DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER
ATLANTIC CITY, NEW JERSEY 08405
PROPULSION SECTION, NA-542.

January 1969

NA-542

DATA REPORT NO. 51

FLASH-POINT AND THERMAL DEGRADATION OF SELECTED INTERIOR MATERIALS

PROJECT NO. 510-001-11X

John F. Marcy

PURPOSE:

To conduct studies and tests on the thermal characteristics of combustible materials which may be related to the tendency of organic materials to "flash fire" when heated in a closed environment such as an aircraft cabin.

BACKGROUND:

Full-scale fire tests at NAFEC during the period of 1964-65 on a completely furnished DC-7 passenger cabin showed that a catastrophic fire could suddenly erupt from a relatively small seat fire and propagate with great rapidity, as in a gas explosion, throughout the length of a passenger cabin within less than one (1) minute. This phenomenon is variously described as either a "flash-fire" or "flash back." The results of tests on this type of fire were published in Report ADS-44, "A Study of Air Transport Passenger Cabin and Materials." The report confirmed and extended the earlier findings of the Boeing Co. (Test No. T6-2447, "Cabin Fire Mock-up", April 1963). The Boeing test had been completed as part of a general investigation into the causes and nature of the cabin fire on a TWA Boeing 707-187 aircraft, which had burned up on the ramp at the San Francisco International Airport during a maintenance check in Feb. of 1961. Severe and recurrent fire losses of this type have continued to emphasize the deficiencies of current cabin materials and construction to resist fire propagation. Tests conducted at NAFEC during the past two years using regular aircraft urethane seat foam as the only fire load in a closed insulated 640-cu. ft. compartment have invariably produced flash-fire as a normal occurrence.

It would seem safe to assume that the tendency for flash-fire is somehow related to the rapid thermal degradation of the materials represented by weight loss as these become heated to some critical temperature. The large quantitites of hot combustible gases that become liberated at the decomposition temperature of the material apparently escape the immediate area of the fire and begin to accumulate under the ceiling. Then, when these gases have reached a sufficiently high concentration to form a flammable mixture with air, the mixture is ignited by the flames of the fire. The resulting conflagration is especially destructive of the material located on the ceiling and upper sidewalls in direct contact with the flash fire.

DISCUSSION:

The minimum temperature to which a combustible material, either liquid or solid, must be heated to burn with a flame both in the presence (i.e. flash-point) or in the absence (i.e. self-ignition) of an ignition source is generally recognized as fundamental thermal properties of a given material. The apparatus and techniques for obtaining the temperature data for solids was developed at the National Bureau of Standards by N. P. Setchkin (NBS Research Paper RP2052, Dec. 1949). The test method was adopted as a standard by ASTM designated as D 1929-62T. The Setchkin apparatus is also used to establish a non-combustibility rating for construction materials at a maximum temperature of $1382^{\circ} \pm 10^{\circ}F$ as per ASTM E 136-65.

The rate at which a combustible material decomposes, represented as a percentage of weight loss of the original test specimen as the material is heated is also of considerable importance since this is directly related to the flash-point temperature. In fact, this type of test data can greatly facilitate the laborious work required to obtain reliable minimum flash-point temperatures. Such temperatures would always be higher than the temperature at which the material begins to rapidly increase its rate of decomposition and release of gases.

In addition to thermal gravimetric analyses (TGA) as described above, differential thermal analyses (DTA) is usually also carried out on the same materials. The latter is accomplished by a measurement of the heat balance of the materials as it undergoes a change in body temperature. Heat required to raise the specimen to its combustion point (i.e. endothermic) and heat excess released by the specimen as it continues to be heated (i.e. exothermic) are measured by the test apparatus. The type of curve obtained showing a strong exothermic reaction at some temperature should match the flash-point temperature and TGA curves. Discrepancies and lack of better agreement could be expected since all decomposition gases resulting in weight loss are not necessarily combustible, as for example water vapor, hydrochloric gas, sulfur dioxide, etc.

TEST EQUIPMENT AND PROCEDURES:

1. Setchkin's Hot-Air Ignition Apparatus

A cross-section of the apparatus is shown in Figure 1. Fresh air is admitted into the test section proper of the chamber after being heated to the desired temperature by electrical heating elements imbedded in the cylinder wall. Test samples of the material were cut into 3/4-inch square pieces and fastened together to make up a bundle of 3 ± 0.5 grams weight. Thermocouples were used to record both the ambient air temperature surrounding the test specimen as well as its internal body temperature. The specimen was placed in the furnace only after the desired air temperature was reached in accordance with the latest proposed changes in the standard. Initially the test procedure consisted of varying both the furnace air temperature and rate of air flow until it was believed that an irreducible temperature limit had been reached (± 25°F) below which the material would not flash. After testing several materials in this way, an air flow of 6.5 cu. ft. per hour was selected for testing all materials. ASTM - 1929 -

2. DuPont 950 Thermogravimetric Analyzer (Catalog No. 950000)

The apparatus consists essentially of a furnace in which a small test sample of the material (5 to 10 milligrams) is being continuously weighed in air while being subjected to a constant increase in ambient temperature at the rate of 36°F per minute. The test on a number of materials furnished by NAFEC were conducted as part of an evaluation of this apparatus.

SUMMARY OF TEST RESULTS:

A description of the materials investigated is furnished in Table I. The materials listed are typical for the most part of the newer types furnished by various suppliers, with presumably higher heat stability and superior fire resistance than that of the more conventional plastics.

Minimum flash-point and self-ignition temperatures for the materials are given in Table II. Tests were repeated at various furnace air temperatures to approach true minimum temperatures within ± 25°F. The lowest flash-point temperature at 510°F was obtained with the cotton fabric ticking. Other materials with comparatively low flash point temperatures - below 700°F - were the urethane seat foams, both the regular and self-extinguishing types. Of the 27 materials tested, nine materials showed a flash point temperature above 1000°F. The most notable materials in this group were the aromatic polyamides (DuPont Nomex and Monsanto X101) and the the fluorinated plastics (Teflon and ALCAR). In addition, there were seven more materials with flash-point temperatures of between 900°F and 1000°F. Typical heating curves up to the flash-point temperatures for several materials are shown in Figures 2 to 8.

These included the polysulfone thermoplastic, which not only possesses superior fire resistance (i.e. low flame-spread index below 25) but also produces very low smoke (i.e. optical smoke factor D_s of less than 16). Of special interest in this group, were the modacrylics (Verel and Dynel) which have a low flame index and are, as well, self-extinguishing. These materials are presently used extensively in cabin drapery.

Although regular foam is very much more flammable than the flame retardant (FR) variety in the Bunsen burner tests, the behavior of the two materials to increased temperature as shown in Figures 2 and 3 were very similar. Also, the flash-point temperatures were almost identical.

Considerable R&D effort in polymer chemistry has been expended in recent years to produce plastics that can begin to match the performance of some of the lighter metals at elevated temperatures. This has contributed directly to the availability of materials with high flash-point temperatures. Tests on such new materials (Report NA 68-30) have shown that these burn with difficulty, tend to be self-extinguishing within a short burn length and exhibit a low flame-spread index when subjected to the Radiant Panel test.

Weight loss from release of gaseous decomposition products as the temperature environment of several high-temperature plastics was increased is shown in Figures 9 and 10. Rapid degradation of the materials at some critical temperature is displayed by the curves. Thirty percent (30%) weight loss for all materials tested occurred within a range of 900°F to 1200°F. This range of temperature is in general agreement with the flash-point temperatures recorded. All the materials were completely pyrolized at temperatures in excess of 1250°F.

Direct evidence that materials which decompose and release combustible gases at only high temperatures are of definite benefit in minimizing the flash-fire danger has been established elsewhere. Full-scale cabin mock-up tests (See Aerospace Industries Report No. AIA CDP-2, pp. 42-44) have shown that a much higher temperature for flash-fire or flash-over to occur is required with the improved or higher temperature materials. Whereas, flash-fire can occur as low as 600°F to 700°F temperatures in a cabin with conventional materials, the requirement for its occurrence with the improved materials is increased to about 1000°F. Further and more definitive evidence of the relation of combustibility characteristics to flash-fire should be provided by NBS from a test program on model enclosures being conducted for FAA.

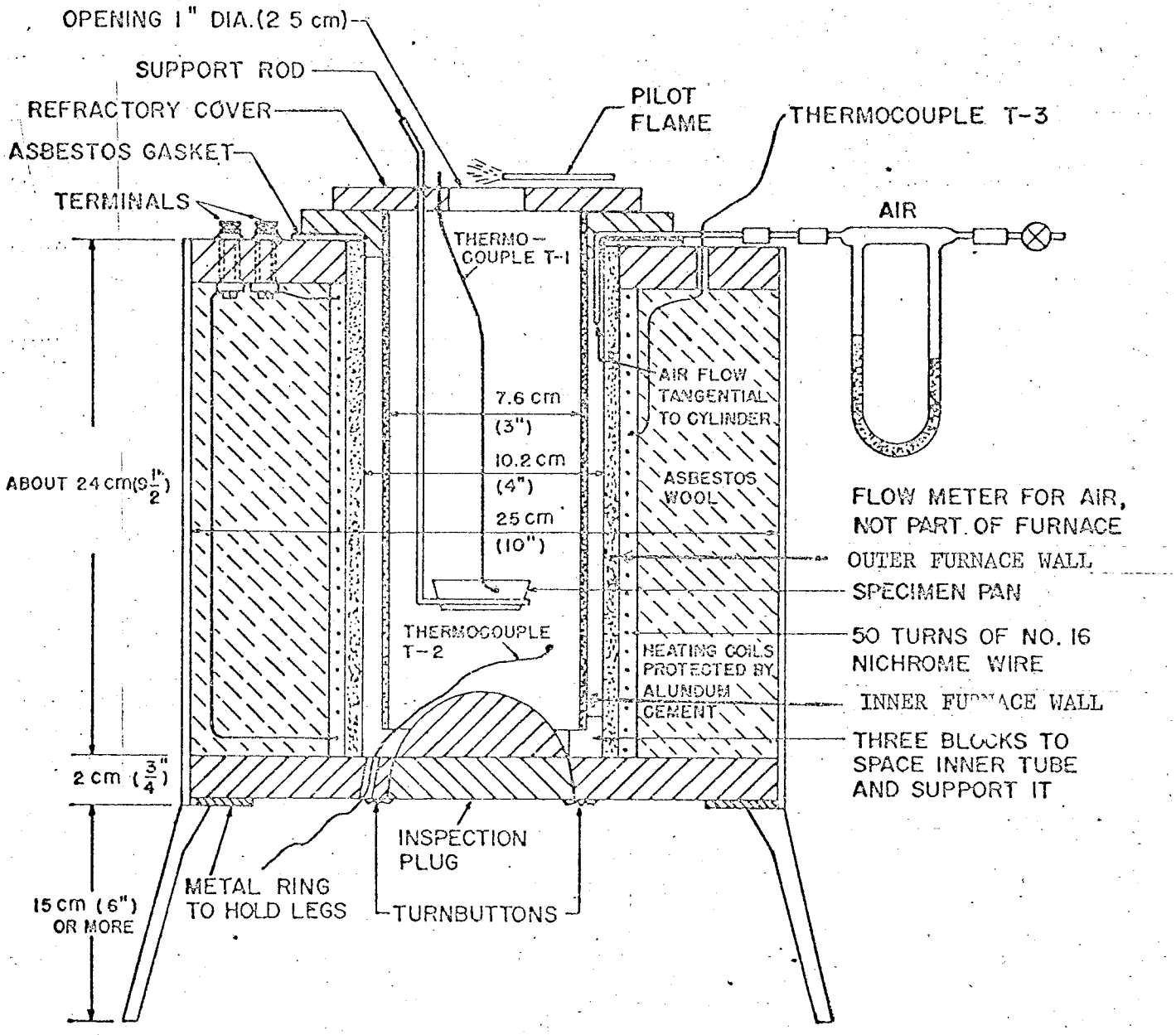

FIG. 1.—Cross-Section of Hot-Air Ignition Furnace Assembly.

TABLE I

MATERIALS DESCRIPTION

Material No.	Code	Thickness (in.)	Weight (oz/yd^2)	Color and Surface	Designation	Intended Use	Composition
28	F-1	.028	8.0	Tan/Gold Trace	Fabric(UC)	Drapery	Modacrylic
56	S-3	.057	55	White Matte	Sheet(R)	Seat panels	PVC/PMMA (90:10)
102	F-1	.015	6.1	Green	Fabric(UC)	Drapery	Polyamide (Aromatic type)
107	F-1	.013	5.8	White	Fabric(UC)	Drapery	Modacrylic (100%)
108	F-1	.013	5.9	Orange	Fabric(UC)	Drapery	Modacrylic (100%)
109	S-3	.080	62	Yellow Glossy	Sheet (R)	Paneling	Poly (phenylene oxide)
112 A	S-2	.060	54	Clear	Sheet (SR)	Fabricated parts	Polysulfone
B		.020	18	Glossy			
116	S-2	.020	17	Tan Smooth	Sheet (SR)	Panel sub-strate	Polyamide (Aromatic type)
118 A	S-1	.002	2.1	Amber	Sheet (F)	High temperature insulation	Polytetrafluoroethylene films over polyimide
B		.005	5.4	Clear			
C		.003	3.5				
D		.005	5.9	Glossy			
121	S-3	.063	64	Tan Smooth	Sheet (R)	Panel Sub-strate	Polyamide (Aromatic type)

TABLE I (CONTINUED)

MATERIALS DESCRIPTION

Material No.	Code	Thickness (in.)	Weight (oz/yd^2)	Color and Surface	Designation	Intended Use	Composition
128	S-1	A 4.0	89	White Open Cell	Foam (F)	Seat padding	Polyether Urethane (FR)
		B 4.0	67	White Open cell			Polyether Urethane
129	S-1	.071	99	Black smooth	Sheet (F)	Elastometer, Seals	Copolymer of Tetrafluoro-ethylene/Vinylidene fluoride
132	F-1	.028	8.7	Green	Fabric (UC)	Drapery	Modacrylic and Metallized fiber (94:6)
138	F-1	.015	5.8	Green Smooth	Fabric (UC)	Drapery (FR)	Polyamide (Aromatic type) Cotton (50%:50%)
140	F-1	.024	12	White/Blue Smooth	Fabric (UC)	Mattress ticking (FR)	Cotton
141	S-2	.031	28	Cream Semi-clear Glossy	Sheet (SR)	Fabricated parts (FR)	Polysulfone
146	F-1	.035	9.9	White	Fabric (UC)	Upholstery, Drapery	Polyamide (more Aromatic groups than 143 & 144)
149	F-1	.15	10	Cream Fluffy	Fabric (UC)	Blanket	Modacrylic (100%)
155	S-3	.060	53	Clear Glossy	Sheet (R)	Window panes Fabricated parts	Polycarbonate
157	F-1	.035	10	White	Fabric (UC)	Drapery	Modacrylic (100%)

TABLE I (CONTINUED)
MATERIALS DESCRIPTION

Material No.	Code	Thickness (in.)	Weight (oz/yd^2)	Color and Surface	Designation	Intended Use	Composition
162	F-1	.020	13	White	Fabric (UC)	High-temperature insulation fabric	Asbestos/Glass/Polyamide (Aromatic type)
213	S-1	4.0	104	White Open cell	Foam (F)	Seat Padding	Polyether Urethane(FR)
223	S-1	4.0	212	Lt.Brown Open cell	Foam (F)	Seat Padding	Neoprene
226	R-1	.25	59	Blue/Black Loop	Rug (UP)	Flooring	Wool/Neoprene latex
227	S-3	.062	58	White Smooth	Sheet (R)	Paneling Moldings	ABS
228 A	F-2	.0025	3.5	White Smooth	Fabric (C)	Liner	Poly(difluorochloroethylene) on glass fabric
B		.005	6.9				
230 A	S-3	.080	82	White	Sheet (R)	Fabricated parts	Polysulfone
B		.030	28	Smooth			

ABBREVIATIONS

C - coated
UC - uncoated
P - padded
UP - unpadded
F - flexible
SR - Semi-rigid
R - Rigid
FR - Fire retardant treated
PVC - Poly vinyl chloride
ABS - Acrylonitrile/Butadiene/Styrene
PMMA- Poly methyl methacrylate

TABLE II

MINIMUM FLASH-POINT AND SELF-IGNITION TEMPERATURES OF SELECTED MATERIALS-ASTM TEST METHOD 1929 (SETCHKIN'S FURNACE)

Material No.	Code	Initial (1) Furnace Temp. °F	Time For Flash min.	Flash (2) Point Temp. °F	Self-Ignition (2) Temp. °F
28	F1	900	2.5	943	N.T.
46	S3	800	3.7	840	N.T.
102	F1	1050	N.F.	1100+	N.T.
107	F1	1000	0.6	980	N.T.
108	F1	1030	1.8	1060	N.T.
109	S3	800	8.6	830	
		900	3.8		980
112	S2	950	6.8	980	
		1100	4.3		1195
116	S2	1200	1.0	1195	
		1150	3.8		1170
118	S1	1200	2.6	1200	N.T.
121	S3	1150	5.7	1175	
		1200	1.4		1185

TABLE II (CONTINUED)

MINIMUM FLASH POINT AND SELF-IGNITION TEMPERATURES OF SELECTED MATERIALS--ASTM TEST METHOD 1929 (SETCHKIN'S FURNACE)

Material No.	Code	Initial (1) Furnace Temp. °F	Time For Flash min.	Flash (2) Point Temp. °F	Self-Ignition (2) Temp. °F
128A	S1(4)	600	8.8	660(3)	
		750	4.2		840
128B	S1(5)	650	10.0	685(3)	
		750	7.0		800
129	S1	910	4.0	945	
		900	3.5		945
138	F1	1150	0.6	1130	N.T.
140	F1	475	11.5	510	
		950	1.8		975
141	S2	950	5.5	972	
		1050	5.2		1135
146	F1	1100	1.2	1075	N.T.
149	F1	1000	4.1	960	
		1200	2.3		1265
155	S3	790	7.0	825	
		1100	N.F.		1200+

TABLE II (CONTINUED)

MINIMUM FLASH-POINT AND SELF-IGNITION TEMPERATURES OF SELECTED MATERIALS-ASTM TEST METHOD 1929 (SETCHKIN'S FURNACE)

Material No.	Code	Initial (1) Furnace Temp. °F	Time For Flash min.	Flash (2) Point Temp. °F	Self-Ignition (2) Temp. °F
157	F1	850	5.5	880	
		900	N.F.		965+
162	F1	1200	N.F.	1240+	N.T.
213	S1	600	5.8	630	
		650	3.7		700
223	S1	625	3.3	670	
		900	N.F.		965+
226	R1	850	4.0	900	
		850	3.7		900
227	S3	725	5.6	750	
		950	3.5		1020
228	F2	1200	1.3	1215	
		1200	1.6		1245
230	S3	950	6.1	975	
		1100	2.4		1115

Notes: (1) Temperature at which specimen was placed in furnace
(2) Air flow set at 6.5 cubic feet per hour for all tests
(3) Violent reaction - numerous flashes
(4) Flame-retardant foam
(5) Regular foam

Abbreviations:
N.T. - No test - Insufficient material
N.F. - Did not flash at indicated furnace temperature.

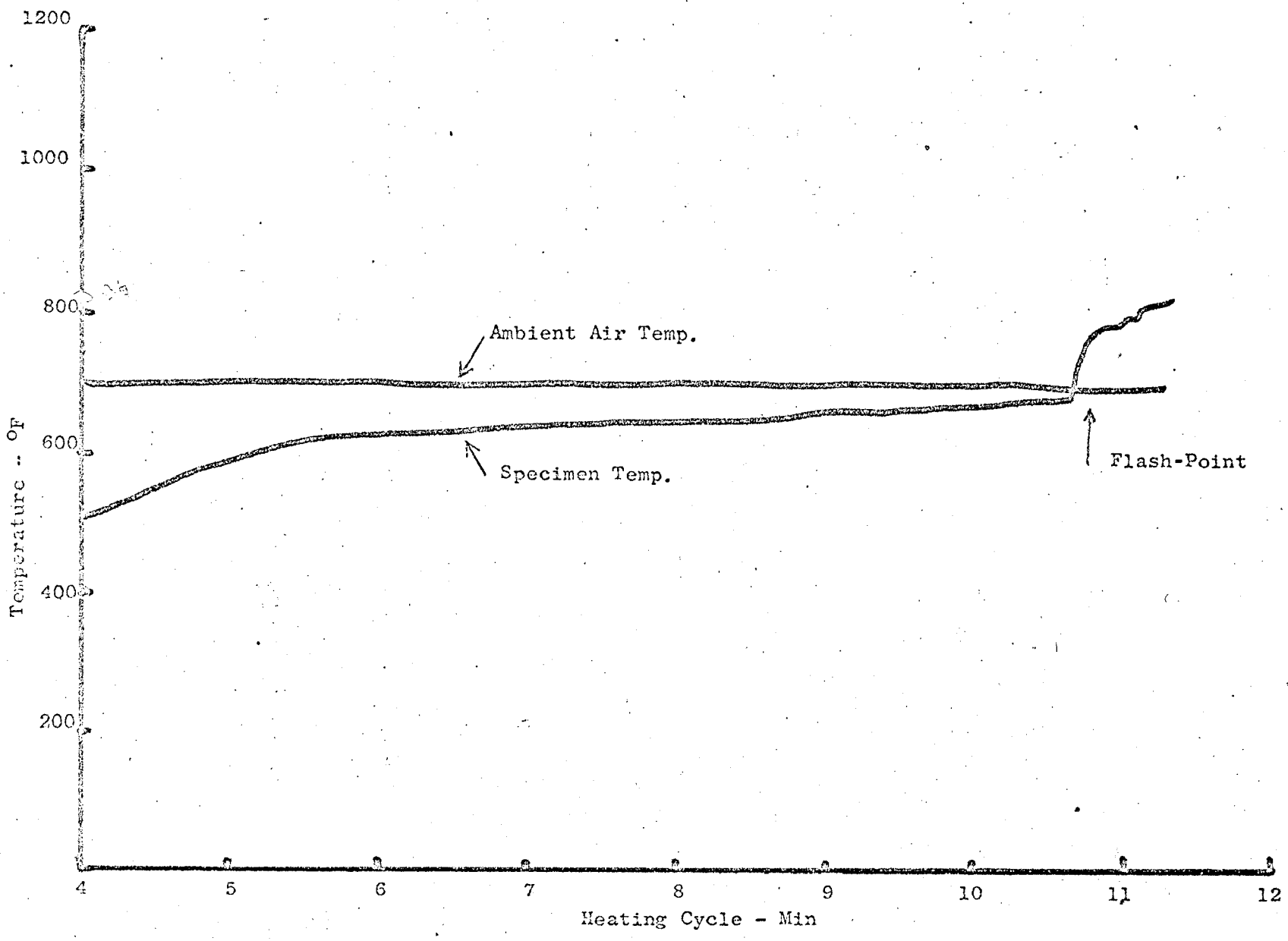

FIG. 2 COMBUSTION CHARACTERISTICS OF URETHANE FOAM (REGULAR)

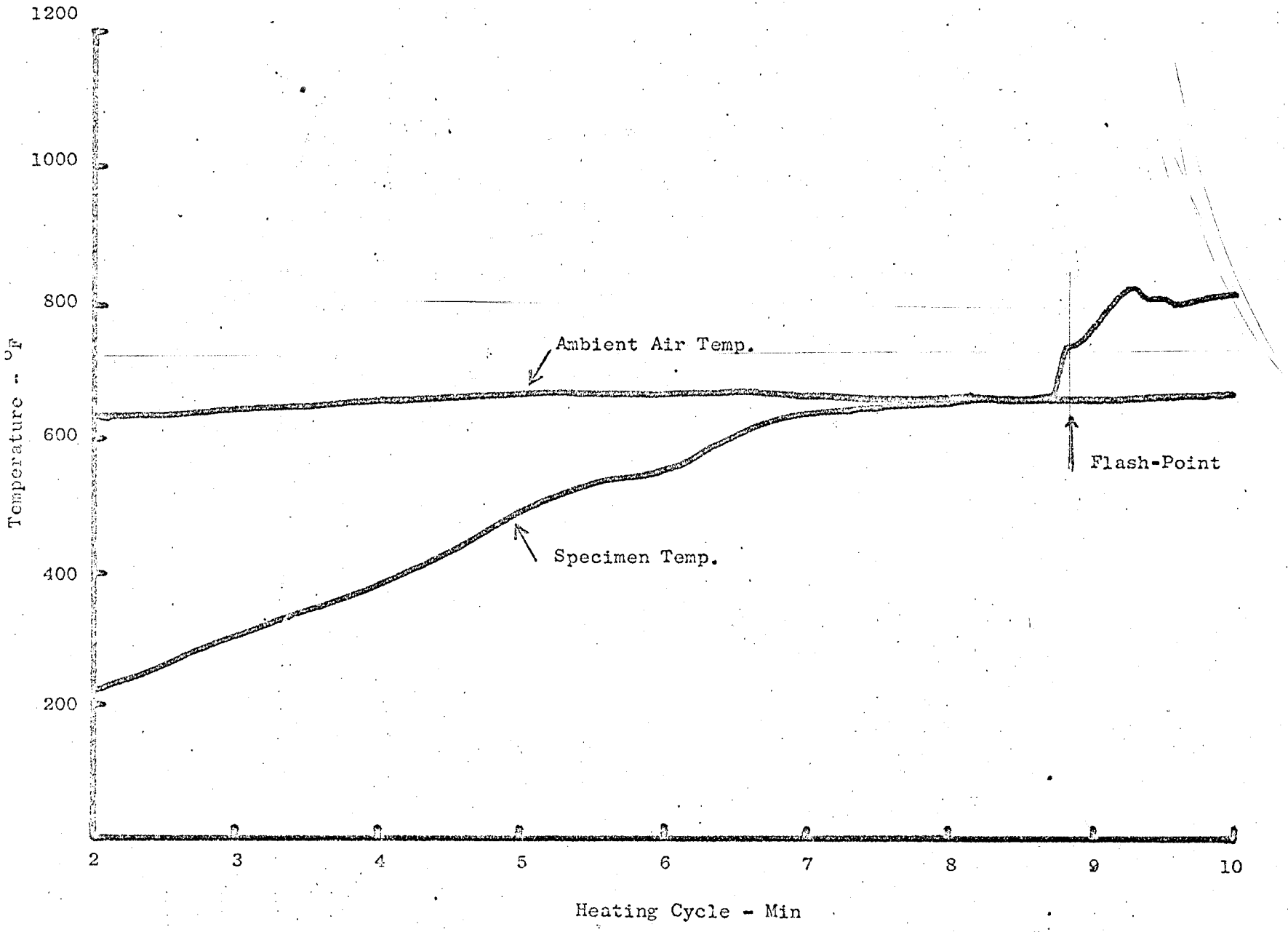

FIG. 3 COMBUSTION CHARACTERISTICS OF URETHANE FOAM (FIRE RETARDANT)

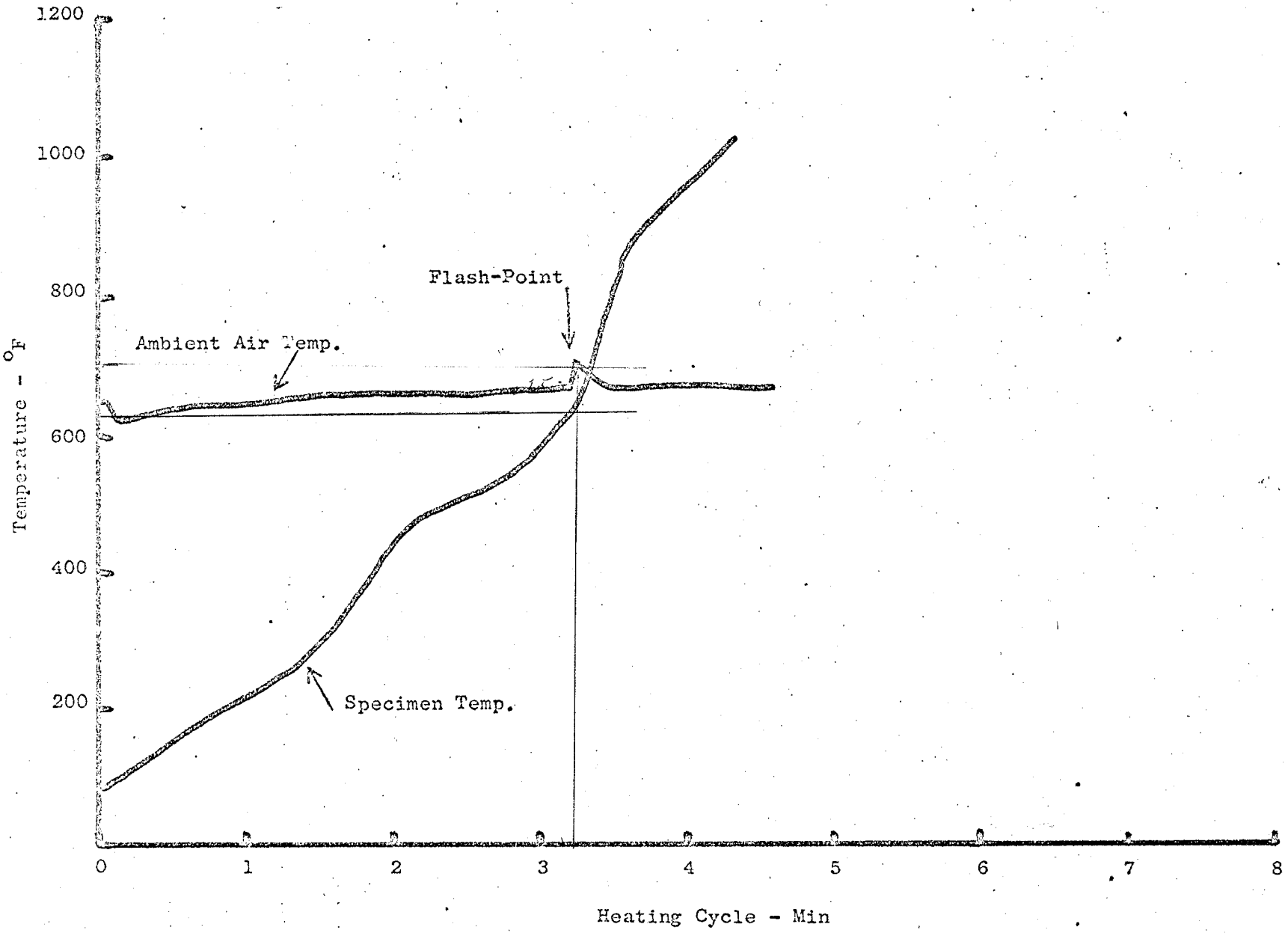

FIG. 4 COMBUSTION CHARACTERISTICS OF NEOPRENE FOAM 223

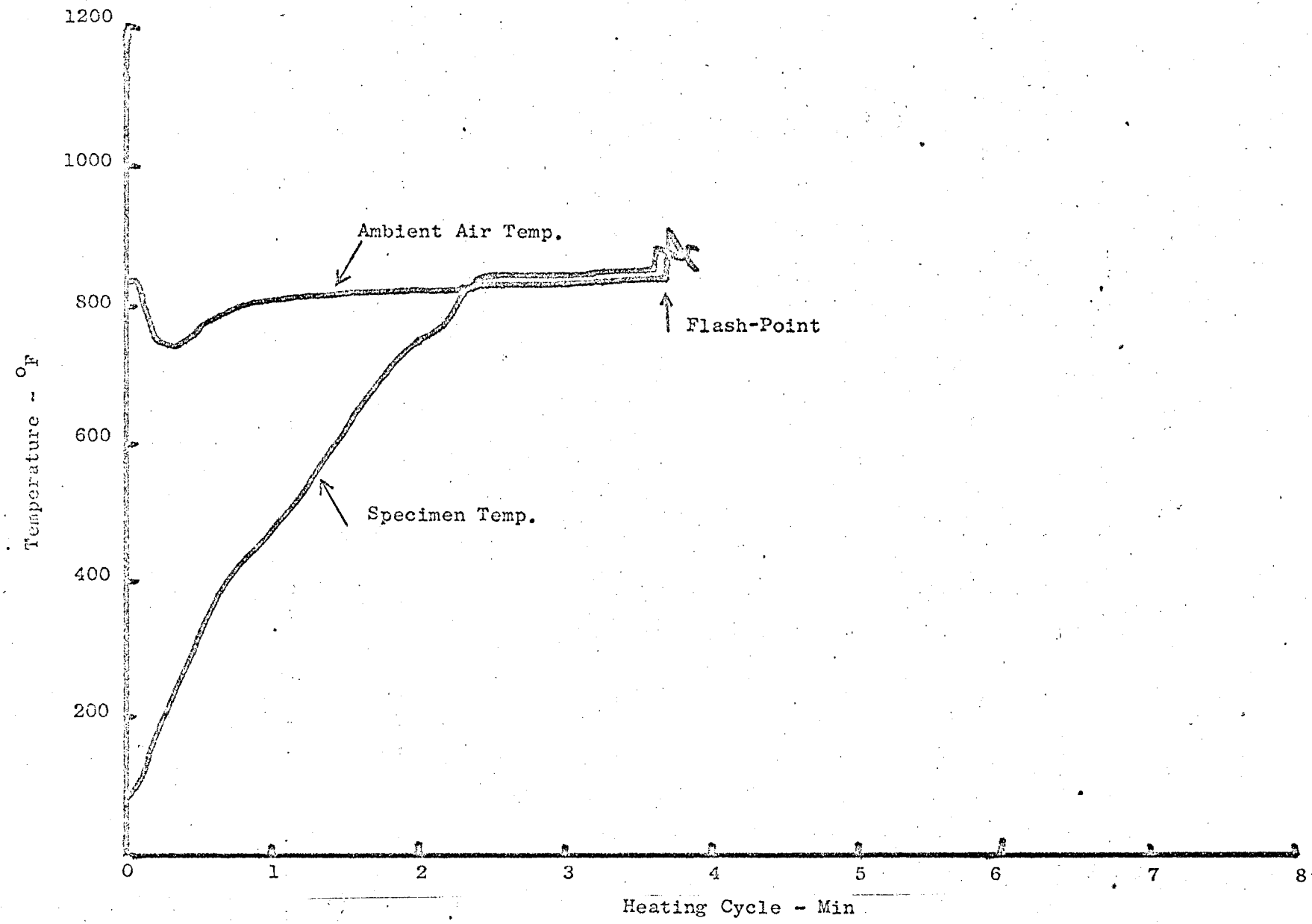

FIG. 5 COMBUSTION CHARACTERISTICS OF KYDEX SHEET

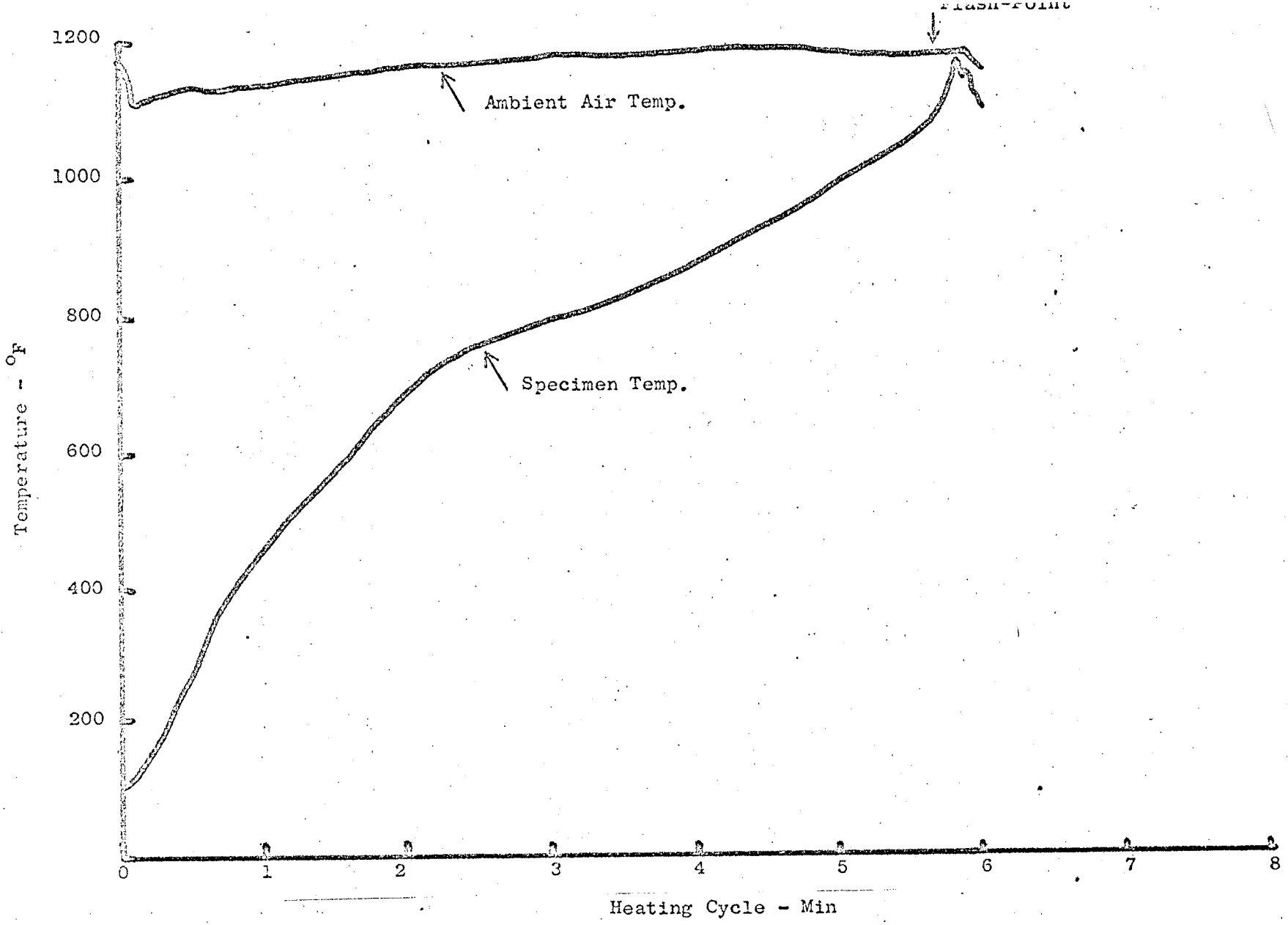

FIG. 6 COMBUSTION CHARACTERISTICS OF NOMEX SHEET