Cigarette Ignition of Soft Furnishings

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ABSTRACT

Changes in the propensity of cigarettes to ignite upholstered furniture and bedding could reduce fire losses significantly. This paper describes fundamental and empirical studies of the effect on ignition propensity of varying cigarette characteristics. Reduced tobacco density, circumference and paper porosity were especially effective. Energy transfer from the cigarette to the substrate was measured and relationships between cigarette combustion behavior and ignition propensity were explored. Using these data, computer modeling of the cigarette on a substrate manifested key features of the ignition process. A fully-documented technical report is available. [1]

INTRODUCTION

Cigarette ignition of upholstered furniture and mattresses is by far the single leading cause of fire deaths in the United States. For the 600 B cigarettes sold annually [2], the probability of one being dropped, igniting soft furnishings and leading to a death or injury is small. Yet in 1984, 49,000 cigarette-initiated fires resulted in 1,530 deaths, 7,000 serious injuries, and $320 million of destroyed property. [3]

Extensive efforts have been devoted to reducing the susceptibility to cigarette ignition of both upholstered furniture and mattresses. A mandatory standard for mattresses [4] and voluntary standards for upholstered furniture [5,6] have led to manufacture of less readily-ignited soft furnishings. Yet, even these highly-productive efforts are not enough to end the losses from cigarette-initiated fires quickly. These commodities have average lifetimes of about fifteen years [7], so the full impact of the improved furniture on fire safety will not be realized for decades to come. By contrast, cigarettes are consumed within a few months of their production, leading to the possibility that fire losses could be reduced sooner if the cigarette were suitably modified.

This paper describes a major project to measure and model the impact of changes in cigarette traits on the ignition of upholstered furniture and mattresses. The work was performed under the Cigarette Safety Act of 1984 as part of a program to determine the technical and commercial feasibility, as well as the economic impact, of developing less ignition-prone cigarettes. Reports on the complete program are available.

Cigarette ignition of furniture occurs when the burning cigarette heats the furniture fabric or padding to the point where it begins to smolder (Figure 1) Therefore, a less ignition-prone cigarette must generate le heat (i.e., burn less fuel), restrict access of oxygen to the fuel, or heat the fabric less efficiently.

A cigarette is a cylinder (column) of tobacco strips wrapped in paper, usually with a filter tip at one end. A cigarette can be described by the type of tobacco, the density of that tobacco in the column, the length and circumference of that column, the thickness and porosity of the wrapping paper, and any additives to either the tobacco or the pape The tobacco density may be decreased by expanding the volume of the tobacco strands and by cutting them wider. Citrates are conventionally added to the paper to produce an even, clean-appearing burning. This description suggests a number of cigarette characteristics for variatio

APPROACH

The work reported here ranges from basic research into the physics of t ignition process to highly empirical studies of the manifest cigarette features affecting ignition.

An inexpensive, rapid procedure was adopted for evaluating a variety of test cigarettes on a range of substrates.[1] The bench-scale mockups of furniture (Figure 2) that were used also provided a link to the bulk of previous testing of this ignition process. [8,9] To assess the validit of the mockup tests, some experiments were run using mockups and chairs made of the same materials.

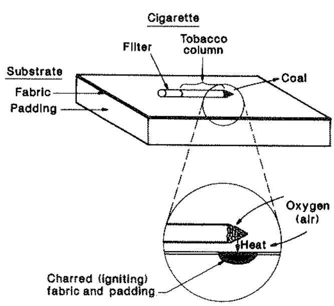

Figure 1. Cigarette Ignition of Upholstered Furniture.

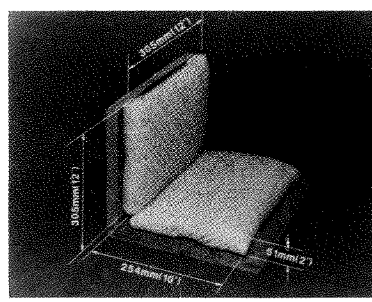

Figure 2. Furniture Mock for Ignition Testing.

[1]The term "substrate" is used to characterize a piece of upholster furniture, a mattress, or a laboratory mockup of one of these. It mean one combination of a specific fabric and padding, in either a flat or crevice configuration, with or without a cover sheet. (The cover sheet simulates, e.g., a sheet pulled over the real-life dropped cigarette.) For example, one substrate would be the flat area of a piece of polyurethane foam covered with an olefin fabric, with the cigarette covered by sheeting. The flat area with the same materials, but with tl cigarette not covered would be a different substrate.

Twelve commercial cigarette types were chosen that fit the following criteria: (1) high, low, or middle expected ignition propensity; and/or (2) large market share. The cigarettes were supplied by their manufacturers without brand identification and were designated numbers 1-12. With much difficulty, substrates were found that would differentiate among the ignition propensities of these twelve cigarettes, indicating that the differences in ignition propensity among these commercial cigarettes were small. [10]

Forty-one types of experimental cigarettes were specially prepared for this study by the cigarette industry. They varied in tobacco type and density, paper permeability and citrate content, and circumference. The wrappers and fillers were selected for systematic and broad property variation, not necessarily indicative of current commercial cigarettes. Detailed descriptions of the cigarettes' physical and combustion properties were provided or obtained.

Table 1. Description of Experimental Cigarettes

No.	Tobacco	Tobacco Density	Paper Porosity	Citrate Added	Circumference (mm)	Second Paper Wrapping[c]
101	Burley	High	Low	Yes	21	No
102	Burley	High	Low	No	21	No
103	Burley	High	High	Yes	21	No
104	Burley	High	High	No	21	No
105	Burley	Low	Low	Yes	21	No
106	Burley	Low	Low	No	21	No
107	Burley	Low	High	Yes	21	No
108	Burley	Low	High	No	21	No
109	Flue-Cured	High	Low	Yes	21	No
110	Flue-Cured	High	Low	No	21	No
111	Flue-Cured	High	High	Yes	21	No
112	Flue-Cured	High	High	No	21	No
113	Flue-Cured	Low	Low	Yes	21	No
114	Flue-Cured	Low	Low	No	21	No
115	Flue-Cured	Low	High	Yes	21	No
116	Flue-Cured	Low	High	No	21	No
117	Burley	High	Low	Yes	25	No
118	Burley	High	Low	No	25	No
119	Burley	High	High	Yes	25	No
120	Burley	High	High	No	25	No
121	Burley	Low	Low	Yes	25	No
122	Burley	Low	Low	No	25	No
123	Burley	Low	High	Yes	25	No
124	Burley	Low	High	No	25	No
125	Flue-Cured	High	Low	Yes	25	No
126	Flue-Cured	High	Low	No	25	No
127	Flue-Cured	High	High	Yes	25	No
128	Flue-Cured	High	High	No	25	No
129	Flue-Cured	Low	Low	Yes	25	No
130	Flue-Cured	Low	Low	No	25	No
131	Flue-Cured	Low	High	Yes	25	No
132	Flue-Cured	Low	High	No	25	No
201	Flue-cured	Low	Very Low	No	21	No
202	Flue-cured	Low	Very Low	No	25	No
203	Flue-cured	Low	Very Low[a]	No	25	No
204	Flue-cured	Low	Very Low[b]	No	25	No
205	Flue-cured	Low	Very Low[a,b]	No	25	No
206	Flue-Cured	Low	Very Low	No	25	Yes
207	Flue-cured	Low	Very Low[a]	No	25	Yes
208	Flue-cured	Low	Very Low[b]	No	25	Yes
209	Flue-Cured	Low	Very Low[a,b]	No	25	Yes

[a] Electrostatically perforated to "high" permeability after manufacture.
[b] Embossed (to separate the burning tobacco from the substrate)
[c] Two paper layers; inner wrap is extremely porous.

To test these experimental cigarettes, fabrics and padding materials we selected to represent furniture having a range of susceptibility to cigarette ignition. These included some of the most ignition-prone materials available.

Table 2. Materials Used in Ignition Measurement

Fabrics	Paddings
California Standard cotton velvet	Cotton batting (untreated
Blue Denim, cotton	Polyurethane foam
"Splendor," plain weave cotton	
"Haitian" (heavy, raw) cotton	
Heavy velvet	
Cotton duck	
Damask	
Olefin, backcoated	

Five embodiments of cigarette patents were received from their inventor Each was accompanied by "controls," i.e., supposedly identical cigarettes, but without the patented feature. The five patented design features, as provided by the patent holders, were:

- Very low porosity, high weight paper with a high citrate leve then electrostatically perforated to a high porosity;
- Sodium silicate added to 5 mm in the center of the tobacco ro
- Two 6.5 mm bands, 15 mm apart, of low porosity paper attached at fixed intervals to the inside surface of the cigarette wrapper, which has a medium porosity and 0.8% sodium potassiu citrate;
- Application to the exterior paper surface of a water suspensi containing non-fat dry milk and mono-ammonium phosphate; and
- Addition to the tobacco column of an intumescent silicate.

The compositions of the patented cigarettes and their controls were not verified. All these cigarettes and their controls were tested in the same manner as the cigarettes above, including some more ignition-prone substrates.

In all tests, the ignition criterion used was a clear appearance of ignition, confirmed by a significant weight loss of the cigarette/substrate assembly. The testing included both flat and crevi configurations. At least five replicate tests were performed for each cigarette/substrate combination. The data were statistically analyzed for correlations between numbers of ignitions and the individual cigarette characteristics.

Similar testing was performed on chairs manufactured of some of the sam materials, and the data analyzed to determine the extent to which these full-scale results were predicted by the bench-scale tests. In additio samples of some of the materials and cigarettes used were sent to the California Bureau of Home Furnishings for testing to determine interlaboratory reproducibility of these results. [11] Moderate and easy-to-ignite substrates were used.

The ignition process depends on the energy transfer from cigarettes to furniture items. This was studied using fine thermocouples and a heat flux gauge to follow the temperature and energy flux histories while cigarettes smoldered on different substrates. Two-dimensional infrared imaging radiometry was used to map the thermal response of the substrate. Graphical correlations were explored between measured properties of the burning cigarettes and their measured ignition propensities.

Both fundamental and semi-empirical mathematical modeling of the lit cigarette and ignition of the substrate were pursued. Each borrowed heavily from prior efforts elsewhere. A comprehensive list of the involved materials properties and physical processes was compiled. Substantial simplifications were made in representing these. The predictions from the resulting FORTRAN programs were tested, to a limited extent, against the trends observed in the laboratory tests.

Finally, the experience and knowledge gained from the above research were applied to the task of developing a convenient, accurate test method for cigarette ignition propensity. Several previously-suggested and new approaches were analyzed and tested in the laboratory, but the development of a viable test method has not yet been completed.

RESULTS

The principal findings of this research are as follows.

1. In furniture mock-up tests involving a wide range of fabrics and paddings, the best of the experimental cigarettes tested had considerably lower ignition propensities than commercial cigarettes.

Table 3. Ignition Propensities of Selected Test Cigarettes

	Designation	No. Ignitions 20 Tests	%
Experimental Cigarettes			
	201	0	0
	106	1	5
	202	2	10
	130	4	20
	114	4	20
	105	6	30
	113	6	30
	108	7	35
	122	7	35
	129	10	50
	107	11	55
	120	20	100
	127	20	100
Least Ignition-Prone Commercial Cigarettes			
	1	16	80
	2	12	60
Typical Ignition Propensity Commercial Cigarettes			
	3	18	90
	6	20	100

2. Three cigarette characteristics were found to reduce ignition propensity significantly: low tobacco density, reduced circumference, and low paper permeability. Considerably larger reductions were achiev with combinations of these. The tobacco column length, the presence of filter tip, and citrate content of the paper had effects in limited cases. The tobacco blend had minimal impact on ignition propensity.

Table 4. Ignition Propensity as a Function of Experimental Cigarette Characteristics

Cigarette Parameters	Number of Ignitions/Tests	%
Tobacco Packing Density		
High	282/320	88
Low	153/320	48
Cigarette Circumference (mm)		
25	243/320	76
21	192/320	60
Paper Permeability		
High	256/320	80
Low	179/320	56
Paper Citrate Conc. (%)		
0.8	231/320	72
0	204/320	64
Paper Citrate (%) (Low Ignition Propensity Cigarettes)		
0.8	47/100	47
0.0	23/100	23
Tobacco Type		
Flue-cured	222/320	69
Burley	213/320	66

Non-ignitions were often achieved without the cigarettes self-extinguishing during the test; i.e., many cigarettes burned their full length without igniting the substrate.

3. Some of the best-performing experimental cigarettes had average per puff tar, nicotine, and CO yields comparable to or only slightly greate than typical commercial cigarettes. Possible differences in the composition or toxicology of the smoke delivered by these cigarettes we not investigated.

4. Each of five patented cigarette modifications also showed reduced ignition propensity over their submitted controls and the typical curre commercial cigarettes.

5. The interlaboratory repeatability of the mock-up measurements was excellent.

Table 5. Interlaboratory Comparison of the Number of Ignitions for Various Cigarettes and Substrates (flat surface/uncovered cigarettes; 5 tests each)

Cigarette Number	Cotton Batting California Fabric CFR	Cotton Batting California Fabric BHF	Polyurethane Foam Splendor Fabric CFR	Polyurethane Foam Splendor Fabric BHF
3	5	5	5	5
102	2	1	5	5
105	0	0	3	4
106	0	0	1	1
108	3	4	4	5
114	1	2	3	0
118	5	4	5	5
122	3	4	2	3
126	5	5	5	5
201	0	0	0	0

6. Ignition results from the bench-scale testing correlated very well with corresponding data from the experiments with chairs made with the same fabrics and padding materials.

Table 6. Comparison of Ignition Propensities of Tested Cigarettes at Full- and Bench-Scales

Cigarette Number	Percent Ignitions Bench-Scale	Percent Ignitions Full-Scale
6	74	73
129	13	23
106	3	6
114	6	14
201	0	6

7. The physics of the ignition process is a function of both the cigarette and the substrate. Therefore, an accurate ignition propensity measurement apparatus must involve the two components.

Intrusive probes of the ignition process (e.g., thermocouples, heat flux gauges) perturb the delicately balanced system. The induced errors can be estimated if the probes are small and well-selected. With care, (non-intrusive) infrared imaging can be used to study the thermal profiles on non-igniting or igniting substrates.

8. An approximate correlation exists between the cigarette coal area an ignition propensity. (Figure 3) Peak coal surface temperatures (and thu peak heat fluxes) did not vary sufficiently to demonstrate a correlation with ignition tendency for the cigarettes tested.

Oxygen depletion in the vicinity of the ignition site is important durin the ignition process, but was sufficiently similar for all cigarettes examined so as not to account for their relative ignition propensities.

9. It is possible to construct a complex computer model of the smoldering combustion of a cigarette and the response of an idealized substrate. With all its simplifications, this preliminary model is sufficiently realistic to (1) manifest the most important and most sensitive physical features of the ignition process (Figure 4) and (2) reproduce some of the cigarette characteristics that do and do not affec ignition propensity. Thus, the model could potentially be used to scree possible combinations of characteristics that offer increased fire safety. At present, however, the code for this preliminary model is ver slow and not user-friendly.

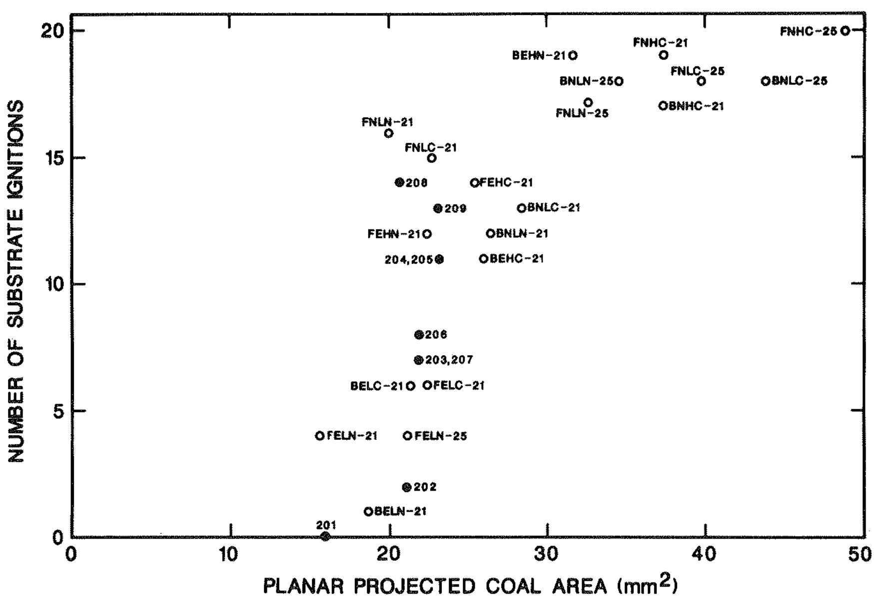

Figure 3. Number of Substrate Ignitions vs. Triangular Estimate of Planar Projected Coal Area.

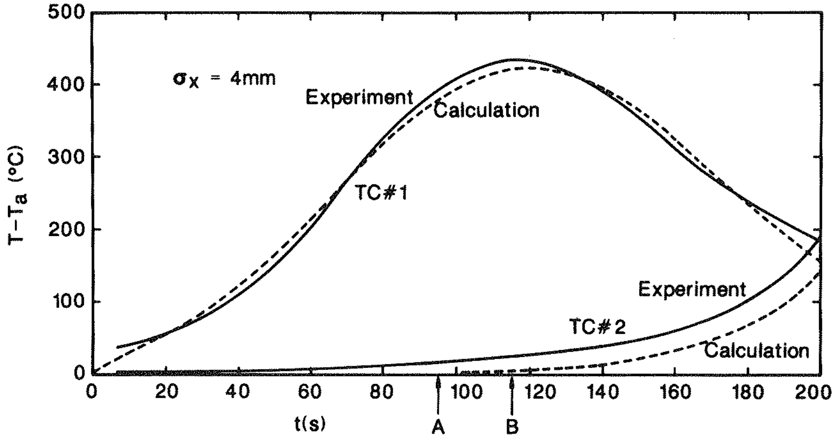

Figure 4. Calculated and Predicted Temperatures at Two Locations in the Substrate as the Smolder Wave from Cigarette 102 Passes Over Them.

10. The current, mini-mockup methods are valid for research measurements of the ignition propensity of cigarettes. However, their use in a standard test method of cigarette performance is compromised by the variability in the commercial fabrics and paddings used in the mockup.

Several alternative candidate test methods for measuring the cigarette ignition propensity of soft furnishings were evaluated; none was usable in its current state of development. Two promising approaches to cigarette testing are proposed. The first modifies the existing mockup procedure using specially-prepared, well-controlled fabrics and paddings. The second uses a non-reactive substrate at variable temperature to determine the minimum needed cigarette heat-loss rate for extinguishment. All need further development before promulgation.

CONCLUSION

This research has identified a number of approaches whose successful pursuit would lead to less fire-prone cigarettes. Prototype computer modeling of the ignition process offers the potential to screen future cigarette designs. Alternatives are proposed for standard measurement of cigarette ignition propensity.

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