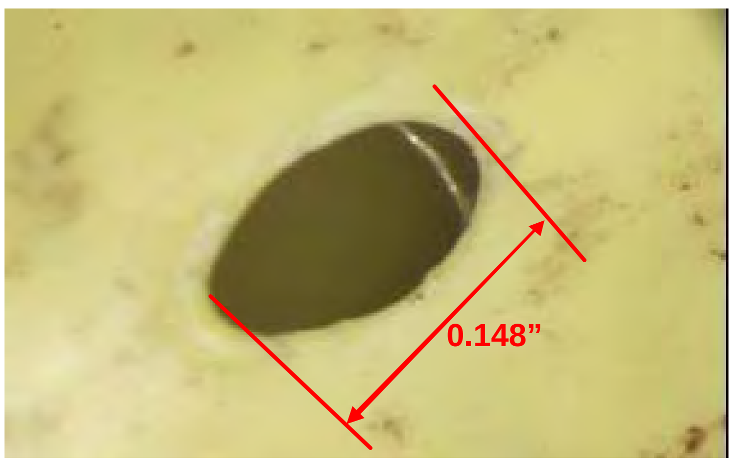

Figure 8: Microscopic View of Perforated CSST

The Frisco Fire Department Report lists escaping gas from the end connectors during lightning events as also being possible sources of ignition[26]. In a previous article written by one of the authors (MEG), this very phenomenon was described on appliance connectors[27]. The fact that a gas line fails at a connection is no surprise, in that gas lines are chosen for mechanical integrity at their junctions, and not necessarily electrical conductivity. Figure 9 shows the end of a failed appliance connector that has arced and caused a fire due to electrical current flow. We might expect to see similar manifestations with CSST at its connectors.

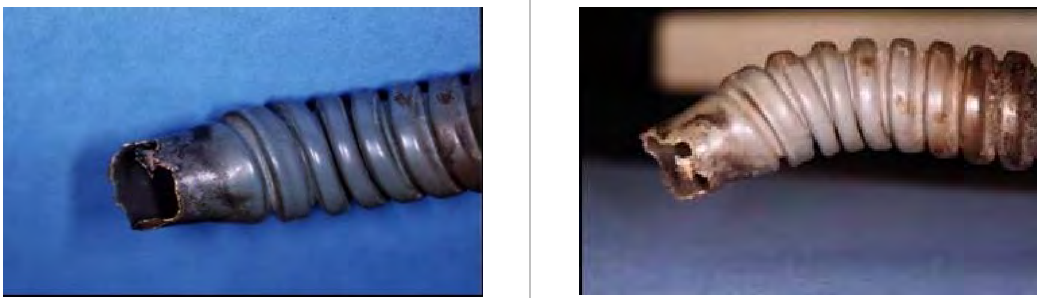

Figure 9: Bottom and side respective views of failed gas line from appliance connectors

In all of our investigations, we have obtained positive lightning reports via STRIKE FAX. The City of Frisco, in their investigation, also made use of STRIKE FAX reports. We must state, however, that in our opinion, the perforated gas line can normally stand on its own in terms of evidentiary value; we know of no other phenomenon that would create a clean arced hole other than lightning. If a copper wire arced to the stainless steel tubing, there should be copper remnants found. Likewise, the melting point of SS will not be reached in most fires. While the lightning reports are useful, we would add that they might add 'too much' information, if that is even possible. The reports list strike magnitude, polarity, distance, and time. If there are multiple strikes, there is a question of which strike is causative. Likewise, is it possible that one strike induced multiple perforations? We are not certain that these additional questions can be answered accurately, nor do we know to what extent these answers may be helpful. In the end, the CSST failed from lightning, or it did not – we have not been concerned as to which of multiple strikes brought on the failure.

In one of our fires, a field examination revealed the hole in the CSST. The STRIKE FAX sent thereafter to the O&C investigator was negative. And yet, a neighbor was a witness to the lightning. The request for a lightning report was re-submitted, and this time the report received was positive for lightning events at the location. In this fire, the physical evidence was very clear and helped to serve as the basis for a requesting a new lightning report.

We have not spoken of spoliation, but it is of course advisable that potential adverse parties be given notice of inspections if litigation is anticipated.

THE ULTIMATE QUESTION:

The ultimate question is whether or not CSST is safe as currently installed. We would offer initially that there is one similar product that reminds us of CSST. Aluminum wiring was approved by the NEC and by a recognized testing group – UL. Aluminum wiring was installed for reasons of economy, in that it was less expensive than copper. Aluminum wiring was also never adequately tested before being placed on the market. We later learned about creep, dissimilar thermal coefficients of expansion, and the insulating properties of oxidized aluminum. When adequate testing was conducted, it was realized that aluminum had numerous problems not posed by copper. Wiring on the inside of houses and business is now all copper, which does not pose the risks associated with aluminum,

In the case of CSST, we know of one manufacturer diligently trying to alter the product so as to prevent losses. We are also aware of the industry proposing changes to codes so as to make CSST less of a threat during lightning. These alterations, combined with mounting fire losses involving CSST and lightning, would suggest that it has deficiencies. The underlying issue, however, is whether or CSST is as safe as conventional black pipe. In this regard, reported fire losses indicate that it is not as safe as black pipe in regards to the issue of lightning. While we cannot state that black pipe will never fail from lightning, we have yet to see such a fire.

<u>REFERENCES:</u>

[1] ANSI, *"Standard for Corrugated Stainless Steel Tubing, LC-1" 1998.*
[2] Faloon, Kelly, "The CSST Battle is Over", Plumbing *and Mechanical*, February 2003, http//:www.pmmag.com.
[3] ANSI, op. cit., p
[4] NFPA, National *Fuel Gas Code Handbook*, International Approved Services, 1997, Section 2.6.3, p 52.
[5] IAPMO *Uniform Mechanical Code*, 2003
[6] IAPMO, *2000 Uniform Plumbing Code Changes Committee Recommendations* Las Vegas, NV May 3, 2000 Item 84 Section 1210.1.
[7] Ibid Section 1210.1.
[8] Lemoff, T., personal correspondence with City of Frisco, January 3, 2003.
[9] Uman, M. A., <u>Lightning</u>, Dover Publications, Inc New York, 1969. p 5
[10] Ibid, p 128.
[11] Vaisala Inc, Tuscon, Arizona, http://www.vaisala.com.
[12] Torbin, R., "*Preliminary Metallurgic Evaluation of Two Fuel Gas Piping Systems*", Review of Technical Report, Foster-Miller Inc.
[13] "Flexible Gas Piping Involved in Fires Caused by Lightning" *Journal of Light Construction*, May 2004.
[14] Frisco Fire Department, "House fires involving lightning strikes and flexible gas lines" Investigative Summary, FFD p 3.
[15] "Frisco Bans Pipes Used in New Homes" <u>Dallas Morning News</u>, April 3, 2003.
[16] Open Records Request, City of Arlington Fire Department.
[17] "The Effect of Lightning on CSST Gas Tubing Papers on Fire Cases", Fire and Arson Conference, Indianapolis, Indiana, August 16-18, 2004
[18] NFPA, *National Fuel Gas Code*, op. cit., Section 3.14b, p 98.
[19] NFPA National Electric Code (NEC), 2002, Section 250.2 fpn p 96.
[20] NFPA, *National Fuel Gas Code*, op. cit., Section 3.14b, p 99.
[21] IEEE/ANSI C62-41, IEEE, New York.
[22] IEC 61643-1.
[23] "New Lightning-Resistant Flexible Gas Line Shines During Demonstration", *Journal of Light Construction*, July 2004
[24] Torbin, R., personal correspondence, August 27, 2004.
[25] Ibid, August 27, 2004.
[26] Frisco Fire Department, op. cit., p 3
[27] Goodson, M. E. "Electrically Induced Gas Fires" *Fire Arson Investigator*, July 1999.

*Principal and Consulting Engineer, respectively