FLAMMABILITY OF PLASTICS AND FLAME TEST METHODS

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INTRODUCTION

Use of a single test method in rating flammability of plastics may lead to confusing results when variations in test geometry are ignored. The use of a multiple test method with wide variation in test geometry greatly reduces this problem and allows a better understanding of flammability parameters inherent in plastics systems.

The nature of a relatively simple fire such as a match burning can be observed and studied carefully without various observers agreeing fully on the mechanism of burning. If this simple illustration is extended to a more complex fire, such as a sofa or chair burning, we see many other factors coming into play. As the example is carried even further, to a house or nursing home fire, the act of burning of the individual items is a most complex and baffling phenomena.

To attempt to predict the burning characteristics of plastics or wood or metal by a single test which would be a valid prediction under various condition of burning seems unrealistic. The main advantage is a time saving in testing.

With increased awareness of safety in consumer products resulting from both legislation and publicity, high interest has evolved in the flammability characteristics of plastic materials used in such conventional home products as furniture, mattresses, carpeting, wall covering and appliance housings. In rating flammability of such materials the investigator must choose from a great number of tests recommended by many organizations. These include technical associations, such as ASTM, SPI, SAE; state, local and federal governmental agencies; independent laboratories of Underwriters Laboratories, insurance groups, building code groups and many industrial corporations. Often, however, these tests are designed to measure one particular parameter of flame testing such as ease of ignition, surface flame spread, fuel contribution, or fire endurance. Quite often, the bench scale test may have little resemblance to the logical fire conditions to be expected in the end-use application.

Consequently, flammability test methods for plastics are often misleading in their results. Ideally, a given test should allow the formulator to rank his product as being satisfactory or unsatisfactory according to the degree of flame retardance required in a given application. A single test, however, can rarely satisfactorily rate materials which are routinely used in a variety of complex shapes or in composites with many other materials.

As an example one may consider the wide variation in flame testing geometry inherent in a chair. It is readily seen that the flame may propagate on a number of surfaces at angles to 0 to 360°. Propagation up the back would be 90°, along the top of the arm 0°, under the arm 180°, or down the back 270°. All other angles of burn as well as many combinations are possible. Figure 1 illustrates these flame progation angles. Additionally, in such an article the flame may propagate on the exposed outer surface or, if ignition occurs under a cushion or on the chair bottom, propagation may occur as internal or backside burning. It is evident that the ignition source and point of ignition may greatly influence the behavior of the fire.

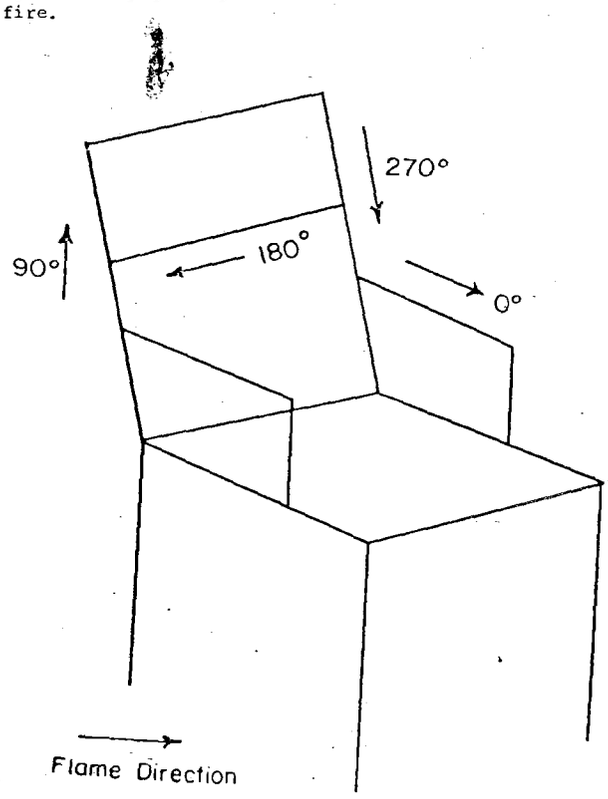


Figure 1. Flame propagation angles in a burning chair.

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Finally, the proximity and use of other materials may greatly affect propagation. A piece of non-flame retarded plastic sheeting will burn readily if unsupported and ignited at 90° with a match. If laminated to a rigid substrate with reasonable resistance to ignition the same film will have reduced propagation and may not ignite under identical conditions.

It is evident that a single test cannot encompass all parameters possible for combustion in a complex article. It is also evident that testing of every parameter would be a costly and laborious process. In actual practice a combination of three or four test methods will generally give a good estimation of the relative flame retardance of a given system[1]. If one is formulating to meet a specific test, of course, these additional test results are valuable as formulation aids to measure incremental changes.

A variety of test methods exist which consider variations in burning conditions.[1,2,3,4,5,6] Figure 2 demonstrates several tests which vary sample geometry. From this it is seen that one can measure the flammability of a sample under a variety of conditions. In general, the most severe condition is that in which the sample is ignited in a vertical configuration (90°). If the sample is mounted in a ceiling position (180°) as in ASTM E-84, equal severity is often obtained. Samples in which the flame propagates away from the surface or propagates downward are less severe providing burning conditions are equivalent.

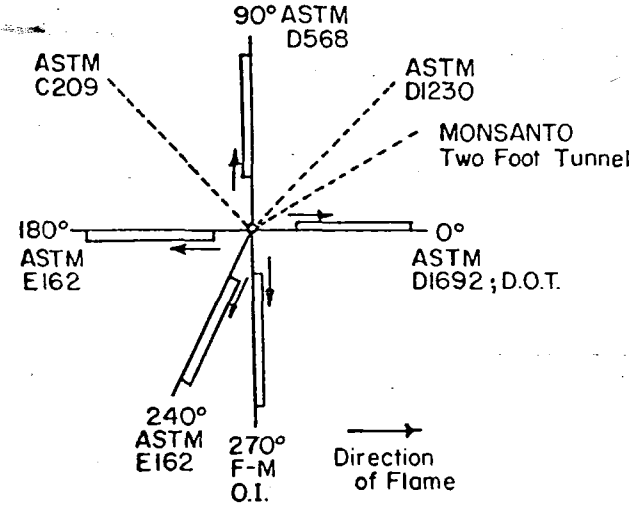


Figure 2. Flame Propagation angles for various flame retardancy test methods.

The Fenimore-Martin oxygen index test[5,6] is an example of a downward burning test. In this test the oxygen content of the atmosphere is raised until the minimum oxygen concentration for combustion to occur is reached. The oxygen index method has been found to be precise, reproducible, and a highly valuable formulation guide. It is important to note, however, that results from this test frequently do not correlate with flame spread results obtained when the bottom of the sample is ignited and the flame propagates upward.

A convenient method of measuring flame spread has been found to be the Monsanto two foot tunnel[4]. In this test the sample forms the roof of a tunnel and is inclined 28° from the horizontal (Figure 3). The spread over a four minute period is measured and a flame rating is determined based on an assigned value of zero for asbestos and one hundred for red oak. In this test the method of mounting the sample is particularly important. A free film of plasticized polyvinyl chloride (PVC) supported by chicken wire will burn much more rapidly than will the same film mounted to a rigid substrate with good thermal conductivity.

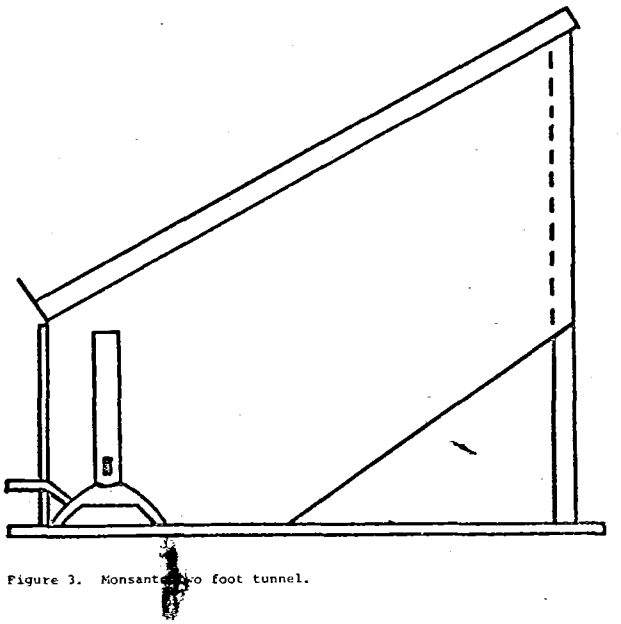


Figure 3. Monsanto two foot tunnel.

Other tests of interest for screening include the methenemine pill test[8] and the proposed Department of Transportation horizontal burn test[9]. In the pill test the pill is ignited on a horizontal surface and allowed to burn. While this test is quite mild on most flat surfaces, it can be of great value when applied to irregular areas as in the right angle formed by a seat cushion and a chair back. The effect is very similar to that caused by a dropped match or cigarette. The DOT test is a method which measures the burning rate of materials in a horizontal configuration. While a useful tool, this test has little correlation to results obtained when the same material is burned in a vertical configuration.

By selecting from these tests, as well as by spot tests such as simply lighting the materials with a match or bunsen burner, it is generally possible to formulate satisfactory flame retardant compositions with a minimum of risk. It also becomes easier to measure incremental changes which might be missed if only one test is used.

In our laboratories, oxygen index, Monsanto two foot tunnel, DOT horizontal burn, and a vertical test (ASTM D-568[10]), are routinely used to screen formulations. Other tests to meet given specifications or accommodate different materials or shapes are added as necessary.

To illustrate the usefulness of multiple tests in formulating, consider an experiment involving flame retarding plasticized PVC of the type normally used in furniture covering. In the experiment incremental

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additions of a flame retardant plasticizer were made to a standard formulation. Oxygen index, DOT horizontal burn, Monsanto two foot tunnel, and vertical burn data were obtained. Samples were milled five minutes at 350°F (176°C) and were calendered into ten mil (0.025 cm) films for testing. The formulations and results are described in Table 1.

Several points are immediately evident. The increase in oxygen index is nearly linear as the concentration of flame retardant phosphate increases. It is also readily seen that the horizontal burning configuration is much less severe than the vertical configuration. In the horizontal test the control burns readily but at a measurable rate (12.5 in./min.). In the vertical

TABLE I

Flame Test Data on 10 mil Unsupported Polyvinylchloride Film

	1	2	3	4	5
PVC Homopolymer (Opalon® 650)	100	100	100	100	100
Di(2-ethylhexyl) Phthalate	70	63	56	49	42
Cresyl Diphenyl Phosphate (Santicizer® 140)	-	7	14	21	28
Ba/Cd Stabilizer	1	1	1	1	1
Epoxidized Soya Oil	3	3	3	3	3
Calcium Carbonate	12	12	12	12	12
Methenemine Pill (Applied to 90° bend)	Ignites	Ignites	Burns Slowly	Does Not Ignite	Does Not Ignite
Oxygen Index	21.6	22.4	23.6	24.1	25.1
Flame Spread (Monsanto Two Foot Tunnel)					
Film Supported on Wire	135	72	64	48	29
Film Laminated to Transite	54	34	26	17	10
DOT Horizontal Burn					
Distance Burned (in.)	10	1.5	0*	0*	0*
Time of Burn (sec.)	48	27	0	0	0
Vertical Burn (5 sec. burner ignition of a 1 x 12 inch sample)					
Distance Burned (inc.)	12	12	6.4*	3.2*	1*
Time of Burn (sec.)	3.6	6.9	6	5	2

* Self-extinguishing results

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TABLE II

Relative Flame Hazards Presented by Films from Table I
In Practical Furniture End-Use

Formulation	Probable Result	Relative Flame Hazard
One (0% Flame Retardant)	Ignites readily, burns violently up back, fire spreads readily across arms and cushions.	Very High
Two (10% Santicizer 140)	Ignites readily, burns readily up back, slower propagation than Formulation One.	High
Three (20% Santicizer 140)	Ignites slowly, propagation up back is slow and may self-extinguish. Little spread across arms or back.	Moderate
Four (30% Santicizer 140)	Does not ignite. Probably only scorchs.	Low
Five (40% Santicizer 140)	Does not ignite.	Low

Santicizer® 140 plasticizer is cresyl diphenyl phosphate.

DSW 587785

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test the rate is so rapid (200 in./min.) as to be nearly explosive. The problem previously discussed of geometry in flame testing is well illustrated by these results.

It is also evident by the tunnel test results that mounting a sample on a rigid substrate effectively lowers the flame hazard particularly if the substrate is high in thermal conductivity with good resistance to ignition. Metal, asbestos board, and wood panels have been effective for this purpose. In many cases, however, the improvement is also seen with rigid plastics which prevent the sample from sagging and hence falling into the much more severe vertical configuration.

From the results it is seen that there is little correlation between tests. A relative correlation does exist between the Monsanto two foot tunnel and the oxygen index test in this experiment as incremental additions gave generally linear results in each case. The only reasonable correlation which can be made, however, is that the flammability of the sample decreases with increasing amounts of flame retardant plasticizer.

This approach is valuable as a guide to formulating for a given application. If a specification is to be met one simply picks the geometry and result closest to that required by the specified test and adjusts the formulation as needed. The data obtained by the other tests guard against a false result. Although this example is based on PVC the same general considerations in testing have been found to be valid in other resins, such as polyurethane, polystyrene, polyolefins, etc.

If no specific requirements must be met the results serve as guides for determining how the material will behave in the application. If the vinyl formulations tested were used to cover the chair previously discussed and if ignition occurs at the junction of the back and cushion with a careless match the performance of each formulation may be predicted (Table II).

Several factors, particularly the flammability of the substrate, can affect the results and for real confidence a full scale test should be run. It is probable, however, that the results will be within the "ball-park." The formulator can then work for the best cost-performance system. In the case in point, as the flammability of the vinyl system would be generally reduced by the normal practice of laminating the vinyl film on cloth, a "safe" formulation might require between fifteen and twenty-five per cent of the flame retardant plasticizer.

An additional advantage of the use of multiple tests is that it allows better comparisons of flame retardant systems between different laboratories. Potentially costly anomalous results seldom escape the cross checks of multiple testing. As an example, although the performance of isodecyldiphenyl phosphate (Monsanto's Santicizer® 148) and trioctyl phosphate in a PVC system may appear almost identical in oxygen index and horizontal burn tests (Table III), in vertical burn and tunnel tests, the flame retardance of isodecyl diphenyl phosphate is far superior to that of trioctyl phosphate. Thus, by routinely using multiple tests, product advantages may be easily found.

SUMMARY AND CONCLUSIONS

It has been shown that reliance on a single flame test method may give erroneous or misleading results. The use of several tests utilizing different geometry will generally reduce these potential errors, and may generate bonuses in the comparison of results or in formulating for other applications.

TABLE III

	1	2
PVC Homopolymer (Opalon 650)	100	100
Di (2-ethylhexyl) Phthalate	42	42
Trioctyl Phosphate	28	--
Isodecyl Diphenyl Phosphate*	--	28
Calcium Carbonate	12	12
Ba/Cd Stabilizer	1	1
Epoxidized Soya Oil	3	3
Oxygen Index	23.3	23.3
DOT Horizontal Burn		
Inches Burned	3.6	3.4
Seconds	48	50
Monsanto Two Foot Tunnel		
Free Film, Flame Spread	97	54
Vertical Burn		
Inches Burned	12	4.5
Seconds	17	3.2

* Santicizer 148

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(5) Fenimore, C. P. and Martin, F. J., Modern Plastics 44, No. 3, 141 (November 1966).

(6) Goldblum, K. B., SPE Journal 25, 50-52 (February, 1969).

(7) Am. Soc. Testing Materials, ASTM Std. 14, pp 358-365 (November, 1967).

(8) Federal Specification FS DDD C-95.

(9) Department of Transportation, Docket 3-3, Federal Register, Vol. 34, No. 249, December 31, 1969.

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