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issue: June 2006 APPLIANCE Magazine

IATC 2006 Best Paper

Spontaneous Combustion Tendency of Household Chemicals and Clothes Dryers-Part 1

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A two-part test program studied the spontaneous combustion tendency of various contaminants on clothing loads placed in household clothes dryers.

IATC 2006 Best Paper Winner

The following is an edited version of a paper delivered at the 57th Annual International Appliance Technical Conference (IATC), held March 27-29 in Rosemont, Illinois, U.S. The paper's authors were awarded the Dana Chase, Sr. Memorial Award for the best paper presented at the conference.

Clothes dryers are heat-producing appliances that are frequently blamed for causing residential fires. Clothes dryers apply heat to garment loads to evaporate water; thus, overheating to the point of ignition of those combustibles is a potential hazard. Because of that potential hazard, clothes dryers incorporate engineering safeguards such as high-limit thermostats to prevent fires. Yet many fires involving clothes dryers occur where these engineering safeguards operated properly, and the cause appears to have been ignition of the garment load in the drum. Several researchers have performed investigations of drying oils and cooking oils to reveal that these oils can lead to self-heating of garment loads. If the combustible load generates more heat than it loses to the environment, the temperature may rise high enough to initiate smoldering combustion that can subsequently lead to a fire involving the dryer.
Currently, there is not a comprehensive survey or comparison of the self-heating propensity of the aforementioned oils and other potential household contaminants. This paper describes a study of 32 potential contaminants for garment loads. Their self-heating propensity was evaluated using a modified Mackey Test procedure, and then several dryer tests were conducted. The time-temperature histories for these tests were analyzed to yield characteristics of self-heating contaminants and to identify

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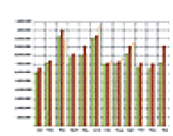

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Spontaneous Ignition

The term "spontaneous ignition" is defined as the delayed ignition of a pile of solid combustible material due to internal heat generation processes. Self-heating behavior leading to ignition is a very complex phenomenon, which has received considerable study. Typically, several criteria must be met for spontaneous ignition to be achieved: the fuel must be prone to exothermic decomposition; the environmental temperature must be above a critical ambient temperature value; the pile must be larger than some critical size; sufficient reactive material must be present so that exothermic decomposition is not limited by reactant depletion; and there must be access of air to the pile. For combustible materials such as cotton fabric, the geometry and environmental considerations are most important. For example, Gross and Robertson computed a critical radius for a sphere composed of uncontaminated cotton linters to be about 300 m for spontaneous ignition at a critical ambient temperature of 80ºC.[1] Obviously, this pile size is much larger than any practical pile of cotton; therefore, spontaneous ignition is not very likely at low temperatures.
The pile size is important due to both the heat transfer limitations imposed by the solid material and the oxygen mass transfer limitations. If the pile is too small in relation to the relative heat generation rate at the given environmental temperature, the heat can be dissipated to the surroundings as fast as it can be generated internally. Subsequently, the pile cannot reach an internal temperature high enough to ignite. Larger piles, however, induce greater resistance to heat losses from internal sources, thus critical environmental temperatures become lower for larger piles. The pile size and packing density will also affect the rate of oxygen diffusion into the reacting interior. If the pile is too large or packed too tightly, oxygen transport may be limited and self-heating may be suppressed.

Contaminants

For spontaneous heating incidents relevant to this work, the typical fuel load is composed of animal, vegetable or synthetic fibers that are contaminated. The contaminants studied here represent vegetable-derived oils, petroleum-derived products and other synthetic chemical mixtures. For most of these contaminants, the heat generation mechanism is oxidation, although some substances also undergo non-oxidative exothermic reactions that could lead to self-heating. Solid bleach product (sodium percarbonate) and pool chlorinator (calcium hypochlorite) are examples of products that may self-heat due to thermal decomposition of the solid as opposed to oxidation. The authors are not aware of any fires caused by the solid bleach product, yet calcium hypochlorite is known to pose a fire hazard under certain conditions.[2]
Vegetable-derived contaminants do not directly react with the fibers to generate heat. Instead, the contaminants are soaked into the mass of fibers. This creates a very large surface area for exposure to air, which increases the rate of oxidation and temperature rise. If the temperature inside the pile rises high enough, smoldering ignition of the oil-soaked fibers will occur inside the pile. Ignition of cotton fibers in such a manner usually occurs above 300ºC.[3, 4, 5]

Vegetable-derived oils (e.g., cooking oils and drying oils) are known to pose a risk of spontaneous ignition when soaked onto rags.[6] These oils contain glycerides of fatty acids such as linolenic acid, linoleic acid or oleic acid. The carbon-carbon double bonds in these glycerides are the chemical components that undergo oxidation. The ease of oxidation has traditionally been measured using the iodine number test, with a higher iodine number indicating a greater propensity for oxidation. Linseed oil is one of the most widely known oils that exhibits self-heating behavior and has an iodine number that ranges from 170 to 205.[7] At the other end of the spectrum, coconut oil has an iodine number from 8 to 10 and is not known to self-heat.[6]

No comprehensive studies have been published that relate the degree of oil contamination, pile size and ambient temperature to spontaneous ignition potential. Some authors report that the most favorable oil to fiber mass ratio for spontaneous ignition is 1:1, but it has been achieved with mass loadings as low as 5 percent.[3, 6]

The Mackey Test

The Mackey Test is a form of isothermal test originally devised to assess the self-heating and ignition hazard associated with oxidation of oils used in the wool industry.[8] An oil sample is soaked into cotton gauze, which is rolled into a cylinder and heated with the internal temperature being tracked by a thermocouple. The original heat source was boiling water, a reliable temperature bath for a 100ºC experiment. Modern modified versions of the test use convection ovens to control the exposure temperature.

The weaknesses of the Mackey Test in general are the short time duration (2 hours) at the low temperature and the effect of packing density on the outcome. More tightly packed specimens will lead to a longer induction time and also may affect the maximum temperature rise. This type of variability could lead to limitations in heat and mass transfer and differing results between seemingly duplicate experiments. However, with a higher temperature and longer duration, this test can qualitatively determine if a contaminant will demonstrate self-heating behavior.

Clothes Dryers and Spontaneous Combustion

Clothes dryers provide a difficult environment for the study of self-heating phenomenon. There are many different models of clothes dryers, both gas and electric. Some of the major differences across the range of models include control settings, thermostat temperature settings, cool-down cycles, loop flow versus axial flow, heater designs, air distributor designs, baffle designs, and drum size. If properly installed and maintained, there will be good mixing of hot air and contaminated garments, which will cause uniform heating of the mass of fabric. After the dryer stops, the piled nature of well-aerated self-heating garments is potentially in a very good configuration to undergo spontaneous ignition.

The shortest radius for heat loss may approach 1/3 of a meter for larger capacity dryers. Most dryers are exhausted to the outside, so household pressure differential can induce very small drafts within the drum when idle that may inhibit self-heating due to cooling effects of ventilation, yet inversely, it may enhance combustion processes once initiated.

In the authors’ experience, inlet air temperatures may exceed 350ºC in the heater box, but drop quickly to operating ranges between 50ºC and 80ºC within the drum. Clothes dryers have several safeguards to ensure that the garment load is not overheated, but if there are multiple failures or poor installation/maintenance practices, there exists the potential to exceed those normal ranges. Perhaps the greatest challenge for the clothes dryer in preventing spontaneous combustion of a contaminated load is the propensity for the user to leave the machine unattended during the drying cycle or after the machine has finished its cycle. Spontaneous ignition may occur anywhere from minutes to hours after the external heating has been applied. The following sections describe the experimental methods and results of modified Mackey Testing to investigate the practical questions posed earlier.

Modified Mackey Test

Thirty-two potential contaminants for a dryer load were identified with the intent of performing a modified Mackey Test to determine with which contaminants and at what concentrations self-heating would become apparent. These contaminants are listed in Table 1.
In this study, four contaminated samples were compared against an uncontaminated reference sample for each run. The data reported for each sample were maximum differential temperature (sample minus reference) and time to reach that maximum temperature.

Experiment

The substrate for the Mackey Test was bleached cotton cheesecloth that met the specifications of UL 2158.[9] The cheesecloth was folded into an eight-ply sheet, with the final cheesecloth sheet measuring 10 cm wide by 69 cm long. The approximate mass for this size of cheesecloth sheet was 20 g. A specified amount of the chemical contaminant was added to the bleached cheesecloth sheet, which was then rolled tightly to form a 4-cm diameter cylinder. The prepared specimen was then mounted in a stainless-steel mesh sample cell to ensure consistent diameter and packing density for each test. The reference packing density was therefore 0.16 g/cm3 for the samples. Five sample cells were used for each run. A Type K thermocouple probe was inserted into the center of each roll of cheesecloth, along its axis, with its tip at the midpoint of the sample. These five cells were placed on the same shelf in a pre-heated convection oven, typically at 125ºC, with the reference cell located in the middle and a 1-inch gap between cells.

Cooking Oils	**Petroleum Products**
Sunflower Oil	Gasoline
Soybean Oil	Coleman Fuel (Camp Stove)
Peanut Oil	10W-30 Engine Oil
Vegetable Oil	Wheel Bearing Grease
Extra Virgin Olive Oil	Power Steering Fluid
Canola Oil	Diesel Fuel
Corn Oil	Brake Fluid
	Used Motor Oil

Laundry Products	**Personal Care Products**
Tide Free Liquid Detergent	Personal Warming Liquid
Tide with a touch of Downy	Massage Oil Mist
Tide with Bleach Powdered Detergent	Bath & Body Works Aromatherapy
Bounce Fabric Softener Sheet	Orange Ginger Massage Oil
Downy Liquid Fabric Softener	Baby Oil

Oxi Clean (50% Sodium Percarbonate) Clorox Regular Bleach Liquid	
Pool Care Product	**Painting/Finishing Products**
HTH Super Sock It (60% Calcium Hypochlorite)	Polyurethane Minwax Wood Sheen Rubbing Oil Boiled Linseed Oil Latex Paint Enamel Paint

Table 1. Chemicals for Mackey Tests

Discussion of Results

Results from the Mackey Test can be used to evaluate two main effects: the relative self-heating potential across the various contaminants and the influence of concentration effects on the self-heating behavior. The obvious shortcoming of the Mackey Test is that it is only indicative of self-heating behavior under a very specific set of parameters. These parameters are not representative of conditions found in household dryers. While the Mackey Test can give a relative gauge of the self-heating potential across a variety of contaminants, it does not guarantee that dryer loads contaminated with these same chemicals will also self-heat to the point of ignition. Factors such as the temperature cool-down profile of the dryer as well as the packing density of the load and size cannot be mimicked via the Mackey Test. As such, the Mackey Test is a poor predictor of those conditions necessary to obtain self-heating to the point of ignition. It is, however, ideally suited for screening purposes. A list of common household chemicals was initially compiled for screening (see Table 1). These fell into the following six main categories, with the number of representative samples in parentheses: cooking oils (7), laundry products (7), petroleum products (8), personal care products (4), painting/finishing products (5), and a pool care product (1). The results of the Mackey Test runs are shown in Table 2 through Table 6. The tables have been abbreviated to depict only vegetable-derived oil results and other contaminants that demonstrated significant self-heating. (A full copy of the data tables is available in the complete online version of this article or by contacting the primary author.) The oil or contaminant loading for the tests is reported here as a percentage of the initial dry weight of the cloth or cheesecloth sample. In most cases, oil loadings were 10 percent, 25 percent, 50 percent, and 100 percent. While the large number of screening runs prohibits the display of temperature profiles for each individual run in this paper, representative samples from each class of contaminant studied are shown in Figures 1 through 5. In general, samples tested from the same category of material displayed similar self-heating characteristics. In many cases, this behavior was traced back to similar functional groups involved in the chemistry of self-heating (i.e., the cooking oils, drying oils, hydrocarbon/fuels) and/or the presence of a common chemical ingredient (i.e., the massage oils). Under the conditions tested, self-heating to the point of ignition was not displayed by any of the laundry products, petroleum products, detergents and oxidizing cleaner, or the pool care product. In many cases, the lack of a strong exothermic reaction allowed other physical phenomena such as thermal lag and/or evaporative cooling to be observed (see Figures 1, 2 and 3). Cooking oils, massage oils and drying oils displayed self-heating behavior under the experimental testing conditions. This is evidenced by the large positive temperature differentials observed in Figure 4 and Figure 5, for linseed oil and sunflower oil, respectively. All of the massage oils contained sunflower oil, among other essential oils, as a component. In both plots, a minimum concentration of contaminant is necessary in order to obtain sufficient self-heating to the point of ignition. Too little contaminant results in a completion of various oxidation/exothermic reactions prior to ignition being obtained. Linseed oil showed the highest potential for self-heating of all the chemicals tested. An interesting result was apparent in many tests: greater contamination did not lead to more intense combustion or earlier ignition. This may be due to the increased difficulty of oxygen transport, which is necessary for the exothermic reaction to occur. Additional experiments were run using sunflower oil to determine the sensitivity of results to oven temperature. The results are summarized graphically in Figure 6 and Figure 7. Mackey Test operating conditions were such that variations in temperature of 20°C as well as changes in concentration could produce drastically different self-heating performance. For instance, in Figure 6, at 80ºC, a change in mass loading from 25 percent to 50 percent changed the behavior from no self-heating whatsoever to sufficient self-heating to cause ignition. Furthermore, a test run at 100°C showed substantial thermal damage to samples with mass loadings greater than 5 percent. Increasing mass concentrations resulted in no significant change in the time delay until maximum temperature for concentrations above 5 percent to 10 percent (see Figure 7). Across all the cooking oils, similar behaviors were observed (see Figure 8).

Figure 1 | Figure 2 | Figure 3 | Figure 4 | Figure 5 | Figure 6 | Figure 7 | Figure 8

Table 2. Mackey Test
Table 3. 4. 5. Mackey Test

Conclusion

The Mackey Test yielded an extensive list of chemicals that could potentially self-heat in a dryer and lead to spontaneous ignition. Vegetable oils, massage oils and drying oils definitively self-heated to the point of ignition. Some of the other chemicals did self-heat, yet did not spontaneously ignite under the 125ºC conditions of the test. Of the laundry products, only the solid bleach product exhibited self-heating behavior.

The next installment of this paper will discuss a series of full-scale clothes dryer tests with contaminated loads. The dryer tests provided insight into the problem of self-heating to ignition by a contaminated load in a clothes dryer. The level of contamination and the boundary conditions for the individual tests controlled the likelihood of ignition in those dryer tests. These tests will be described in detail in a paper to be published in the July 2006 issue of APPLIANCE.

Spontaneous Combustion Tendency of Household Chemicals and Clothes Dryers-Part 2

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