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

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The following is the second installment of the edited version of the 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.

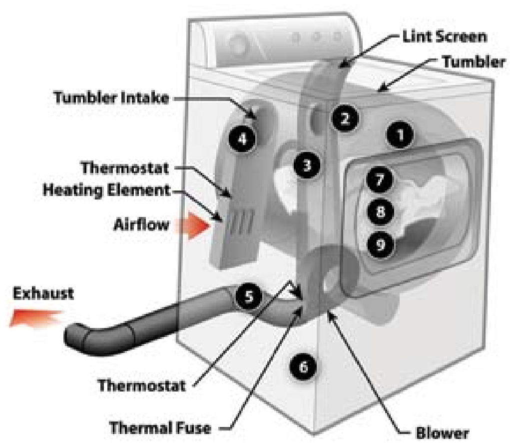

Figure 1. Probe locations are as follows: (1) drum front air temperature, (2) outlet air temperature (lint screen), (3) drum back air temperature, (4) inlet air temperature after heating element, (5) outlet exhaust temperature, (6) lower cabinet temperature, (7) top of load, (8) middle of load, and (9) bottom of load.

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

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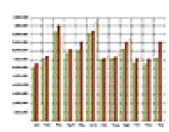

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loads. If the combustible load generates more heat than it loses to the environment, the temperature may rise high enough to initiate smoldering combustion that can subsequently lead to a fire involving the dryer.

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 the second installment of a study of potential contaminants for garment loads. Their self-heating propensity was evaluated using a modified Mackey Test procedure in the first installment of this paper.[1] The time-temperature histories for these tests were analyzed to yield characteristics of self-heating contaminants and to identify important variables in the clothes dryer that may mitigate self-heating of contaminated loads. As a result of those Mackey Tests, full-scale self-heating tests in clothes dryers were performed. This paper describes those tests and gives conclusions of the overall program.

Dryer Tests

Based on the results from Mackey Testing, full-scale dryer tests were focused on three liquid contaminants: sunflower oil, vegetable oil and boiled linseed oil. Towel loads were contaminated with these oils and run through a timed dry cycle then left idle to watch for self-heating. It proved difficult to get loads to heat to ignition in these tests with sunflower and vegetable oils; out of nine tests, only one ignited.

Experiment

The dryer used for this testing was a Whirlpool Model LER8648LW1 (240 V, 28 A), which is equipped with a wide-opening, hamper-style side door. This was a loop-flow type dryer, where hot air enters the drum at the top left rear (facing dryer) and exits through the lint chute at the top right rear of the drum. Tests were run using a load of either 33 or 66 cotton towels. The towels were nominally 22-inch by 34-inch, double-hemmed, cotton towels (approximate weight of 100 g each) purchased from Textile Innovators and met the specifications for UL 2158.[2] Prior to testing, all towels were washed in hot water using liquid detergent (Tide Free, Proctor and Gamble) and were then dried. The dryer drum had a volume of 7.6 cubic feet (0.21 m3), with a length of 22 inches (56 cm) and maximum diameter of 27.5 inches (70 cm). The drum is not a perfect cylinder, so the effective diameter based upon axial length is 24 inches (62 cm). A loosely tumbled load of 33 towels was piled to an average height of 14 inches (36 cm), leading to a packing density of approximately 0.030 g/cm3. A loosely tumbled load of 66 towels was piled to an average height of 19 inches (48 cm), leading to a packing density of approximately 0.042 g/cm3. These values are five times smaller than the packing density of the Mackey Test (0.16 g/cm3).

Depending on the individual test, a select number of sheets from the load were partially/fully soaked with the oil to be tested. Test cases were run by contaminating the following: dry towels prior to washing, wet towels after washing and dry towels without washing. Following contamination, towels were either immediately returned to the dryer or washed in a Whirlpool Model LXR7244PQ0 top-loading washing machine. For hot water washes, the water source temperature was 38ºC.

The temperature within the operating and idle dryer was monitored at several locations during each test. Nine Type K thermocouple probes were numbered and positioned at various locations throughout the dryer for this purpose, as depicted in Figure 1. Probes 1 through 6 were permanently installed at fixed locations within the dryer. Insertion of probes 7 through 9 was performed at the conclusion of the dryer cycle. The dryer was stopped prior to the cool-down portion of its cycle, and probes were quickly inserted while trying to minimize heat losses and

pile disturbance.
The end of the heating cycle was determined based on temperature data from thermocouples probes 2 and 4, corresponding to the outlet and inlet air temperatures, respectively. Timing was selected to coincide with the peak of the dryer temperature cycle as determined by probe 4 and probe 5. Under normal operating conditions, the maximum dryer inlet temperature was determined to be 300°C to 350°C.
Probe 2 was used to ensure that the number of heating cycles was sufficient for the towels to reach their maximum temperature. The outlet air temperature typically peaked to 65°C to 70°C, although later attempts to circumvent thermal protection devices resulted in higher temperatures. In many cases, probe 8 was bunched with several, if not all, of the contaminated sheets before being placed in the center of the dryer load. A typical operating and cool down temperature history is provided in Figure 2.

Discussion of Results

Table 2. Maximum Pile Temperatures without Self-Heating

Run	Max T (°C)
1 (33 towels)	76
8/11 (66 towels)	80/76
13 (66 towels, blocked exhaust)	57
14 (66 towels, thermostat removed from duct)	96
16 (66 towels, thermostat electrically bypassed)	100

A total of 16 dryer tests were performed. Conditions for these tests are listed in Table 1. Of these, three tests were observed to exhibit self-heating to the point of ignition. The various runs are summarized in the table.

Linseed Oil

Run 2: No Washing Post Contamination

After washing 33 towels, one labeled towel was removed and soaked with 51.6 g of linseed oil. This was re-inserted into the center of the load and the dryer was set to Timed Dry, High Heat. The load was dried to completion (~1 hour), and probes 7 to 9 were inserted.
Approximately 1 hour later, a small quantity of smoke was observed coming from the rear of the dryer unit, which gradually increased in intensity. Upon opening the dryer door, a thick, acrid yellow smoke rolled out. All towels in the load were observed to be yellow in color, indicating a dispersion of the linseed oil away from the initially contaminated towel. Seconds afterward, the load was observed to transition to flaming at the backside of the drum.
Figure 3 shows the temperature profile at the center probe (Probe 8), during the self-heating phase of the test. For reference, a typical cool-down curve for a non-contaminated towel load is also shown. Although the contaminated towel was mostly consumed, a significant portion of the load was undamaged during this test.

Run 3: Wash with Hot Water Post-Contamination

Four towels were selected and pre-labeled. All 33 towels were then washed, and each towel was weighed afterwards to obtain an average weight for the spun-dry, washed towels. The load was dried to completion, and four pre-labeled towels were each contaminated with ~100 g (400 g total) of linseed oil. Following contamination, the entire load was washed using hot water at the “normal” load setting. Each towel was weighed once more after the wash cycle.
After washing, the four contaminated towels did not show observable discoloration due to linseed oil, and weight comparison revealed various amounts of linseed oil contamination remaining. Values of 5.7

g, -6.7 g, 3.5 g, and 1.6 g were obtained when compared to the earlier just-washed towel weights of the four pre-selected towels. For the remaining 29 towels, an increase of 1.2 g in the average towel weight was noted. Given the variance in the towel weights (+/-3.3 g), however, the statistical significance of this change is indeterminable. Upon drying the load to completion,
two of the four pre-selected towels were removed and re-bunched together surrounding probe 8. The resulting temperature profile is shown in Figure 3. The slight increase in the temperature profile following thermocouple equilibration is indicative of self-heating. As shown, however, the run conditions failed to result in ignition of the dryer contents.

Run 4: Wash with Cold Water, Post-Contamination
Experimental Run 3 was duplicated, with the only significant difference being the use of cold water in the wash and rinse cycles.
Following washing, re-deposition and cross-contamination of linseed oil on clean towels was noted by visual inspection on nine previously clean towels while originally contaminated towels remained yellow in color. This is unlike Run 3, wherein no distinct yellow color was observed on any of the towels following washing. A comparison of the average just-washed weight for the towel load reveals a statistically significant amount of contaminant remaining following washing (167.3 +/-5.0 g versus 160.6 +/-3.3 g for the control). Two of the four contaminated towels were set aside to air dry during the active dryer test; these showed a net weight gain of 7.6 g and 27.8 g of oil that was not removed during the cold wash cycle. The other two towels were dried with the remaining 29 towels in the dryer.
Unlike Run 3, the temperature within the center of the pile continued to rise after the cycle had concluded. An acrid odor was apparent near the dryer prior to observing smoke. Smoke was eventually observed coming from the rear of the dryer unit. The test was terminated shortly after the center pile temperature exceeded 400ºC (see Figure 3). As towels were removed from the drum (approximately 3 minutes after door was opened), flaming ignition was observed. The delay required for the pile center to reach 400ºC was double that of Run 3, which may be attributed to the lower residual quantity of linseed oil that remained after washing.

Table 1. Dryer Test Run Description

Sunflower Oil/Vegetable Oil Testing
Initially, similarly to Run 2, Run 5 used 33 washed towels, with a subset of four towels contaminated with 50 g of sunflower oil. This test failed to result in self-heating behavior; the temperature dropped comparably to control runs. As listed in Table 1, several increasingly aggressive variations were then attempted, which can loosely be categorized by increases in contamination (Runs 10, 12, 15, and 16), bypassing of the control thermostat and thermal fuse (Runs 7, 15 and 16), and attempts to increase heat retention, either through external preheating of the towels or through increasing the towel load (Runs 9, 10, 12, and 15-17). Doubling the pile size did not affect the maximum temperature of the pile, but did delay the cool down of the pile center significantly. As shown in Figure 4, doubling the number of towels did not affect the ultimate rate of cooling, yet created an offset of approximately 30 minutes (i.e., it took 30 minutes longer for the pile to cool from 75ºC to 35ºC). The maximum pile temperatures (without self-heating) for the various options are listed in Table 2.
As evident from these variations, temperature conditions under normal operation were insufficient to result in an ignition scenario for the vegetable oils in these tests. Only by bypassing the thermal safeguards altogether (Run 16) was a higher initial drum temperature obtained (100°C), which was sufficient to lead to spontaneous ignition. Prior to

ignition, oily water condensate was observed running down the exterior of the dryer door. Additionally, an intense, acrid odor was present near the dryer for several minutes prior to ignition. Ignition was observed approximately 110 minutes after probe insertion (see Figure 5).

Conclusions

The Mackey Tests described in the first installment of this paper [1] 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 products 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.

Given the abundance of literature to this effect, it is not surprising that linseed oil was found to be capable of undergoing self-heating to the point of ignition. The efficacy of the liquid detergent in removing the linseed oil was significantly impacted by the temperature of the wash/rinse cycles. Based on visual observations and measurements of changes in weight after washing, efficacy of linseed oil removal is quite poor when using cold water. Moreover, a secondary effect of washing under these conditions was cross-contamination of remaining towels in the load. From a safety standpoint, washing with hot water is recommended.

Unlike linseed oil, ignition of the selected cooking oils in dryer testing required much more aggressive conditions. Even without washing the towels post-contamination, an ignition scenario under normal dryer operating conditions was not observed in these tests.

At this point, it is relevant to list many of the potential variables in this testing and for the problem, in general, which may inhibit or promote spontaneous heating to the point of ignition within a clothes dryer. Small changes to these variables will likely affect the success or failure of spontaneous combustion. The complex problem as defined in this work is affected by (at least) the following:

- Type of contamination (e.g., virgin soybean oil versus soybean oil used to fry food)
- Amount of contamination (i.e., size of “hot spot” within the pile)
- Dispersion of contaminant within the pile (e.g., spread out versus confined to one garment)
- Size of pile, type of garment(s) and fabric composition
- Clothes dryer geometry, age and model (i.e., heat loss from the appliance)
- Clothes dryer environment (e.g., large room versus closet, ventilation, ambient temperature, etc.)

In the current tests, the maximum pile temperature was found to be the most significant factor in determining whether self-heating to the point of ignition would occur. The size of the wadded contaminated towel(s) was not controlled/measured so the pile temperature and ambient temperature turned out to be the best-measured variables available for correlating self-heating behavior. Only by bypassing the thermal safeguards on the dryer under these conditions were sufficiently high drum temperatures attained to result in ignition.

It should be noted that this dryer was not installed in a way to mimic residential use. External heat losses would be significantly higher in the current test configuration than in a typical residential installation due to the volume of the enclosure, leakage through the overhead exhaust fan, and an ambient temperature of 16ºC to 22ºC during the various tests. If these heat losses were reduced, for example, by using a mock-up laundry room, the minimum drum temperatures necessary to lead to spontaneous combustion would likely decrease. If the size and geometry of the wadded contaminated towel(s) at the center of the pile were controlled, it would also lead to more predictable results. A number of other scenarios could be envisioned based upon the experimental variables noted in the previous list.

One interesting observation noted in each of the runs with ignition was the redistribution of the contaminant throughout the load. Even in cases where contamination was initially localized to a few select towels, the high internal temperature due to self-heating was sufficient to result in vaporization and re-deposition of the contaminant throughout the load prior to ignition. Whether or not this phenomenon facilitates bulk self-heating, however, is under continued investigation. This effect may also hold some promise in the detection of oil residue after spontaneous combustion of a load.

All of the oils released a sharp, burning acrid odor long before visible smoke was emitted from the dryer. As a practical matter, users should realize such fumes indicate a potential fire hazard. The Consumer Product Safety Commission (CPSC) has issued a warning, Safety Alert 5022, to publicize this hazard.[3]

This test program was successful in identifying and categorizing household contaminants that could lead to spontaneous combustion of a clothes dryer drum load through use of a modified Mackey Test. The dryer tests successfully demonstrated that spontaneous combustion of drum loads contaminated with vegetable oils was possible under a specific set of parameters. While a substantial amount of fire investigation results support spontaneous combustion of drum loads, limited empirical data currently exists in the literature that is directly useful in predicting the occurrence of the phenomenon. The findings of this test program indicate that further work is necessary for determining the range of contributing factors to the clothes dryer spontaneous combustion problem.

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

References

[1] Morrison, Delmar, Yee San Su and Mark J. Fecke, "Spontaneous Combustion Tendency of Household Chemicals and Clothes Dryers," APPLIANCE magazine, Vol. 63 No. 6, pp 36-41 (June 2006).
[2] UL 2158 Electric Clothes Dryers, Section 4.3, page 20A (May 24, 2004).
[3] CPSC Safety Alert 5022: Overheated Clothes Dryers Can Cause Fires (June 2005)

Suppliers mentioned in this article:
• Whirlpool Corporation