ELECTRIC WATER HEATER FIRES

BY MARK E. GOODSON, P.E.—One of the cardinal sins that an investigator can commit is to state that a certain type of fire can NEVER occur. Such a statement is sure to invite challenges from other investigators, as well as a barrage of questions in future depositions. It is for these reasons that the author will not state that an electric water heater cannot cause a fire. But the underlying theme of this paper is that over the years, numerous electric water heaters have been examined by the author as being potential causes of fires; not once did they turn out to be the actual cause.

In order to investigate an electrical water heater as a fire cause, it is necessary to understand how they operate. The usual electric water heater is electrically depicted in the schematic of Figure 1. Incoming 240 VAC power first passes through a high limit thermostat, and then to one of two thermostats and resistance heaters. The resistance heaters, made of a resistance wire encased in magnesium oxide and an outer metal sheath, are each rated at 3500 to 5500 watts. Photo 1 shows a "low boy" electrical water heater, with the cover plates removed to expose the thermostats, wiring, and heating element connections.

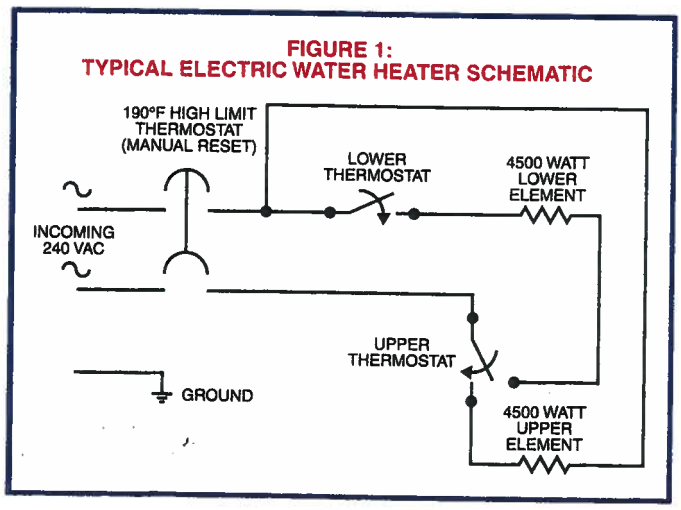

FIGURE 1: TYPICAL ELECTRIC WATER HEATER SCHEMATIC

PHOTO 1—"Low boy" electric water heater with side covers removed showing thermostats, wiring and heating element connections.

In use, the water heater heats incoming cold water by powering the upper heating element. Once the water temperature has risen to the setting of the upper thermostat, the upper element turns off. If the lower thermostat senses that the lower portion of the tank is cold, the lower element will be powered until the water is sufficiently hot. Temperature settings for the lower and upper elements are adjustable, with the usual range being between about 100 and 170°F. Once the water temperature has reached the desired points (as determined by the thermostats), the heating elements will stay off until the water cools (cooling occurs naturally as heat is dissipated into the atmosphere, and also when cold water enters to replace the hot water that is being consumed). The length of time that the heating elements are powered is determined by thermostat settings, inlet wa-

ter temperature, heating element wattage, efficiency of the surrounding insulation, and flow rate for the exiting hot water.

While the above description of operation applies to many electric water heaters, it should be noted that some units have only 1 heating element. In addition, some smaller units (5 gallons) make use of power from a 120 VAC source. While these units are electrically different, they function in a similar manner as the 240 VAC units with 2 heating elements.

Fire causation

This writer has investigated numerous fires (35 to 40) where it was alleged that combustion was brought on by electric water heaters. In that the typical water heater has heating elements with combined ratings of about 7000 to 11,000 watts, it is often suspected of igniting nearby combustibles. However, the design of the electric water heater makes such fire causation close to impossible. Outlined here are both the theories and the realities that make such a fire scenario unlikely.

The most common allegation heard is that the heating element was responsible for the fire. This is a very doubtful scenario. In order to ignite a combustible, it is necessary to have temperatures in the neighborhood of 500 to 550°F. The heating elements, by their very design, are immersed in water. The thermostats will cut off electrical current to the heating elements if the temperature exceeds about 170°F. In the event that the operational thermostats fail, then the water temperature will rise to about 190°F. At this later point, a double pole high limit thermostat will open, cutting off power to the unit. This double pole unit usually has a manual reset button preventing cycling of the unit. The effect of this circuitry within the water heater is to keep the temperature from ever rising above about 190°F. If the water temperature is never above 190°F, then heat from a normally functioning water heater will not cause a fire by igniting nearby combustibles. Photo 2 shows a view of both an operational thermostat and the high limit switch.

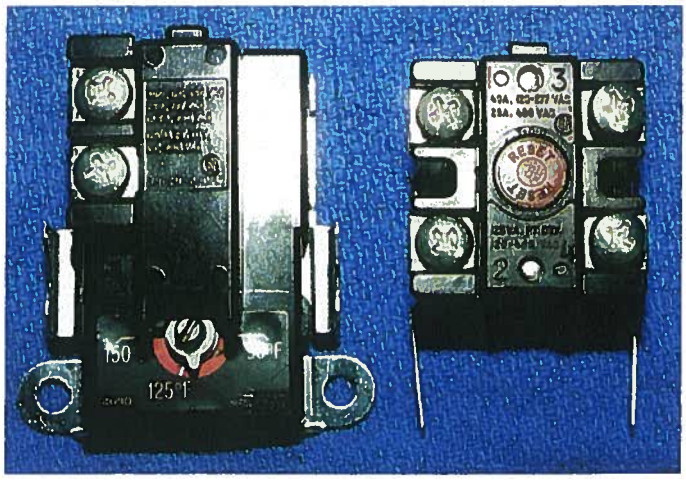

PHOTO 2—Operational thermostat and high limit switch.

The question arises as to simultaneous failures of both the operational thermostat and the high limit thermostat. In this scenario, water would continue to heat until it greatly exceeded the 212°F point (atmospheric boiling), with a fire resulting from the overheating. For this type of scenario, the operational and the high limit thermostat would have to fail, allowing continued heating of the water. Such a failure would be extremely rare. In the event that it does occur, the water temperature will rise. If we assume, however, that the water heater is plumbed according to Uniform Plumbing Code part 1007, the water heater T&P (Temperature and Pressure) valve will open. Usually set by the manufacturer at 210°F, and either 125 or 150 psi, the opening of this valve will dump the hot water outside of the tank, causing the tank to be refilled with cold water. The purpose of this valve is to prevent the tank from rupturing when the water approaches boiling pressures and temperatures. A picture of a T&P valve is shown in Photo 3.

PHOTO 3—The temperature & pressure valve (T&P) will prevent the tank from rupturing if the water approaches boiling by dumping the hot water outside the tank.

Several water heaters examined by the author did not have water present at the time they were involved in fires. Fire investigators were curious as to whether this set of conditions could lead to a fire. Most electric water heaters make use of high watt density heating elements. The design of these elements is such that they cannot be "dry fired" without immediately failing. With these types of heating elements, the water is not present to carry away the heat, and the concentration of heat at the element sheath causes the heating element to electrically open. A similar type of element can be dry fired for about 1 minute before it fails. Photo 4 shows such an element that has been dry fired and thus failed. The bulge in the sheath depicts the location where failure occurred. Needless to say, there is insufficient time available so as to cause ignition of combustibles when the tank is empty and the element is dry fired and opens.

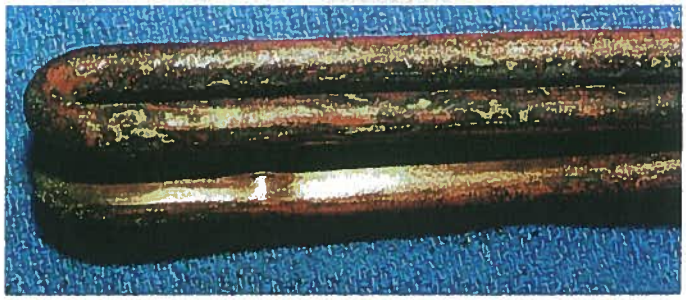

PHOTO 4—This heating element failed when "dry fired." Note the bulge in the sheath where the failure occured.

There is a type of element that can be "dry fired" without sustaining damage. These elements are capable of functioning for a long period of time without water. The question then arises as to whether a 4500 watt resistance heater that is enclosed in a 30 or 40 gallon steel drum can create sufficient heat so as to ignite nearby combustibles. The lack of water thus changes the mechanism of heat transfer from one of conduction to convection. Testing by the author shows that the thermostats will function so as to cut off electrical current flow to the heating element. Once the temperature of the steel tank reaches the thermostat set point, the thermostat cuts off power to the heating element. The thermostats trip in the 100 to 190°F range. When these temperatures are reached on the steel tank, power will be removed. In one investigation carried out by the writer, the heating thermostat was not intimately mounted to the steel tank and did not react to the increase in temperature caused by dry firing. The thermoplastic insulation on the power wiring to the thermostat failed from the heat buildup,

and a short occurred between the grounded tank and the wiring. This short tipped a breaker, and the power was removed.

The one area of a water heater that would be prone to cause problems would be the connections. This observation is true with not only water heaters, but almost any electrical device that carries sizeable amounts of electrical current. Connections that are loose or improperly made can overheat and cause fires if combustible materials are too close. Photo 5 shows the thermal image of a water heater with one of the side covers removed. The high limit switch, thermostat, and heating element are all present. The connections on the left hand side of the high limit switch and thermostat have been backed off about 1/4 turn, with the results being obvious.

PHOTO 5—This thermal image shows the results of loosened connections on the thermostat and high limit switch of an electric water heater.

Incoming power is normally brought to the water heater by #10 AWG solid copper wire. With the water heater on continually (i.e., hot water constantly leaving with cold water entering the tank), the temperature rise of this copper wire is barely perceptible in a nominal 75°F atmosphere. Using #12 and #14 wires to bring power to the same water heater with 4500 watt elements, steady state temperature rises of 91 and 102°F, respectively, were found. It is certainly against the electrical code to overload these wires in this fashion, but no short term damage to the wiring was seen with this level of overloading. The astute investigator will check the wire sizes, breaker position, breaker rating, and connections to the water heater after a fire to determine if there is any evidence of code violations or connector problems with the wiring.

The thermal insulation on water heaters consists of both fiberglass fibers and a type of urethane foam. Obviously, the fiberglass will not combust in a fire. The author has seen several types of foam that have been used in water heaters; some do not support combustion, while others were readily ignited under some circumstances. The best test when examining a given fire scene is to take some of the foam from an exemplar heater and determine whether it can sustain a flame on its own. If the foam readily combusts, one must determine what the heat source (if any) was. Did the foam ignite early in the fire (a possible cause)? In terms of combustibles, the foam and the insulation on the wiring are about the only combustibles that an electric water heater has. Absent any arcing within the wiring in the water heater, it is very unlikely that the foam was ignited by an internal source. It should also be pointed out that if the urethane foam will combust well in free air, it is very unlikely to effectively combust in a closed space. The foam is well sandwiched by an outer sheet metal skin and an inner steel tank. Unless the two steel cover plates have been removed from the outer skin, there is simply insufficient oxygen available to allow for proper oxygenation of the urethane foam inside the unit.

This writer has seen one water heater in which electrical operation was verifiably not proper and which the homeowner suspected of causing a fire. The homeowner stated that several days prior to the fire, he had to manually reset the high limit thermostat overload switch by depressing its red button. A fire occurred about 48 hours later, and the water heater was suspected. Inspection revealed that on this water heater, the thermostats would have had no effect in controlling water temperature. Corrosion had attacked the lower element internal to the tank, causing the element to short out to its inner sheath; Photo 6 shows this heating element, as well as the good upper unit. When this corrosive process and resultant failure occurs, the heating element turns into a lower wattage unit and is given power by the upper thermostat and the ground connection of the sheath. Water will continually heat, albeit slowly. Because the lower thermostat in this scenario is bypassed, the water will continue to overheat until the 190°F point is reached and the high limit thermostat is tripped. While this scenario is unsafe from both scalding and electrical shock standpoints, it is not causative of a fire.

Throughout this paper, the writer has assumed that the water heater is properly installed in accordance with both NEC and UPC requirements. If these requirements are not met, then some of the comments made do not apply. As an example, NEC requirements state that an appliance must be installed and used in its intended fashion. If the installer has left the cover plates off of the water heater at either the heating elements or the wiring inlet, then obviously the risk increases for ignition of combustibles by a shorting/arcing process.

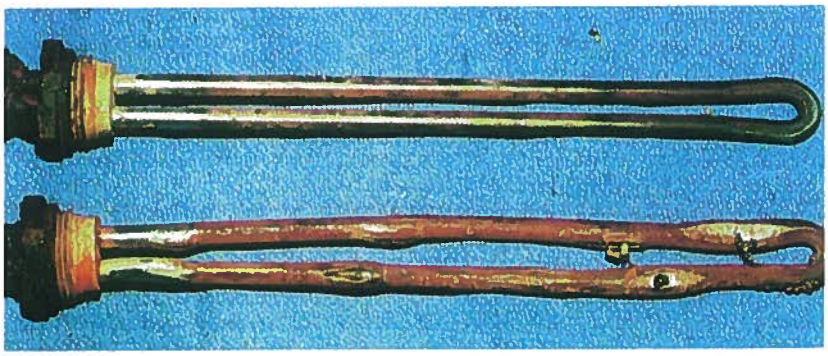

PHOTO 6—Corrosion caused the lower element to fail by shorting out to its inner sheath. The still good upper element is shown at the top.

Summary

In general, electric water heaters do not cause fires. The majority of the heat is well contained and absorbed by water. There are several electrical controls present which are intended to prevent overheating. Should these controls fail, the T&P valve will cause cold water to purge the tank, thus eliminating the chances for fires. When water is lost from a tank, most heating elements are designed to immediately open. Water heaters do use a power source (240 VAC, 30 ampere

breaker) that is capable of delivering substantial amounts of power. In most cases an overheated connection, a direct short of the hot wire or a loose wire that shorts to ground (with combustibles in too close proximity) are the most probable causes for fires involving electric water heaters. In general, however, electric water heaters do not pose the fire hazard that one would expect from a heat generating device rated at many kilowatts of power.

About the Author
Mark Goodson, PE, is the principal in Mark E. Goodson PE, Consulting Engineers, of Denton, Texas. This firm specializes in electrical and mechanical failure analysis related to fires, electrical shock incidents, and machine and equipment failure. Mr. Goodson received the BSEE from Texas A&M in 1979, and then studied both fire investigation and forensic medicine. Mr. Goodson is the engineering consultant for many medical examiner's offices in the state of Texas, and his firm has provided services to national, state, and local investigative agencies in regards to fire investigations.

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I AM COMPELLED TO COMPLIMENT INVESTIGATOR BARRETT ON THE SUCCESS OF HIS ENDEAVORS

I have read with great interest the passionate responses to Investigator Bill Barrett's comments concerning NFPA 921 Proposal 114 (12-2.4) and Proposal 6 (1-2). Having done so I am compelled to compliment Investigator Barrett on the success of his endeavors.

Investigators Barrett's comments were clearly meant to stimulate, if not provoke, members of the fire investigation community into learning about and participating in the NFPA 921 publication process. I know this because Investigator Barrett requested my input on his comments prior to his submitting them for publication in the *Fire Trailer*. His comments and concerns in fact spurred me to review the Report on Proposals and to submit 16 separate Comments on Proposals reported out of the Technical Committee.

With regard to the critical and vindictive responses from Mr. Daniel Churchward and Mr. John Lentini, I believe they both missed the forest for the trees in their reading of Barrett's comments. I make no secret of the fact that Bill Barrett is a trusted friend and colleague, and a true gentleman. Anne who has worked with Bill will attest to his impeccable character and commendatory work ethic. I know of no one in the field of fire investigation who works harder at seeking the truth. Suffice it to say Bill leveled no personal attacks in his comments although it is clear he struck a nerve among some members of the Technical Committee.

My reading of Barrett's comments on the issue of "Negative Corpus" indicated to me a concern that the Committee was preparing to publish language that could (and most certainly would) be used to seriously undermine many sound criminal investigations wherein the perpetrator simply walked away from the fire scene with the ignition source in hand. The wording of the Proposal negated the value of circumstantial evidence in determining the cause of a fire and essentially eliminated the need for judge or jury to weigh such evidence. And, judging from Mr. Lentini's self-congratulatory report on the Committee's subsequent actions on this Proposal, it appears he and other Committee members shared Barrett's concerns.

And Barrett's comments on the issue of "Consensus" speak not only to the process by which the NFPA 921 document is constructed, which is the apparent interpretation of both Churchward and Lentini. Rather, Barrett was also commenting on those "professional" fire investigators who would experience the irresistible urge to use such language to bolster their opinions and the document itself. If one accepts the definition of "consensus" to be a collective opinion, then NFPA 921 is definitely the consensus opinion of the Technical Committee. Likewise, if the document is approved by vote of the NFPA members in attendance at the Fall 2000 Meeting, it can be argued that the document is the "consensus" of those members all 300 (or so) of them. However, when a learned "professional" attempts to bolster his or the document's authority by asserting that NFPA 921 is backed by the "full force and weight of the 66,000 members of the NFPA," I call that "a deliberate deception perpetrated for unfair gain," or a "fraud" as defined in *Webster's II New Riverside Dictionary*.

Finally, I am compelled to comment that neither Mr. Churchward's nor Mr. Lentini's responses to Investigator Barrett's comments do anything to allay the commonly held opinion of many public sector fire investigators that a high level of animosity against them exists within certain sections of the Technical Committee. I am weary of hearing such members impugn the professionalism of fire investigators who disagree with their agendas by constantly associating them with the old wive's tales of spalling, crazing and annealing. Likewise, the characterization of a fire investigator who publicly questions the actions of the Technical Committee or its members as "those who would have no standards" clearly reveals the self-righteous attitude of at least one Committee member. And, I am sure there are many fire investigators who are relieved to know they have John J. Lentini acting as chief negotiator and problem solver between the "ACLU types" and "jack-booted thugs" "camps" of the Committee.

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