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Effectiveness of Gas Fired Water Heater Elevation in the Reduction of Ignition of Vapors from Flammable Liquid Spills

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Abstract. Elevating ignition sources to protect against the ignition of vapors from flammable liquid spills has a long history in the national standards and codes. Accident data from the Consumer Product Safety Commission and the National Fire Protection Association identify gas fired water heaters as the major ignition source of flammable liquid vapor accidents in the home. During the past ten years, numerous different laboratories have conducted tests to evaluate the effectiveness of elevating gas fired water heaters to prevent the ignition of flammable liquid vapors. Analysis of the results of 48 tests from three laboratories demonstrate the effectiveness of elevating gas fired water heaters in reducing the ignition of flammable liquid vapors in the home.

Key words: water heater, flammable vapor, 18 inch

Introduction

The ignition of flammable liquid vapors by floor level and low level ignition sources in industrial settings has long been recognized as a significant fire hazard. More than 25 years ago, the Consumer Product Safety Commission (CPSC) also identified the ignition of flammable liquid vapors as a significant hazard in residential settings. The Calspan Report, a study commissioned by the CPSC in 1975, showed that gas fired water heaters were the predominant ignition source for flammable liquid spills (e.g., gasoline) in the home [1, 2]. This paper will examine the code and standard background as they relate to ignition source elevation, and methods to reduce or eliminate the ignition of flammable liquid vapors by gas fired water heaters. Test results from three different laboratories that spilled gasoline in the vicinity of an elevated water heater are presented and analyzed. Test data demonstrate the effectiveness of elevation of the pilot flame/burner on the reduction of ignition potential of the appliance.

Background

Flammable liquids, are generally defined as liquids having a flashpoint below 100° Fahrenheit (38° Celsius), and combustible liquids are generally defined as liquids having a flashpoint at, or above, 100° Fahrenheit (38° Celsius) [3]. The U.S. Department

of Transportation, as well as most national and international bodies that regulate the transportation and use of flammable liquids, use these definitions.

Flash point is the lowest temperature of a liquid at which the concentration of vapors in the space above the liquid (e.g., in the flash point test apparatus) will propagate combustion away from an introduced pilot flame. The minimum concentration, or percentage, of vapors in air by volume at the flash point is equivalent to the lower flammable level (LFL) of the liquid. Concentrations of flammable vapors in air below the LFL will burn in the presence of a flaming ignition source, but will not propagate combustion away from the flame. This condition is often referred to as *too lean*. In other words, there are too few fuel molecules mixed with air to sustain a chemical reaction when ignited.

All flammable liquids have vapors which are heavier or more dense than air (i.e., density ratio to air >1). The vapor density of a flammable liquid is a function of the molecular weight of the compound(s). The density of a flammable liquid vapor/air mixture, is a function of the vapor density of the liquid and the amount or percentage of the vapor in air. No matter what the proportion, all flammable liquid vapor/air mixtures are more dense than air. Because the mixture is heavier than air, it is influenced by gravity and tends to spread out and flow, just as water flows under the influence of gravity, albeit not as dramatically or visibly. In a quiescent atmosphere, mixtures of flammable vapor and air, which form from a layer of evaporating liquid (e.g., a spill) will spread, primarily in lateral directions, away from the spill until obstructed by a barrier or disturbed by an external force such as movement.

In many fires that have occurred from the ignition of flammable vapors by gas fired water heaters, gasoline is the source of flammable vapors. Gasoline vapors have a density that is approximately four times that of air. At its LFL, the density of a gasoline vapor/air mixture is about 1.04 times that of air. At the equilibrium vapor pressure at room temperature, the density of gasoline vapor air mixture is about 1.7 times that of air (i.e., just above the liquid surface). Gasoline has been used as the source of flammable liquid vapors in tests conducted by Safety Engineering Laboratories, Inc. (SEL), Stress Engineering Services, Inc. (SES), and Arthur D. Little, Inc. (A.D. Little).

Elevation of Ignition Sources

The elevation of "conventional" water heaters to a location that places the combustion air inlet and burner/pilot flame at least 18 inches above the floor has been used as a means to reduce the potential for the ignition of flammable vapors (See Table 1). This practice reflects the identification of this zone (i.e., 18 inches) as a hazardous area where flammable vapors may be present. The National Electric Code (i.e., NFPA 70, NEC) first classified hazardous areas in the 1951 edition [4]. The classification of hazardous areas as Class I, Division 1 and Class I, Division 2—based on the presence, or potential presence, of flammable and combustible liquid vapors—is well known. Class I, Division 1 locations are areas where flammable vapors may be present in air in sufficient quantities to provide an ignitable or explosive mixture.[1] Class I, Division 2 locations are areas where an accident or equipment failure (i.e., some condition other than normal) is necessary for flammable vapors to be present and mixed with air to provide an ignitable or explosive mixture. The NEC requires electrical equipment used in these hazardous areas to be rated for such use. Some equipment may be intrinsically safe, including

TABLE 1
Codes and Standards Requiring the Elevation of Water Heaters/Gas Fired Appliances

Uniform Mechanical Code	1970	Sec. 508	Appliances generating a glow, spark, or flame capable of igniting flammable vapors may be installed in a garage, provided the pilots and burners, or heating elements and switches are at least **18 inches** above the floor level.
BOCA Basic Building Code	1978	413.1.5	Boilers, furnaces, hot water heaters, or any other appliances having an open flame or exposed heated surfaces. . . shall have the combustion chamber, ash pit etc., raised a minimum of **eighteen (18) inches** above the floor to eliminate a possible source of ignition.
BOCA National Mechanical Code	1987	M-404.2	The combustion chamber of fuel-burning appliances shall be installed a minimum of **18 inches** (457 mm) above the floor.
International Mechanical Code	1998	304.2	Equipment and appliances having an ignition source, shall be elevated such that the source of ignition is not less than **18 inches** (457 mm) above the floor in hazardous locations, and public garages, private garages, repair garages, automotive service stations and parking garages.
NFPA 30A —Automotive and Marine Service Station Code	1984	7-4	Heating equipment using gas or oil fuel may be installed in the lubrication or service room where there is no dispensing or transferring of Class I liquids. . . provided the bottom of the combustion chamber is at least **18 inches** above the floor. . .
NFPA 54—National Fuel Gas Code	1980	5.1.9(a)	Gas utilization equipment in residential garages shall be installed so that all burners and burner ignition devices are located not less than **18 inches** above the floor.[1]
SBCCI Standard Gas Code	1991	402.7.1	Gas appliances in residential garages shall be installed so that all burners and burner ignition devices are not located less than **18 inches** above the floor.
CABO One and Two Family Dwelling Code	1983	M-1114	Boilers, furnaces, hot water heaters, or any other appliances having an open flame or exposed heated surfaces. . . shall have the source of ignition combustion chamber, ash pit raised a minimum of **eighteen (18) inches** above the floor to eliminate a possible source of ignition.

[1]Original requirement in a modified form appeared in 1960.

some solid state and/or low voltage devices [5]. Others may be the familiar "explosion proof" type of equipment, such as motors, switches, and other electrical devices.

NFPA 30, Flammable and Combustible Liquids Code [6], uses the NFPA 70/NEC hazardous area classifications to define specific hazard areas when storing, handling, and using flammable liquids. Inherent in the protection of these hazardous areas is the elimination of ignition sources[2] within the classified area. For industrial plants, chemical plants, refineries, and bulk storage facilities using flammable liquids, the extent of the classified area is provided in the code. In each case where the extent of the classified area

is defined, the heavier-than-air property of flammable vapor/air mixtures is employed. For example, for indoor or outdoor filling stations, the Division 1 area is within three feet of the vent and fill opening in all directions. The Division 2 area extends to 5 feet vertically from the source of vapors, and horizontally 10 feet up to a height of 18 inches. In other words, all ignition sources within the classified area must be eliminated or controlled. This includes the volume around the sources of vapors in enclosures 10 ft × 10 ft × 18 inches in height, recognizing the density of the vapor/air mixture as a factor in spreading from the source.

Standards and codes have taken into account the potential ignition of flammable vapors in hazardous locations by appliances with burners, pilot flames, and other ignition sources for over 70 years. In 1928, the American Gas Association's (AGA) *Requirements for House Piping and Appliance Installation* [7] required that ignition sources, such as heater burners, be raised 24 inches in residential garages. The 1951 NEC required that equipment within 48 inches of the floor in residential storage garages, conform to the requirements for equipment in a Class I, Division 2 location. In 1953, the requirement was changed to identify Class I, Division 2 locations as within 18 inches of the floor in a residential storage garage [8]. Currently, the NEC continues to identify the space below an elevation of 18 inches in commercial garages as Class I Division 2 locations.

The National Fuel Gas Code (NFPA 54) has required the elevation of ignition sources for over forty years, recognizing the reduced potential for the ignition of flammable vapors by gas utilization appliances when these appliances are elevated. The 1960 edition of NFPA 54 requires the elevation of water heaters to 18 inches when installed in residential garages, unless the ground outside the garage door opens at or below grade [9]. Subsequent editions of the code, amplified and strengthened the requirement for elevation of water heaters and other gas utilization devices. Currently, gas water heaters that take combustion air from the floor, cannot be installed in locations where flammable liquids are handled, dispensed, or openly used [10].

Other building, mechanical, and gas codes have required elevation of ignition sources in hazardous locations for over twenty years. The Uniform Mechanical Code [11], the International Mechanical Code [12], the Standard Gas Code [13], the National Mechanical Code [14], the Basic Building Code [15], and the One and Two Family Dwelling Code [16], all require the elevation of potential ignition sources on appliances installed in hazardous locations, particularly residential garages (see Table 1). Since the 1960s and 1970s, the requirements in these codes have been strengthened and amplified, and have consistently required that potential ignition sources be located at least 18 inches above the floor, in areas where flammable vapors are likely to be present.

Another method for reducing the potential for the ignition of flammable vapors by gas fueled appliance ignition sources is by direct venting: sealing the combustion chamber at floor level, and drawing the combustion air from an elevated source, or from outside of the room where the appliance is located[3] [17]. A residential direct vent water heater has been commercially available for more than 15 years. This adaptation of the existing water heater design permits combustion air to be drawn from, and exhausted to, a location outside of the home or garage. When properly designed and installed, direct vent water heaters eliminate the potential for the ignition of flammable vapors from spills of flammable liquids in the room or area where the water heater is located.

A modification of the direct vent design, has also been shown to be effective in preventing the ignition of flammable vapors from spills near, and under, a water heater. This modification permits air to be taken from the room in which the heater is installed, but at a level of four feet or higher. Combustion air taken from this level, under most circumstances, would not contain flammable vapors, within the flammable range, when flammable liquids are spilled. While this method, in theory, would not eliminate the potential for ignition of a flammable vapor/air mixture, it so greatly reduces the potential for an ignition to occur, that the risk becomes insignificant. The technology of taking combustion air from elevated sources, or sources outside of the room in which the gas fueled appliance is located, has been in use for more than thirty years.

Flame arrester technology is also used to mitigate the risk of igniting flammable vapors. A residential gas fired water heater that uses a screen to prevent the escape of flames created in the combustion chamber, when flammable vapors enter into the chamber, is available to consumers [18]. This product uses an existing technology which was developed to control the propagation from ignition of flammable vapors, by containing the flames within a combustion chamber. A fusible link in the combustion chamber activates when gasoline vapors burn within the chamber to shut off gas to the burner/pilot.

While there has been some effort since the 1970s by the water heater industry to design a floor mounted, gas fired product effective in reducing or preventing ignition of flammable vapors by the low level pilot flame/burner, only one manufacturer has brought a product, described above, to market.

Water Heater Flammable Vapor Ignition Problem: Time Line

Using data from hospital emergency rooms, the National Electronic Injury Surveillance System of the Consumer Product Safety Commission (CPSC) reported 3800 water heater associated injuries during the 1973 calendar year [19]. A significant number of the cases involved ignition of flammable vapors from gasoline and other flammable liquids by the flame of gas and oil[4] fired water heaters.

In 1974, the CPSC contracted Calspan Corporation to research hazards associated with gas-fired appliances. Calspan published two reports: *Identification and Classification of Potential Hazards Associated with the Use of Residential Flame-Fired Furnaces, Hot Water Heaters, Clothes Dryers, and Ranges* [1] and *Investigation of Safety Standards for Flame Fired Furnaces, Hot Water Heaters, Clothes Dryers, and Ranges* [2].

In 1975, the CPSC reported that in one year over 1200 persons were treated for burn injuries received in fire accidents involving gas fired water heaters [20]. The data revealed that flammable solvents and flammable cleaning agents, whose vapors are heavier than air, were ignited by the gas water heater pilot flame or burner. The most serious accidents involved gasoline which was either used intentionally as a cleaning agent or was unintentionally spilled in the vicinity of a gas fired water heater. The vapors of gasoline, which remain close to the floor, traveled from the source, and were ignited by the water heater. Two factors were identified that led to an increased occurrence of accidents involving the ignition of flammable vapors and gas fired water heaters: (1) the location of the gas fired water heater, and (2) a lack of conscious awareness by the consumer of the standing pilot flame at the base of the water heater.

In the first Calspan report, the flammable liquid/vapor problem and gas fueled appliances was emphasized. Unlike problems associated with the operation of appliances, this hazard was not attributed to appliance misuse or defect, but to the location (e.g., garage, utility room, or basement), and the higher potential for use or storage of flammable liquids in these locations. Further, the location of the pilot flame/burner and combustion air intake near the floor, coupled with the tendency of flammable vapors to remain and flow close to the floor, increased the potential for ignition. The report states that flammable vapors accounted for the majority of the injury producing accidents involving gas fired water heaters.

In 1987, the NFPA published a special report which examined national reports and data of residential fires which occurred between 1980 to 1984, and involved flammable and or combustible liquids. Between 1980 and 1984, the annual average number of residential fires per year was 13,560; the annual average number of deaths was 182; the annual average number of injuries was 1,390; the annual average property loss was $119.5 million dollars. Each year between 1980 and 1984, five and one-half percent (5.5%) of residential fires originated in areas containing heating equipment/water heaters. Water heaters, within the general classification of heating equipment, led to 2,088 (15.4%) fires, causing 361 (26.0%) injuries, 21 (11.8%) deaths, and costing $16 million (13.5%) in property loss. This data clearly show that water heaters are a disproportionately large source of ignition for fires involving combustible and flammable liquids.

The CPSC summarized fire data from a ten year period (1985 to 1994) and found that, on average, 1440 fires were caused per year by the ignition of flammable vapors by a gas fired water heaters [22]. These fires caused an annual average of 260 injuries and 20 deaths. The average direct costs for property loss were $15.5 million dollars per year.

Between 1994 and 1998, the annual average number of residential structure fires caused by gas fired water heaters was 4,880 [23]. In the broad category of residential gas-fired equipment, which includes heaters, furnaces, ranges, ovens, and clothes dryers, gas water heaters accounted for 9% to 10% of the residential fires. In the narrow category of residential gas fired heating equipment, gas water heaters accounted for 39% to 43% of the fires per year. On average, 24 deaths occurred each year from residential fires involving gas fired water heaters.

In 1992, Rheem Corporation received a patent (filed in 1991) for a water heater design which specifically addressed the flammable vapor problem [24]. In the patent, the water heater modification included a floor supported, horizontally enlarged drain pan with a height of 18 inches. The pan was constructed so that all combustion air delivered to the burner, still at floor level, is taken from a height at least 18 inches above the floor. This design is often referred to as the "bucket" design. The use of a vertical barrier separating floor mounted water heaters from potential spill or vapor accumulation areas, was recognized as an acceptable mitigation method by the CPSC based on internal testing [25].

The AGA Laboratories performed gasoline spill tests with electric water heaters, floor mounted gas fired water heaters, elevated water heaters, and 18 inch "bucket" designs [26]. The results of the AGA tests show that when water heaters were elevated or contained in a "bucket," flammable vapor ignitions are significantly reduced.

To determine how pervasive the problem of residential water heater flammable vapor ignitions was, the Gas Appliance Manufacturers Association (GAMA) commissioned A.D. Little to (1) investigate the hazards associated with ignition of flammable vapors, and (2) to compile a comprehensive database of incidents from which trends could be established. In addition, the analysis considered the activities and awareness of gas water heater installers and the consumer. From the database, A.D. Little identified seven scenarios which represent 80–90% of the gas water heater ignition incidents. As part of the project, A.D. Little constructed representative test rooms, and performed a series of tests using gasoline with floor mounted and elevated water heaters. The overall results of the A.D. Little study show that elevation is an effective means for mitigating the water heater flammable liquid vapor ignition hazard.

The A.D. Little Task 1 Report included an analysis of California Fire Incident Reporting System (CFIRS) data for fires involving gas fired water heaters in single-family dwellings [27]. Their analysis showed that during the 14 years following adoption of the requirement for elevation in garages, the garage fire incident rate had dropped to one-third of the 1974 incident rate. No analysis of the data was undertaken to determine if any fires had occurred in a garage when the water heater was elevated.

Testing and Analysis

During the past ten years, a significant number of tests have been conducted to show that floor mounted water heaters do ignite vapors from gasoline spills. Likewise, a significant number of tests have been conducted that show elevation of water heaters on 18 inch stands is effective in preventing ignition of vapors from gasoline spills. This summary includes those tests conducted by A.D. Little in 1993 for the GAMA Consumer Information and Education Committee Water Heater Division using AGA Laboratories facilities in Cleveland, OH, and by independent laboratories Stress Engineering Services (SES), Inc. in Houston, TX, and also by Safety Engineering Laboratories (SEL), Inc. in Warren, MI, between 1992 and 2001.

A.D. Little conducted a study of fire scenarios, and a series of tests in which gasoline was spilled in the vicinity of gas fired water heaters [28]. The reported purpose of the tests was to evaluate whether or not elevation would reduce ignition of vapors from gasoline spills under a variety of conditions. The A.D. Little tests evaluated a number of factors including: 1) room size; 2) spill quantity, ranging from 0.5 gallon (1.9 liters) to 2.0 gallon (7.6 liters); 3) room temperature, ranging from 72 °F (22 °C) to 105 °F (40 °C), with floor temperatures ranging from 57 °F (14 °C) to 114 °F (46 °C); 4) spill distances, ranging from about 2 feet 4 inches (0.7 m) to 14 feet 1 inch (4.3 m), and 5) with and without simulated human movement after the spill, using a plywood cut out.

In the A.D. Little testing, ignition of gasoline vapors by the pilot flame/burner of an elevated water heater occurred during four of their seven tests, when spills of up to 2 gallons were initiated at distances of 30 inches or more from the elevated water heater in their large test room. Ignition occurred during six of eight tests, when a 1 gallon spill was initiated at distances of 28 inches or more from the elevated water heater in their small test room. Some aspects of the A.D. Little tests were flawed, with respect

to realistic conditions: both test rooms had steel floors with heating elements to provide temperature control above ambient. Even under normal temperature conditions, the rate of evaporation, and size of the pool from a spill on steel, is significantly larger than on unheated concrete. Both test rooms were also essentially sealed, which slowed the rate of vapor dissipation from the room through normal construction features, such as spaces under personnel doors, or under and around typical overhead garage doors. Furthermore, none of the A.D. Little tests with water heaters on elevated stands were conducted with any door openings. These conditions would not be typical for garages or utility rooms throughout the United States.

Given the peculiarities of the A.D. Little test rooms, their results of the testing of elevated water heaters are consistent with results obtained by SEL and SES, and with predictable results based on engineering and scientific principles.

A total of 48 tests were conducted by the three test laboratories using operating water heaters elevated on 18 inch stands. No ignitions occurred when the test room was of typical garage/utility room construction on concrete floors, usually with an overhead garage door and/or personnel door. Ignitions did occur in tests by A.D. Little in sealed test rooms with heated steel floors that would be considered "tight" construction. For convenience of analysis, the 48 tests have been sorted into three tables by spill size of 0.5 gallon or less, 1.0 gallon, and more than one gallon.

Table 2 lists 16 tests in which one half gallon or less of gasoline was spilled within 36 inches of an elevated operating water heater. In 12 of the 16 tests, no ignitions occurred. In fact, ignitions occurred only in the A.D. Little small test room with heated steel floor, and no door openings. No ignitions occurred on concrete floors, with and without open doors, and with and without simulated human activity, or motion, in the test room.

Table 3 lists 19 tests in which spills of one gallon of gasoline, from as far as seven feet, to directly under the water heater were done. In only 7 of the 19 tests did ignition occur. All of the ignitions occurred in the A.D. Little tests, in both the sealed large and small test rooms, with heated steel floors. No ignitions occurred in tests on concrete floors, with or without motion, when a door was open. Interestingly, no ignitions occurred in three of the four tests in the A.D. Little test room, in which the room was sealed and had periodic motion.

Table 4 lists 13 tests in which gasoline spills of 1.5 gallons or larger were initiated near elevated water heaters. Only 6 of the 13 tests resulted in ignitions. All six ignitions occurred in the A.D. Little large test room with a heated steel floor, and no openings into the room.

Tests were also conducted by A.D. Little for a range of scenarios in which the operating water heater was not elevated, i.e. floor mounted with the air intake located two inches above the floor. In three tests conducted in the large test room, with a one gallon gasoline spill at eight feet from the water heater, ignition occurred in less than one minute on average. In the fourth test, ignition occurred in just over two minutes, when one gallon of gasoline was spilled 13 feet from the floor mounted water heater in the large test room. Similar results were obtained with floor mounted water heaters in tests conducted by SEL and SES. Table 5 lists the results from spills of gasoline with the water heater on the floor.

TABLE 2
Results of Elevated Water Heater Testing with a Gasoline Spill Volume of One-Half Gallon or Less

Test Lab	Spill Size (Gallon)	Spill Distance (Inches)	Room Size (Feet)	Ventilation		Motion	Floor	Floor Heated (Deg. F)	Ignition (Y/N)	Total Test Time (Min.)
				Door Open	Floor Vent					
SEL-005	0.25	30	6 × 8	No	No	No	Concrete	No	No	42
SEL-006	0.29	30	6 × 8	No	No	No	Concrete	No	No	46
ADL-030	0.5	30	8 × 8	No	Yes	Yes	Steel	99	Yes	3
ADL-034	0.5	30	8 × 8	No	Yes	Yes	Steel	77	Yes	3
ADL-036	0.5	30	8 × 8	No	Yes	Yes	Steel	72	Yes	8
ADL-037	0.5	30	8 × 8	No	Yes	Yes	Steel	76	Yes	5
SES-002	0.5	0	10 × 9	Yes	No	Yes	Concrete	No	No	30
SES-003	0.5	0	5 × 10	Yes	No	Yes	Concrete	No	No	30
SES-005	0.35	0	10 × 10	Yes*	No	Yes	Concrete	No	No	30
SES-006	0.5	2	10 × 12	Yes	No	Yes	Concrete	No	No	30
SES-007	0.34	8	11 × 25	Yes*	No	Yes	Concrete	No	No	30
SES-009	0.5	0	16 × 9	Carport*	No	Yes	Concrete	No	No	30
SEL-001	0.5	36	8 × 10	Yes	No	Yes	Concrete	No	No	30
SEL-002	0.5	36	8 × 10	Yes	No	Yes	Concrete	No	No	25
SEL-003	0.5	25	8 × 10	Yes	No	Yes	Concrete	No	No	31
SEL-004	0.5	25	8 × 10	Yes	No	Yes	Concrete	No	No	31

*Water heater in closet with closet door closed.

TABLE 3
Results of Elevated Water Heater Testing with a Gasoline Spill Volume of One Gallon

Test Lab	Spill Size (Gallon)	Spill Distance (Inches)	Room Size (Feet)	Ventilation		Motion	Floor	Floor Heated (Deg. F)	Ignition (Y/N)	Total Test Time (Min.)
				Door Open	Floor Vent					
SEL-008	1	72	11 × 24	Yes	No	No	Concrete	No	No	30
SEL-009	1	72	11 × 24	Yes	No	Yes	Concrete	No	No	14
SEL-010	1	72	11 × 24	Yes	No	Yes	Concrete	No	No	14
SES-008	1	35	8 × 8	Yes	No	Yes	Concrete	No	No	30
SES-010	1	0	20 × 30	Yes	No	Yes	Concrete	No	No	30
SES-011	1	0	20 × 30	Yes	No	Yes	Concrete	No	No	30
ADL-008	1	8	10 × 20	No	No	Yes	Steel	59	No	117
ADL-012	1	30	10 × 20	No	No	Yes	Steel	99	No	45
ADL-015	1	30	10 × 20	No	No	Yes	Steel	94	No	77
ADL-026	1	30	10 × 20	No	No	Yes	Steel	89	Yes	15
ADL-027	1	30	10 × 20	No	No	Yes	Steel	88	No	95
ADL-002	1	28	10 × 20	No	Yes	No	Steel	52	No	156
ADL-029	1	30	8 × 8	No	Yes	No	Steel	97	No	120
ADL-003	1	28	8 × 8	No	Yes	Yes	Steel	54	Yes	46
ADL-004	1	28	8 × 8	No	Yes	Yes	Steel	45	Yes	15
ADL-006	1	28	8 × 8	No	Yes	Yes	Steel	60	Yes	4
ADL-033	1	30	8 × 8	No	Yes	Yes	Steel	84	Yes	3
ADL-028	1	30	8 × 8	No	Yes	Yes	Steel	77	Yes	4
ADL-035	1	30	8 × 8	No	Yes	Yes	Steel	86	Yes	4.25

TABLE 4
Results of Elevated Water Heater Testing with a Gasoline Spill Volume of More Than One Gallon

Test Lab	Spill Size (Gallon)	Spill Distance (Inches)	Room Size (Feet)	Ventilation		Motion	Floor	Floor Heated (Deg. F)	Ignition (Y/N)	Total Test Time (Min.)
				Door Open	Floor Vent					
SEL-011	5	72	20×40	Yes	No	No	Concrete	No	No	30
SES-001	1.5	6	10×18	Yes	No	Yes	Concrete	No	No	30
SES-004	1.5	6	10×18	Yes*	No	Yes	Concrete	No	No	30
ADL-013	2	30	10 × 20	No	No	No	Steel	114	Yes	73
ADL-014	2	30	10 × 20	No	No	No	Steel	94	No	131
ADL-019	2	30	10 × 20	No	No	No	Steel	83	No	88
ADL-023	2	30	10 × 20	No	No	No	Steel	78	Yes	109
ADL-024	2	30	10 × 20	No	No	No	Steel	97	No	255
ADL-009	2	72	10 × 20	No	No	Yes	Steel	63	Yes	19
ADL-021	2	30	10 × 20	No	No	Yes	Steel	84	Yes	7
ADL-020	1.5	30	10 × 20	No	No	Yes	Steel	89	No	53
ADL-022	1.5	30	10 × 20	No	No	Yes	Steel	81	Yes	5
ADL-025	1.5	30	10 × 20	No	No	Yes	Steel	96	Yes	7

*Water heater in closet with closet door closed.

TABLE 5
Results of Tests with Gasoline Spills in Test Rooms with Floor Mounted Gas Fired Water Heaters

Test Lab	Spill Size (Gallon)	Spill Distance (Inches)	Room Size (Feet)	Ventilation		Motion	Floor	Floor Heated (Deg. F)	Ignition (Y/N)	Total Test Time (Sec.)
				Door Open	Floor Vent					
SEL-007	0.28	30	6 × 8	No	No	No	Concrete	No	Yes	60
SEL-013	1	72	11 × 24	Yes	No	No	Concrete	No	Yes	300
SEL-014	1	72	11 × 18	No	No	No	Concrete	No	Yes	54
SES-012	1	6	10 × 18	Yes	No	Yes	Concrete	No	Yes	60
SES-013	1	35	8 × 8	Yes	No	Yes	Concrete	No	Yes	56
ADL-001	1	29	8 × 8	No	Yes	No	Steel	57	Yes	15
ADL-007	1	96	10 × 20	No	No	No	Steel	68	Yes	51
ADL-010	1	96	10 × 20	No	Yes	No	Steel	72	Yes	40
ADL-011	1	96	10 × 20	No	Yes	No	Steel	69	Yes	68
ADL-016	1	156	10 × 20	No	No	No	Steel	68	Yes	123

Conclusions

Elevation of ignition sources in areas where flammable liquid vapors may be present has long been known to be effective in mitigating this hazard. The test data presented here on elevated gas fired water heaters confirm that under many typical household circumstances, elevation is effective in preventing ignitions. The data show that with spills occurring on concrete floors, under a wide variety of room sizes and configurations, elevation of the water heater prevents ignition of flammable vapors.

Notes

1. Under normal or typical circumstances. The code actually applies to flammable gases, as well as vapors. The discussion presented here is limited to Class I or flammable liquids, and does not include gases.
2. This includes not only electrical equipment, but hot surfaces, flames, hot work, sparks/sparking tools, pilot lights, etc.
3. Sealed combustion chamber water heater for installation in "hazardous" locations have been available for more than thirty years.
4. Oil fired water heaters are less than 1% of the total.

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