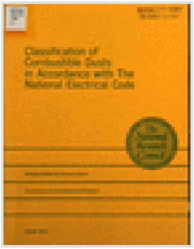

Classification of Combustible Dusts in Accordance With the National Electrical Code: Report of the Panel on Classification of Combustible Dusts of the Committee on Evaluation of Industrial Hazards (1980)

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Combustible dusts are classified using the grouping of the 1978 National Electrical Code, based on judgments of resistivity. Combustion properties of the dusts were also included in reaching the recommended classifications. A new classification scheme is proposed in which Group F is eliminated and dusts are classified on the basis of electrical resistivity, and of ignition sensitivity and explosion severity into Groups E and G.

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dusts in accordance with
the national electrical code

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Classification of Combustible Dusts in Accordance with The National Electrical Code

OR5

Report of the
Panel on Classification of Combustible Dusts of the
Committee on Evaluation of Industrial Hazards

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OR3 National Materials Advisory Board
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NOTICE

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competence and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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PREFACE

The Occupational Safety and Health Administration (OSHA) of the U.S. Department of Labor requested that the Committee on Evaluation of Industrial Hazards of the National Research Council classify certain combustible dusts of interest to OSHA in accordance with the classification groups in Article 500 of the National Electrical Code. These combustible dusts are listed on pages 3-107 through 3-114 in the 14th edition of the Fire Protection Handbook issued by the National Fire Protection Association.

In order to fulfill OSHA's request, the committee established the Panel on Classification of Combustible Dusts.

This is the third in a series of three reports, the first (NMAB 353-1) being directed toward the classification of certain chemicals based on physical and flammability data and the second (NMAB 353-2) being concerned with the methodology for testing dusts.

Table 1 in this report contains physical and combustibility data for the dusts of interest, along with the classification groups assigned by the panel.* In addition, a new dust-classification scheme is proposed and described.

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* In this report, mixed units (metric and U.S. customary) are used because numbers are quoted from other documents and equipment has been built according to a given system of units.

The chairmen of the committee and the panel express their sincere thanks to the members, liaison representatives, and technical advisors of the panel and the committee and to Stanley Barkin of the National Materials Advisory Board for their deliberations and efforts in completing this task.

Homer W. Carhart, Chairman
Committee on Evaluation of
Industrial Hazards

Leland J. Hall, Chairman
Panel on Classification of
Combustible Dusts

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Chapter 1

CLASSIFICATION OF COMBUSTIBLE DUSTS

INTRODUCTION

Dust explosions have plagued humanity for a great many years. Indeed, the first well-documented case occurred in a flour mill in Italy in 1785.[1] Since that time, dust explosions have also occurred persistently in a wide variety of other industries, including agriculture, mining, chemicals, and plastics. The possibility of such explosions is often unrecognized because the parent material in bulk form presents little or no explosion hazard. However, the same material in the form of a dispersible dust can increase the hazard significantly.

The present National Electrical Code (NEC) maintains the practices of many previous code editions with regard to classification of dusts and to specified operating temperatures of electrical equipment. Dusts have been classified in general terms, such as agricultural, carbonaceous, and metallic. Selection and installation rules for electrical equipment recognize the electrically conductive, semiconductive, and nonconductive properties of these dusts in Groups E, F, and G, respectively. However, these properties are not quantified.

The Occupational Safety and Health Administration (OSHA) of the U.S. Department of Labor requested that the National Academy of Sciences classify combustible dusts of commerce according to the classification structure of the NEC, Article 500 (NEC 500) of the National Fire Protection Association (NFPA) (NFPA 70, 1978), using available physical and chemical properties pertaining to combustibility. OSHA specifically desired the establishment of suitable criteria for categorizing various dust atmospheres, including those not previously considered in the NEC groupings. It was decided that combustible dusts should be classified based on their known or easily determined physical, chemical, or combustibility properties rather than on exhaustive physical testing of unclassified dusts to determine combustion and explosion properties.

To comply with OSHA's request, the Panel on the Classification of Combustible Dusts was established. This report has been prepared by the panel and has been reviewed and approved by the parent Committee on Evaluation of Industrial Hazards. The panel assigned classifications to dusts, using the grouping of the 1978 NEC, based on judgment of resistivity. Combustion properties of the dusts were also included in reaching the recommended classifications. The panel also proposed a new classification scheme in which Group F is eliminated and dusts are classified on the basis of electrical resistivity, and of ignition sensitivity and explosion severity into Groups E and G. The resistivity of the dust is determined by the method described in the second report of this series, NMAB 353-2.[2]

CLASSIFICATION OF DUSTS IN ACCORDANCE WITH THE 1978 NATIONAL ELECTRICAL CODE

Background

The present NEC concept used in grouping combustible dusts is shown as Figure 1. The dusts are divided into three groups. The first is Group E, metals; the second is Group F, carbonaceous dusts; and the third is Group G, consisting of other dusts, such as grains.

Classification by Resistivity

The present code provides no guidance in designating the Groups E, F, and G in accordance with any physical parameters. If the present groups are retained, the panel proposes that E, F, and G be classified according to measured electrical resistivity values of the dust or the parent material (see NMAB 353-2, Item D, p. 32), as appropriate.

The panel proposes that boundary limits be assigned

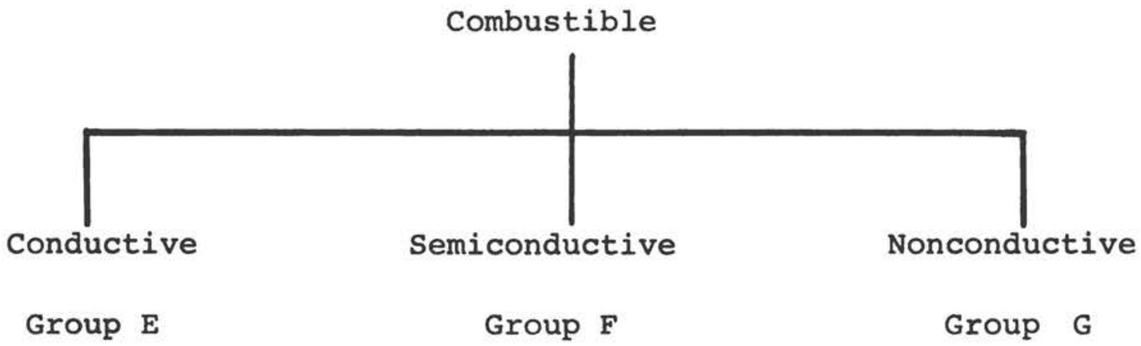


FIGURE 1 Classification of Dusts According to the 1978 NEC 500 groups.

The code states that Group E consists of metal dust, Group F, of carbon black, charcoal, coal, or coke having more than 8 percent volatiles, and Group G , of flour, starch, or grain dust.

for defining the classifications E, F, and G as follows:

$$\text{Group E, } \rho \leq 10^2 \text{ ohm-cm,}$$

$$\text{Group F, } 10^2 < \rho \leq 10^8 \text{ ohm-cm,}$$

$$\text{Group G, } \rho > 10^8 \text{ ohm-cm.}$$

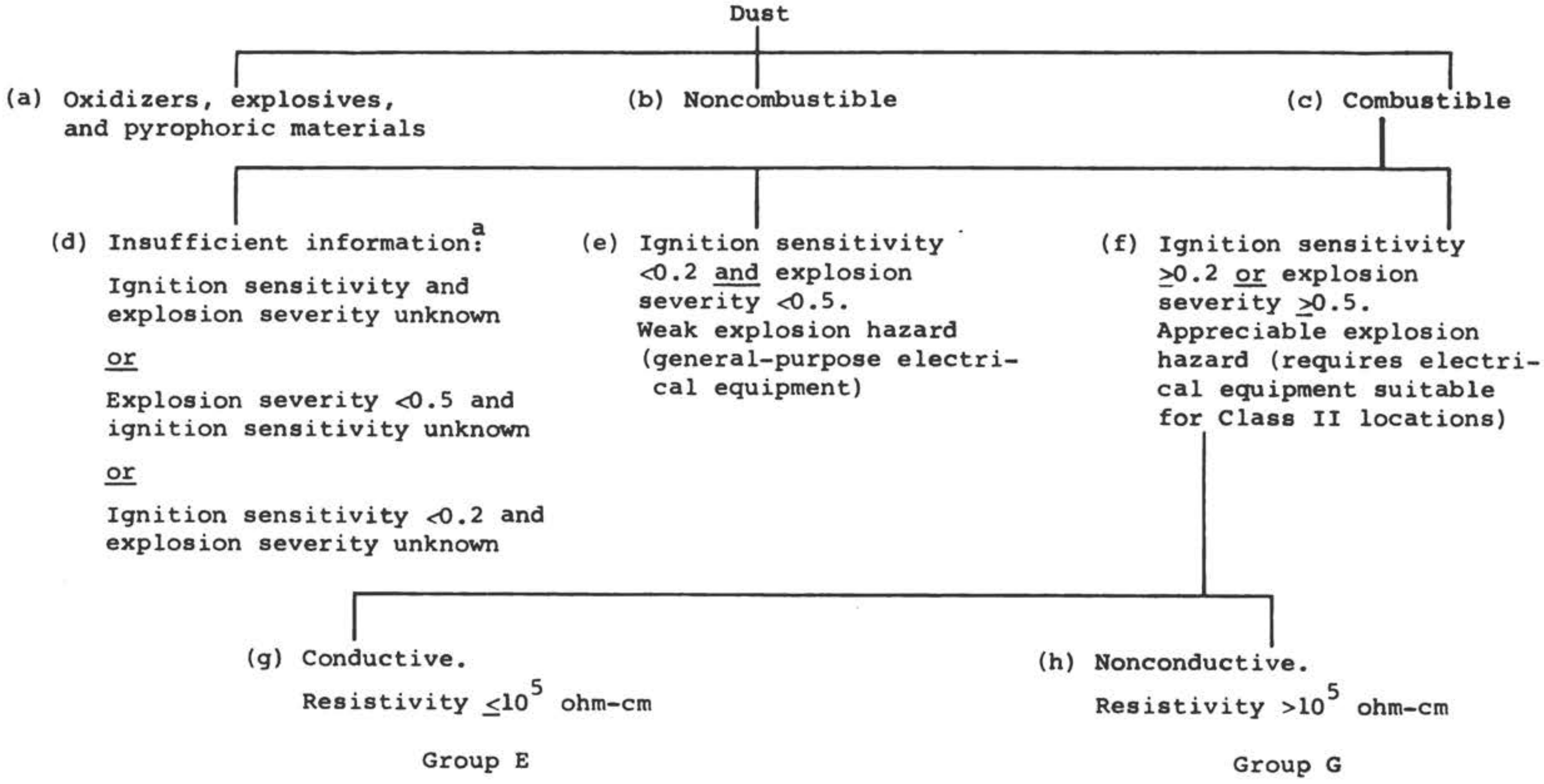
where ρ, the resistivity or specific resistance, is defined as the electrical resistance of a material of unit cross section and of unit length.

Existing information[3] indicates that few materials have resistances within the 10^2-to-10^8-ohm-cm limits.

PROPOSED NEW CLASSIFICATION OF DUSTS

The panel proposes that future classifications be made as outlined in Figure 2. The proposal separates dusts into two rather than three groups, in effect eliminating Group F. Group F is considered unnecessary and undesirable in the proposed new classification scheme because, first, Group F now includes dusts with electrical resistivities both greater and less than the proposed dividing line between conductive and nonconductive combustible dusts and, second, the proposal changes the dust ignition temperature from a criterion for classification of combustible dusts into groups to one for installation and operation of equipment.

The first point to consider in classification is to determine whether a dust is an oxidizer, an explosive, or a pyrophoric material; noncombustible; or combustible. If the dust is considered an oxidizer, explosive, or pyrophoric material it may possess characteristics that require safeguards beyond those required for atmospheres in which Class II equipment can be used and the electrical equipment designed for Class II locations shall not be utilized without further testing or evaluation. (Electrical equipment for Class II locations is equipment conforming to the requirements of NEC 500 for installation in locations made hazardous by the presence of combustible dust.)



Dust

(a) Oxidizers, explosives, and pyrophoric materials

(b) Noncombustible

(c) Combustible

(d) Insufficient information:[a]

Ignition sensitivity and explosion severity unknown

or

Explosion severity <0.5 and ignition sensitivity unknown

or

Ignition sensitivity <0.2 and explosion severity unknown

(e) Ignition sensitivity <0.2 and explosion severity <0.5. Weak explosion hazard (general-purpose electrical equipment)

(f) Ignition sensitivity ≥ 0.2 or explosion severity ≥ 0.5. Appreciable explosion hazard (requires electrical equipment suitable for Class II locations)

(g) Conductive.

Resistivity $\leq 10^5$ ohm-cm

Group E

(h) Nonconductive.

Resistivity $>10^5$ ohm-cm

Group G

[a] Treat as (f); group classification based on resistivity or on best judgment of the panel.

FIGURE 2 Proposed New Scheme for Classification of Dusts

If the dust is determined to be noncombustible, electrical equipment suitable for Class II locations is not required.

If the dust is combustible, one first determines whether there is adequate information regarding the dust. If data on ignition sensitivity and/or explosion severity* are insufficient or not available, the dust is placed into the category of insufficient data. It would be necessary to run tests on these dusts to obtain data on ignition sensitivity, explosion severity, or both before proceeding to categorize the dusts with respect to relative hazard.†

A dust that has an ignition sensitivity less than 0.2 and an explosion severity less than 0.5 should be considered a weak explosion hazard and therefore should not require Class II electrical equipment. Any dust having an ignition sensitivity equal to or greater than 0.2 or an explosion severity equal to or greater than 0.5 should require electrical equipment suitable for Class II hazardous locations. Test procedures for quantifying ignition sensitivity and explosion severity are described in Appendix A. The value of ignition sensitivity for each dust is shown in column 1 of Table 1. Explosion severity is listed in column 2. The factors used in calculating explosion severity, namely, maximum explosion pressure and maximum rate of pressure rise, are given in columns 3 and 4, respectively. The factors used in calculating ignition sensitivity, namely, cloud ignition temperature, minimum ignition energy, and minimum explosion concentration, are given in columns 5, 7, and 8, respectively. The values in the table are the best available but may depend on sample and test conditions.

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* See Appendix A for definitions of these terms.

† If ignition sensitivity data and/or explosion severity data are not available, a dust can be assigned a group classification based on resistivity data. The classification will err on the side of safety because the dust may not present an explosion hazard requiring Class II equipment.

Correlation of the indices with relative degrees of hazard is shown in Table 3 in Appendix A.

A dust having a resistivity less than or equal to 10^5 ohm-cm should be classified as Group E. A dust having a resistivity greater than 10^5 ohm-cm should be classified as Group G.

CLASSIFICATION OF VARIOUS DUSTS

OSHA requested that the panel classify dusts according to the NEC. The materials considered are listed in Table 1, which was taken from Table 3-8A of the Fire Protection Handbook, 14th edition.

Column 9 of Table 1 lists the classifications of these materials according to the 1978 NEC. The last column of Table 1 lists classifications according to the recommended scheme described above.

It is recognized that the materials tabulated in Table 1 do not include all the potentially hazardous dusts that might be found in industry, particularly in the future. The choice of compounds listed was based on the availability of data.

TABLE 1 Classification of Dusts by National Electric Code[a]

Type of Dust	Ignition Sensitivity	Explosion Severity	Max. Explosion Pressure[b] (psig)	Max. Rate of Pressure Rise[b] (psi/s)	Ignition Temperature Cloud (°C)	Ignition Temperature Layer (°C)	Min. Cloud Ignition Energy (J)	Min. Explosion Concentration (oz/cu ft)	NEC Classification 1978	NEC Classification Recommended
1. Agricultural Dusts										
Alfalfa meal	0.1	1.2[c]	66	1,100	460	200	0.32	0.100	G	G
Almond shell	0.9	0.3	72	800	440	200	0.08	0.065	G	G
Apricot pit	1.6	1.2	94	2,500	440	230	0.08	0.035	G	G
Cellulose	1.0	2.8	119	4,500	480	270	0.080	0.055	G	G
Cellulose, alpha	2.7	4.4	106	8,000	410	300	0.040	0.045	G	G
Cellulose, flock, fine cut	2.5	3.8	103	7,000	420	260	0.035	0.055	G	G
Cereal grass	<0.1	0.1	52	500	550	220	0.80	0.20	G	[d]
Cherry pit	2.0	2.2	104	4,000	430	220	0.08	0.03	G	G
Cinnamon	2.5	2.3	114	3,900	440	230	0.03	0.06	G	G
Citrus peel	1.1	0.9[c]	51	1,200	490	270	0.06	0.06	G	G
Coca bean shell	3.6	3.8[c]	69	3,300	470	370	0.03	0.04	G	G
Cocoa natural, 19% fat	0.5	1.1[c]	53	1,200	510	240	0.10	0.075	G	G
Coconut shell	2.0	2.1	97	4,200	470	220	0.06	0.035	G	G
Coffee, raw bean	0.1	0.1[c]	33	150	650	280	0.32	0.15	G	[d]
Coffee, fully roasted	0.2	0.1[c]	38	150	720	270	0.16	0.085	G	G
Coffee, instant spray-dried	-	0.1	44	500	410	350	[e]	0.28	G	[d]
Corn	2.3	3.0	95	6,000	400	250	0.04	0.055	G	G
Corncob grit	2.2	1.8	110	3,100	450	240	0.045	0.045	G	G
Corn dextrine, pure	3.1	3.9	105	7,000	400	370[f]	0.04	0.04	G	G
Cornstarch, commercial product	2.9	4.0	108	7,000	380	330[f]	0.04	0.045	G	G
Cornstarch (thru No. 325 sieve)	4.3	5.4	115	9,000	390	350[f]	0.03	0.04	G	G
Cork dust	3.6	3.3	96	7,500	460	210	0.035	0.035	G	G
Cotton linter, raw	<0.1	<0.1	48	150	520	-	1.92	0.50	G	[d]
Cottonseed meal	1.4	1.2	104	2,200	470	200	0.06	0.05	G	G
Cube root, South American	2.7	2.4[c]	69	2,100	470	230	0.04	0.04	G	G
Egg white	<0.1	0.2	58	500	610	-	0.64	0.14	G	[d]
Flax shive	0.7	0.3	81	800	430	230	0.08	0.08	G	G
Garlic, dehydrated	0.2	1.2[c]	57	1,300	360	-	0.24	0.10	G	G
Grain dust, winter wheat, corn, oats	2.8	3.3	115	5,500	430	230	0.03	0.055	G	G
Grass seed, blue	0.1	0.1[c]	24	200	490	180	0.26	0.29	G	[d]
Guar seed	1.7	1.4[c]	70	1,200	500	-	0.06	0.04	G	G
Gum, arabic	0.7	1.6[c]	65	1,500	500	260	0.10	0.06	G	G
Gum, karaya	0.2	1.5[c]	80	1,100	520	240	0.18	0.10	G	G
Gum, Manila (copal)	6.2	2.9[c]	63	2,800	360	390[f]	0.03	0.03	G	G
Gum, tragacanth	2.3	3.0[c]	78	2,400	490	260	0.045	0.04	G	G
Hemp hurd	3.3	5.4	103	10,000	440	220	0.035	0.04	G	G
Lycopodium	4.2	3.7[c]	75	3,100	480	310	0.04	0.025	G	G
Malt barley	2.6	2.1	92	4,400	400	250	0.035	0.055	G	G
Milk, skimmed	1.6	0.9	83	2,100	490	200	0.05	0.05	G	G
Moss, Irish	-	<0.1	12	300	480	230	[e]	[g]	G	[d]
Onion, dehydrated	-	<0.1[c]	18	100	410	-	[e]	0.13	G	[d]
Pea flour	1.8	2.1[c]	68	1,900	560	260	0.04	0.05	G	G
Peach-pit shell	3.1	2.3	98	4,400	440	210	0.05	0.03	G	G
Peanut hull	1.9	2.0	82	4,700	460	210	0.05	0.045	G	G
Peat, sphagnum sun-dried	1.9	2.0	87	4,400	460	240	0.05	0.045	G	G
Pecan-nut shell	3.1	2.4	106	4,400	440	210	0.05	0.03	G	G
Pectin (from ground dried apple pulp)	1.9	4.7	112	8,000	410	200	0.035	0.075	G	G
Potato starch, dextrinated	4.1	4.1	97	8,000	440	-	0.025	0.045	G	G
Pyrethrum, ground flower leaves	0.5	0.6	82	1,500	460	210	0.08	0.10	G	G
Rauwolfia vomitoria root	1.9	4.2	106	7,500	420	230	0.045	0.055	G	G
Rice	1.8	1.3	93	2,600	440	220	0.05	0.05	G	G
Rice bran	1.1	1.3[c]	61	1,300	490	-	0.08	0.045	G	G
Rice hull	1.6	1.7	90	3,600	450	220	0.05	0.055	G	G
Safflower meal	3.2	1.3	84	2,900	460	210	0.025	0.055	G	G
Soy flour	0.6	1.1[c]	79	800	540	190	0.10	0.06	G	G
Soy protein	2.2	3.3	96	6,500	520	260	0.05	0.035	G	G
Sucrose, chemically pure	1.1	2.9[c]	71	2,500	420	470[f]	0.10	0.045	G	G
Sucrose	4.1	1.8[c]	66	1,800	350	460[f]	0.04	0.035	G	G
Sugar, powdered	4.0	2.4	91	5,000	370	400[f]	0.03	0.045	G	G
Tea, instant, spray-dried	-	<0.1	30	250	580	340	[e]	[g]	G	[d]
Tobacco stem	-	<0.1	7	200	420	230	[e]	[g]	G	[d]
Tung kernels, oil-free	0.2	2.3[c]	74	1,900	540	240	0.24	0.07	G	G
Walnut shell, black	3.0	1.7	97	3,300	450	220	0.05	0.03	G	G
Wheat, untreated	1.0	1.9	103	3,600	500	220	0.06	0.065	G	G
Wheat flour	2.1	1.8	95	3,700	380	360	0.05	0.05	G	G
Wheat gluten, gum	1.0	-	-	-	520	-	0.08	0.05	G	G†[h]

TABLE 1 Classification of Dusts by National Electric Code^a (Continued)

Type of Dust	Ignition Sensitivity	Explosion Severity	Max. Explosion Pressure^b (psig)	Max. Rate of Pressure Rise^b (psi/s)	Ignition Temperature Cloud (°C)	Ignition Temperature Layer (°C)	Min. Cloud Ignition Energy (J)	Min. Explosion Concentration (oz/cu ft)	NEC Classification 1978	NEC Classification Recommended
Wheat starch, edible	4.3	3.4	100	6,500	420	-	0.025	0.045	G	G
Wheat starch, allyl chloride treated	8.5	3.3	98	6,500	380	–	0.025	0.025	G	G
Wheat straw	1.6	3.1	99	6,000	470	220	0.050	0.055	G	G
Wood, birch bark, ground	3.7	1.8	98	3,500	450	250	0.060	0.020	G	G
Wood flour, white pine	3.1	3.2	110	5,500	470	260	0.040	0.035	G	G
Yeast, torula	1.6	1.4	105	2,500	520	260	0.050	0.050	G	G
2. Carbonaceous Dusts										
Charcoal, hardwood mixture	1.4	0.9	100	1,800	530	180	0.020	0.140	F	G
Charcoal, activated, from lignite	–	–	–	–	590	370	–	2.000^i	F	G†^{h}
Carbon, activated from petroleum acid sludge	–	–	–	–	760	490	–	–	F	G†^{h}
Gilsonite, Utah	6.9	1.5	78	3,700	580	500	0.025	0.020	F•^{j}	G
Pitch, coal tar	4.0	2.8	88	6,000	710	–	0.020	0.035	F	G
Asphalt, blown petroleum resin	2.8	2.2	85	5,000	510	550	0.040	0.035	F	G
Pitch, petroleum	2.8	1.4	71	3,800	630	–	0.025	0.045	F	G
Lampblack	–	–	–	–	730	520	–	–	F	G†^{h}
Carbon black, acetylene	–	–	–	–	^{k}	900	–	–	F	G†^{h}
Carbon, petroleum coke and pitch electrodes	–	–	–	–	870	–	–	–	F	G†^{h}
Coal, Kentucky (bituminous)	2.2	1.8	88	4,000	600	180	0.030	0.050	F	G
Coal, Pennsylvania, Pittsburgh (Experimental mine coal)	1.0	1.0	83	2,300	610	170	0.060	0.055	F	G
Coal, Pennsylvania (anthracite)	–	–	–	–	730	400	^{e}	^{g}	F	^{d}
Coke, petroleum	–	–	–	–	670	200	–	1.000^i	F	G†^{h}
Graphite	–	–	–	–	^{k}	580	–	–	F	G†^{h}
Lignite, California	5.7	3.8	90	8,000	390	180	0.030	0.030	F	G
3. Chemicals										
Acetoacetanilide	7.6	1.9	89	4,100	440	–	0.020	0.030	G	G
Acetoacet-o-toluidide (2-methylacetoacetanilide)	–	–	–	–	710	–	–	–	G	G†^{h}
Acetoacet-p-phenetidide	12	>4.9	78	>10,000	560	–	0.010	0.030	G	G
Adipic acid	1.7	1.1	76	2,700	550	–	0.060	0.035	G	G
Anthranilic acid	3.3	1.6	77	3,900	580	–	0.035	0.030	G	G
Aryl nitroso methyl amide	5.5	3.3	90	7,000	490	–	0.015	0.050	G	G
Azelaic acid	5.3	1.2	67	3,500	610	–	0.025	0.025	G	G
2,2'-Azobisisobutyronitrile	12.5	4.3	102	8,000	430	350^j	0.025	0.015	G	G
Benzoic acid	5.4	2.1	74	5,500	620	Melts	0.020	0.030	G	G
Benzotriazole	5.1	3.3	82	7,600	440	-	0.030	0.030	G	G
Bisphenol A	11.8	2.5	73	6,500	570	–	0.015	0.020	G	G
o-Chloroacetoacetanilide	3.0	1.8	88	3,900	640	–	0.030	0.035	G	G
p-Chloroacetoacetanilide	4.4	2.4	85	5,500	650	–	0.020	0.035	G	G
Dehydroacetic acid	10.4	3.4	82	8,000	430	–	0.015	0.030	G	G
Diallyl phthalate	7.0	2.7	79	6,500	480	–	0.020	0.030	G	G
Dicumyl peroxide suspended on $CaCO_3$ (40–60)	2.7	2.5	74	6,500	560	180	0.030	0.045	G	G
Dicyclopentadiene dioxide	10.7	3.8	85	8,500	420	–	0.030	0.015	G	G
Dimethyl isophthalate	9.3	2.9	79	7,000	580	–	0.015	0.025	G	G
Dimethyl terephthalate	5.9	5.8	92	12,000	570	–	0.020	0.030	G	G
3,5-Dinitrobenzoic acid	1.9	2.1	92	4,300	460	–	0.045	0.050	G	G
Dinitrotoluamide (3,5-dinitro ortho toluamide)	5.4	>5.6	106	>10,000	500	–	0.015	0.050	G	G
Diphenyl	10.7	1.6	82	3,700	630	–	0.020	0.015	G	G
Ditertiary butyl para cresol	10.7	3.9	82	9,000	470	–	0.020	0.020	G	G
Ethyl hydroxyethyl cellulose	8.6	0.7	84	1,500	390	–	0.030	0.020	G	G
Fumaric acid	1.3	1.2	79	2,900	520	–	0.035	0.085	G	G
Hexamethylene tetramine	32.7	5.6	98	11,000	410	–	0.010	0.015	G	G
Hydroxyethyl cellulose	4.9	1.4	106	2,600	410	–	0.040	0.025	G	G
Isatoic anhydride	3.3	2.0	80	4,700	700	–	0.025	0.035	G	G
dl-Methionine	6.2	1.5	92	3,100	370	360	0.035	0.025	G	G
Nitrosoamine	5.0	8.5	125	13,000	270	–	0.060	0.025	G	G
Para oxy benzaldehyde	17.7	2.4	77	6,000	380	430	0.015	0.020	G	G
Para phenylene diamine (milled)	4.3	2.1	85	4,700	620	–	0.030	0.025	G	G
Para tertiary butyl benzoic acid	7.2	2.8	82	6,500	560	–	0.025	0.020	G	G
Pentaerythritol	16.8	4.5	90	9,500	400	–	0.010	0.030	G	G
Phenyl beta naphthylamine	4.7	1.5	68	4,300	680	–	0.025	0.025	G	G
Phthalic anhydride	13.8	1.6	72	4,200	650	–	0.015	0.015	G	G
Phthalimide	2.1	1.9	79	4,500	630	–	0.050	0.030	G	G

TABLE 1 Classification of Dusts by National Electric Code^{a} (Continued)

Type of Dust	Ignition Sensitivity	Explosion Severity	Max. Explosion Pressure^{b} (psig)	Max. Rate of Pressure Rise^{b} (psi/s)	Ignition Temperature		Min. Cloud Ignition Energy (J)	Min. Explosion Concentration (oz/cu ft)	NEC Classification	
					Cloud (°C)	Layer (°C)			1978	Recommended
Salicylanilide	4.1	1.4	61	4,400	610	Melts	0.020	0.040	G	G
Sorbic acid	14.3	>4.6	88	>10,000	470	460	0.015	0.020	G	G
Stearic acid, aluminum salt (aluminum tristearate)	33.6	3.5	88	7,500	400	300^{f}	0.01	0.015	G	G
Stearic acid, zinc salt (zinc stearate)	19.7	3.4	68	9,500	510	Melts	0.010	0.020	G	G
Sulfur	20.2	1.9	78	4,700	190	220	0.015	0.035	G	G
Terephthalic acid	3.0	2.3	73	6,000	680	–	0.020	0.050	G	G
4. Drugs										
2-Acetylamino-5-nitrothiazole	0.7	4.4	93	9,000	450	450^{f}	0.040	0.160	G	G
2-Amino-5-nitrothiazole	1.9	2.8	94	5,600	460	460^{f}	0.030	0.075	G	G
Aspirin (acetylsalicylic acid)	2.4	>4.3	83	>10,000	660	Melts	0.025	0.050	G	G
Gulosonic acid, diacetone	4.8	1.8	78	4,500	420	–	0.040	0.025	G	G
Mannitol	1.7	1.2	82	2,800	460	–	0.040	0.065	G	G
Nitropyridone	3.0	>5.8	85	>10,000	430	Melts	0.035	0.045	G	G
l-Sorbose	1.0	1.9	76	4,700	370	–	0.080	0.065	G	G
Vitamin B_1, mononitrate	2.7	3.1	99	6,000	360	–	0.060	0.035	G	G
Vitamin C, ascorbic acid	1.0	2.2	88	4,800	460	280	0.060	0.070	G	G
5. Dyes, Pigments, and Intermediates										
1,4-Diamino-2, 3-dihydroanthraquinone (90%), 1-methylaminoanthraquinone (10%) (Violet 200 dye)	1.1	0.9	64	2,800	880	175	0.060	0.035	G	G
1,4-Di-p-toluidineanthraquinone (70%), β-naphthalene-azo-dimethylaniline (30%) (green base harmon dye)	1.7	1.0	73	2,600	770	175	0.050	0.030	G	G
1-Methylaminoanthraquinone (red dye intermediate)	0.9	1.2	71	3,300	830	175	0.050	0.055	G	G
β-Naphthalene-azo-dimethylaniline	3.9	0.8	70	2,300	510	175	0.050	0.020	G	G
6. Metals										
Aluminum, atomized collector fines	5.4	8.7	92	18,000	550	740	0.015	0.045	E	E
Aluminum, flake, A 422 extra fine lining, polished	7.3	>10.2	97	>20,000	610	320	0.010	0.045	E	E
Antimony, milled (95% Sb)	< 0.1	< 0.1	8	100	420	330	1.920	0.420	E	^{d}
Boron, amorphous, commercial (85% B)	> 0.7	1.1	90	2,400	470	400	0.060	<0.100	E	E
Cadmium, atomized (98% Cd)	–	–	–	–	570	250	4.00	–	E	E†^{h}
Chromium, electrolytic, milled (97% Cr)	0.1	1.2	56	4,200	580	400	0.140	0.230	E	E
Cobalt, milled (97.8% Co)	–	–	–	–	760	370	–	–	E	E†^{h}
Copper, electrolytic, Type C (99.5% Cu)	–	–	–	–	900	–	–	–	E	E†^{h}
Iron, hydrogen reduced (98% Fe)	0.7	0.4	46	1,800	320	290	0.080	0.120	E	E
Iron, carbonyl (99% Fe)	3.0	0.5	41	2,400	320	310	0.020	0.105	E	E
Lead, atomized (99% Pb)	–	–	–	–	710	270	^{c}	–	E	E†^{h}
Magnesium, milled, Grade B	3.0	7.4	94	15,000	560	430	0.040	0.030	E	E
Manganese	0.4	0.7	48	2,800	450	240	0.08	0.125	E	E
Nickel	–	–	–	–	–	–	–	–	E	E†^{h}
Selenium, milled	–	–	–	–	^{k}	–	–	–	E	E†^{h}
Silicon, milled (96% Si)	< 0.1	1.1	87	2,400	780	950	0.960	0.160	E	E
Tantalum	> 0.1	0.7	50	2,600	630	300	0.120	<0.200	E	E
Tellurium, electrolytic (98% Te)	–	–	–	–	550	340	–	–	E	E†^{h}

TABLE 1 Classification of Dusts by National Electric Code[a] (Continued)

Type of Dust	Ignition Sensitivity	Explosion Severity	Max. Explosion Pressure[b] (psig)	Max. Rate of Pressure Rise[b] (psi/s)	Ignition Temperature Cloud (°C)	Ignition Temperature Layer (°C)	Min. Cloud Ignition Energy (J)	Min. Explosion Concentration (oz/cu ft)	NEC Classification 1978	NEC Classification Recommended
Thorium (contains 1.2% O)	19.9	0.8	48	3,300	270	280	0.005	0.075	E	E
Thorium hydride (contains 0.94% H)	32.3	2.0	60	6,500	260	20	0.003	0.080	E	[l]
Tin, atomized (96% Sn, 2% Pb)	0.2	0.3	37	1,300	630	430	0.080	0.190	E	E
Titanium (99% Ti)	5.4	2.0	70	5,500	330	510	0.025	0.045	E	E
Titanium hydride (95% Ti, 3.8% H)	1.0	6.0	96	12,000	480	540	0.060	0.070	E	E
Tungsten, hydrogen reduced	–	–	–	–	[k]	420	–	[g]	E	E†[h]
Uranium	37.3	0.9	53	3,400	20	100	0.045	0.060	E	[l]
Uranium hydride	336	1.5	43	6,500	20	20	0.005	0.060	E	[l]
Vanadium (86.4% V)	0.3	0.2	48	600	500	490	0.060	0.220	E	E
Zinc, condensed (97% Zn, 2% Pb)	< 0.1	< 0.1	15	200	690	540	0.960	0.48	E	[d]
Zirconium, prepared from hydride (contains 0.3% O)	503	3.1	65	9,000	20	190	0.005	0.04	E	[l]
Zirconium hydride (93.6%) Zr, 2.1% H)	1.1	3.3	69	9,000	350	270	0.060	0.085	E	E
7. Alloys and Compounds										
Aluminum-cobalt alloy (60–40)	0.1	3.5	78	8,500	950	570	0.100	0.180	E	E
Aluminum-copper alloy (50–50)	0.2	0.9	68	2,600	930	830	0.10	0.10	E	E
Aluminum-lithium alloy (15% Li)	0.3	1.9	96	3,700	470	400	0.14	<0.10	E	E
Aluminum-magnesium alloy (Dowmetal)	2.9	4.5	86	10,000	430	480	0.080	0.020	E	E
Aluminum-nickel alloy (58–42)	0.1	4.1	79	10,000	950	540	0.080	0.190	E	E
Aluminum-silicon alloy (12% Si)	1.3	2.9	74	7,500	670	–	0.060	0.040	E	E
Calcium silicide	0.4	5.0	73	13,000	540	540	0.150	0.060	E[e,j]	E[e,j]
Ferromanganese, medium carbon	0.4	1.0	47	4,200	450	290	0.080	0.130	E[e,j]	E[e,j]
Ferrosilicon (88% Si, 9% Fe)	< 0.1	1.6	87	3,600	860	800	0.400	0.420	E[e,j]	E[e,j]
Ferrotitanium (19% Ti, 74.1% Fe, 0.06% C)	0.5	2.6	53	2,200	370	400	0.080	0.140	E[e,j]	E[e,j]
8. Pesticides										
Benzethonium chloride	4.4	1.6	91	3,300	380	410	0.060	0.020	G	G
Bis (2-hydroxy-5-chlorophenyl)-methane	1.5	0.7	70	2,000	570	-	0.060	0.040	G	G
Dieldrin 20% (50% combustible, 30% inert)	2.3	2.4	82	5,500	550		0.035	0.045	G	G
2, 6-Di-tertiary-butyl-para-cresol	21.3	3.9	82	9,000	420	–	0.015	0.015	G	G
Dithane (zinc ethylenedithiocarbamate)	–	–	–	–	480	180	–	–	G	G†[h]
Ferric dimethyldithiocarbamate (Ferbam)	5.2	2.6	80	6,300	280	150	0.025	0.055	G	G
Manganese vancide	0.3	1.8	77	4,500	300	120	0.280	0.070	G	G
1-Naphthyl-N-methylcarbamate (Sevin) 15% (85% inert)	18.0	1.6	72	4,200	560	140	0.010	0.020	G	G
3, 4, 5, 6-Tetrahydro-3, 5,-dimethyl-2H-1, 3, 5-thiadiazine-2-thione, (Crag No. 974) 5% (95% inert)	8.7	2.0	94	4,000	310	330	0.030	0.025	G	G
α, α′-Trithiobis (N, N-dimethylthioformamide)	3.4	2.6	83	6,000	280	230	0.035	0.060	G	G
9. Thermoplastic Resins and Molding Compounds										
Group I. Acetal Resins										
Acetal, linear (polyformaldehyde)	6.5	1.9	89	4,100	440	–	0.020	0.035	G	G
Group II. Acrylic Resins										
Methyl methacrylate polymer	15.3	1.0	101	1,800	440	-	0.015	0.02	G	G
Methyl methacrylate-ethyl acrylate copolymer	14.0	2.7	85	6,000	480	–	0.010	0.030	G	G
Methyl methacrylate-ethyl acrylate-styrene copolymer	9.2	1.7	75	4,400	440	–	0.020	0.025	G	G
Methyl methacrylate-styrene-butadiene-acrylonitrile copolymer	8.4	1.4	76	3,400	480	–	0.020	0.025	G	G
Methacrylic acid polymer, modified	1.0	0.6	82	1,500	450	290	0.100	0.045	G	G

TABLE 1 Classification of Dusts by National Electric Code[a] (Continued)

Type of Dust	Ignition Sensitivity	Explosion Severity	Max. Explosion Pressure[b] (psig)	Max. Rate of Pressure Rise[b] (psi/s)	Ignition Temperature		Min. Cloud Ignition Energy (J)	Min. Explosion Concentration (oz/cu ft)	NEC Classification	
					Cloud (°C)	Layer (°C)			1978	Recommended
Acrylamide polymer	4.1	0.6	74	1,600	410	240	0.030	0.040	G	G
Acrylonitrile polymer	8.1	2.3	89	5,000	500	460	0.020	0.025	G	G
Acrylonitrile-vinyl pyridine copolymer	7.9	2.4	77	6,000	510	240	0.025	0.020	G	G
Acrylonitrile-vinyl chloride-vinylidene chloride copolymer (70-20-10)	5.9	3.0	83	7,000	650	210	0.015	0.035	G	G
Group III. Cellulosic Resins										
Cellulose acetate	9.1	3.7	108	6,500	420	340	0.015	0.035	G	G
Cellulose triacetate	4.5	1.9	84	4,300	430	–	0.030	0.035	G	G
Cellulose acetate butyrate	7.3	1.5	81	3,500	370	–	0.030	0.025	G	G
Cellulose propionate, 0.3% free hydroxyl	2.9	2.6	105	4,700	460	–	0.060	0.025	G	G
Ethyl cellulose 5–10 μm dust	25.1	3.6	98	7,000	320	330[f]	0.010	0.025	G	G
Methyl cellulose	9.3	3.1	99	6,000	360	340	0.020	0.030	G	G
Carboxy methyl cellulose, low viscosity, 0.3 to 0.4% substitution, acid product	0.5	2.7	114	4,500	450	290	0.140	0.060	G	G
Hydroxyethyl cellulose-mono sodium phosphate sizing compound	2.1	0.8	76	1,900	390	340	0.035	0.070	G	G
Group IV. Chlorinated Polyether Resins										
Chlorinated polyether alcohol	0.6	0.3	66	1,000	460	–	0.160	0.045	G	G
Group V. Fluorocarbon Resins										
Tetrafluoroethylene polymer (micronized)	–	–	–	–	670	570[f]	[e]	[g]	G	[d]
Monochlorotrifluoroethylene polymer		–	–	–	600	720[f]	[e]	[g]	G	[d]
Group VI. Nylon (Polyamide) Resins										
Nylon (polyhexamethylene adipamide) polymer	6.7	3.3	89	7,000	500	430	0.020	0.030	G	G
Group VII. Polycarbonate Resins										
Polycarbonate	4.5	1.9	78	4,700	710	–	0.025	0.025	G	G
Group VIII. Polyethylene Resins										
Polyethylene, high-pressure process	8.2	1.4	81	3,400	410	380	0.030	0.020	G	G
Polyethylene, low-pressure process	24.0	2.2	83	5,000	420	–	0.010	0.020	G	G
Polyethylene wax, low molecular weight	7.2	0.8	74	2,100	400	–	0.035	0.020	G	G
Group IX. Polymethylene Resins										
Carboxy polymethylene, regular	–	2.0	70	5,500	520	–	[e]	0.325	G	G†[h]
Group X. Polypropylene Resins										
Polypropylene (contains no antioxidant)	8.0	2.0	76	5,000	420	–	0.030	0.020	G	G
Group XI. Rayon										
Rayon (viscose) flock, 1.5 denier, 0.020-in. maroon	0.3	0.8	88	1,700	520	250	0.240	0.055	G	G
Group XII. Styrene Polymer and Copolymer Resins										
Polystyrene molding compound	6.0	2.0	77	5,000	560	–	0.040	0.015	G	G
Polystyrene latex, spray-dried, contains surfactants	13.4	3.3	91	7,000	500	500[f]	0.015	0.020	G	G
Styrene-acrylonitrile copolymer (70–30)	3.8	0.5	71	1,400	500	–	0.030	0.035	G	G
Styrene-butadiene latex copolymer, over 75% styrene, alum coagulated	7.3	1.7	82	3,900	440	–	0.025	0.025	G	G
Group XIII. Vinyl Polymer and Copolymer Resins										
Polyvinyl acetate	0.6	0.4	69	1,000	550	–	0.160	0.040	G	G
Polyvinyl acetate/alcohol	0.9	1.2	75	3,100	520	440	0.120	0.035	G	G
Polyvinyl butyral	25.8	0.9	84	2,000	390	–	0.010	0.020	G	G
Polyvinyl chloride, fine	–		–	–	660	290	[e]	[g]	G	[d]
Vinyl chloride-vinyl acetate copolymer	–	–	–	–	690	–	[e]	[g]	G	[d]

TABLE 1 Classification of Dusts by National Electric Code[a] (Continued)

Type of Dust	Ignition Sensitivity	Explosion Severity	Max. Explosion Pressure[b] (psig)	Max. Rate of Pressure Rise[b] (psi/s)	Ignition Temperature		Min. Cloud Ignition Energy (J)	Min. Explosion Concentration (oz/cu ft)	NEC Classification	
					Cloud (°C)	Layer (°C)			1978	Recommended
Vinyl chloride-acrylonitrile copolymer, water-emulsion product (60–40)	3.1	0.6	71	1,600	570	470	0.025	0.045	G	G
Vinyl chloride-acrylonitrile copolymer, water-emulsion product (33–67)	7.2	2.0	87	4,400	530	470	0.015	0.035	G	G
Polyvinyl chloride-dioctyl phthalate mixture (67-33)	3.6	0.8	65	2,300	320	–	0.050	0.035	G	G
Vinylidene chloride polymer molding compound	–	–	–	–	900	–	[e]	[g]	G	[d]
Vinyl toluene-acrylonitrile-butadiene copolymer (58-19-23)	9.5	2.2	71	6,000	530	–	0.020	0.020	G	G
10. Thermosetting Resins and Molding Compounds										
Group I. Alkyd Resins										
Alkyd molding compound, mineral filler, not self-extinguishing	0.2	< 0.1	15	150	500	270	0.120	0.155	G	G
Group II. Allyl Resins										
Allyl alcohol derivative, CR-39, (from dust collector)	5.8	6.7	106	12,000	500	–	0.020	0.035	G	G
Allyl alcohol derivative, CR-149-glass fiber mixture (65-35)	< 0.1	0.2	34	1,000	540	–	1.60	0.345	G	[d]
Group III. Amino Resins (Melamine and Urea)										
Melamine formaldehyde, unfilled laminating type, no plasticizer	0.1	0.2	61	700	810	–	0.320	0.085	G	[d]
Urea formaldehyde molding compound, Grade II, fine	0.6	1.7	89	3,600	460	–	0.080	0.085	G	G
Urea formaldehyde-phenol formaldehyde molding compound, wood flour filler	0.5	0.9	86	2,000	490	240	0.120	0.075	G	G
Group IV. Epoxy Resins										
Epoxy, no catalyst, modifier, or additives	12.4	2.7	86	6,000	540	–	0.015	0.020	G	G
Epoxy-bisphenol A mixture	3.8	0.5	68	1,500	510	–	0.035	0.030	G	G
Group V. Furan Resins										
Phenol furfural	15.2	4.0	90	8,500	530	310	0.010	0.025	G	G
Group VI. Phenolic Resins										
Phenol formaldehyde	9.3	3.9	105	7,000	580	–	0.015	0.025	G	G
Phenol formaldehyde, 1-step	7.9	5.3	92	11,000	640	–	0.010	0.040	G	G
Phenol formaldehyde, 2-step	13.9	4.0	89	8,500	580	–	0.010	0.025	G	G
Phenol formaldehyde, semiresinous	–	< 0.1	18	200	460	–	[e]	0.235	G	[d]
Phenol formaldehyde molding compound, wood flour filler	8.9	4.7	94	9,500	500	–	0.015	0.030	G	G
Phenol formaldehyde, polyalkylene polyamine modified	16.0	2.8	96	5,500	420	290	0.015	0.020	G	G
Group VII. Polyester Resins										
Polyethylene terephthalate	2.9	2.6	91	5,500	500	–	0.035	0.040	G	G
Styrene modified polyester-glass fiber mixture (65-35)	2.0	2.6	84	6,000	440	360	0.050	0.045	G	G
Group VIII. Polyurethane Resins (Isocyanate)										
Polyurethane foam (toluene diisocyanate-polyhydroxy with fluorocarbon blowing agent), no fire retardant	6.6	1.5	84	3,400	510	440	0.020	0.030	G	G
Polyurethane foam (toluene diisocyanate-polyhydroxy with fluorocarbon blowing agent), fire retardant	9.8	1.7	88	3,700	550	390	0.015	0.025	G	G

TABLE 1 Classification of Dusts by National Electric Code[a] (Continued)

Type of Dust	Ignition Sensitivity	Explosion Severity	Max. Explosion Pressure[b] (psig)	Max. Rate of Pressure Rise[b] (psi/s)	Ignition Temperature		Min. Cloud Ignition Energy (J)	Min. Explosion Concentration (oz/cu ft)	NEC Classification	
					Cloud (°C)	Layer (°C)			1978	Recommended
11. Special Resins and Molding Compounds										
Group I. Cold Molded Resins										
Petroleum resin (blown asphalt), regular	6.3	2.3	94	4,600	510	500[f]	0.025	0.025	G	G
Group II. Coumarone-Indene Resins										
Coumarone-indene, hard	25.8	5.4	93	11,000	520	–	0.010	0.015	G	G
Group III. Natural Resins										
Cashew oil, phenolic, hard	6.8	1.8	85	4,000	470	180	0.025	0.025	G	G
Lignin, hydrolyzed-wood type, fines	5.6	2.7	102	5,000	450	–	0.020	0.040	G	G
Rosin, DK	34.4	5.5	87	12,000	390	–	0.010	0.015	G	G
Shellac	25.2	1.4	73	3,600	400	–	0.010	0.020	G	G
Sodium resinate, dry size, grade XXX	2.7	1.8	94	3,600	350	220	0.060	0.035	G	G
Group IV. Rubber										
Rubber, crude, hard	4.6	1.6	80	3,800	350	–	0.050	0.025	G	G
Rubber, synthetic, hard, contains 33% sulfur	7.0	1.5	93	3,100	320	–	0.030	0.030	G	G
Rubber, chlorinated	–	–	–	–	940	290	[e]	[g]	G	[d]
Group V. Miscellaneous Resins										
Alkyl ketone dimer sizing compound, dimer dispersed on silica (50–50)	5.3	2.4	76	6,000	420	160	0.030	0.030	G	G
Chlorinated phenol (bis-(2-hydroxy-5-chlorophenyl) methane)	1.5	0.7	70	2,000	570	–	0.060	0.040	G	G
Ethylene oxide polymer	6.4	0.9	89	2,000	350	–	0.030	0.030	G	G
Ethylene-maleic anhydride copolymer	1.0	0.2	51	700	540	–	0.040	0.095	G	G
Styrene-maleic anhydride copolymer	7.1	4.1	82	9,500	470	490	0.020	0.030	G	G
Petrin acrylate monomer, crude	10.2	8.7	104	16,000	220	–	0.020	0.045	G	G

[a] Materials are from Table 3-8A, *NFPA Fire Protection Handbook*, 14th edition. Data in Table 3-8A was extensively modified by reviewing the following reports of the U.S. Department of Interior, Bureau of Mines: RI 5753, The Explosibility of Agricultural Dusts; RI 6516, Explosibility of Metal Powders; RI 5971, Explosibility of Dusts Used in the Plastics Industry; RI 6597, Explosibility of Carbonaceous Dusts; RI 7132, Dust Explosibility of Chemicals, Drugs, Dyes and Pesticides; and RI 7208, Explosibility of Miscellaneous Dusts.

The data given for ignition temperatures, minimum cloud ignition energy, and minimum explosion concentration were the minimum values for the type of sample tested. The data given for maximum explosion pressure and maximum rate of pressure rise were those obtained for a single sample of a type tested at a concentration of 0.5 oz/ft^3.

[b] All maximum pressure rates and explosion pressures determined at concentrations of 0.5 oz/ft^3.

[c] Determined by dispersing with an airblast from an 80-in.^{3} reservoir charged to 15-p.s.i.g. pressure (Method A). All other results determined by dispersing with an airblast from a 3-in.^{3} reservoir charged to a 100-p.s.i.g. pressure (Method B). Method A is related to Method B by a conversion factor of 3.07.

[d] Ignition sensitivity <0.2 and explosion severity <0.5; constitutes primarily a weak explosion hazard.

[e] No ignition up to 8.32-J spark, the highest tried.

[f] Ignition denoted by flame; all others not so marked denoted by a glow.

[g] No ignition up to a concentration of 2 oz/ft^3, the highest tried.

[h] Explosion severity or ignition sensitivity unknown; dagger indicates classification based on resistivity or best judgement of the panel.

[i] Guncotton ignition source.

[j] Asterisk indicates a difference of opinion among panelists; classification given is the more stringent one.

[k] No ignition.

[l] Material is pyrophoric.

Chapter 2

EQUIPMENT SELECTION

Electrical equipment selected and installed according to the 1978 NEC requirements is essentially the same for atmospheres containing Group E and Group F dusts. Therefore, under the proposed panel recommendations, Group F is eliminated and equipment selection will be restricted to Group E and Group G dusts.

Because dust settles and forms layers on operating equipment, the present NEC states that the maximum surface temperatures under actual operating conditions shall not exceed those shown in Table 2. The panel proposes that a different approach be considered.

The method employed to generate data on dust-layer ignition temperature relies on the possible consequences of the settling of dust on electrical equipment that generates heat. It is realized that surface temperature and ignition temperature depend on layer thickness and dust compactness. Therefore the panel recommends that the maximum surface temperature of the electrical equipment be lower than the specified dust-layer ignition temperature by some differential value, e.g., 25°C. The panel believes that such a safety factor is appropriate and permits the user some flexibility in judgment. Furthermore, it is recommended that, based on experience, an independent upper limit be specified for the surface temperature of the electrical equipment. Under special conditions, a differential other than 25°C may be appropriate, based on field experience or other considerations.

TABLE 2 Maximum Surface Temperatures

	Equipment That Is Not Subject to Overloading		Equipment (Such as Motors or Power Transformers) That May Be Overloaded			
			Normal Operation		Abnormal Operation	
Class II Group	°C	°F	°C	°F	°C	°F
E	200	392	200	392	200	392
F	200	392	150	302	200	392
G	165	329	120	248	165	329

Chapter 3

RECOMMENDATIONS

The present method of grouping combustible dusts (i.e., the 1978 NEC 500) proceeds in a qualitative way as pointed out in Chapter 1. That is, Group E consists of electrically conductive metals, Group F of semiconductive carbonaceous dusts, and Group G of nonconductive materials. The physical and chemical properties of individual dusts are not taken into account specifically, and combustibility data are often not available. In fact, in many cases the properties are not known.

This generalized classification method thus leads to apprehension about the general validity or accuracy of the classification. This apprehension is strengthened by the realization that many new substances enter commerce each year. Ideally, one would incorporate the properties and characteristics of a given substance into a predictive model for the explosion hazard in order to arrive at a classification. However, no such prediction technique or model has been validated. Testing techniques are available that are currently in use and that could be applied to assist in classification. But this is not a satisfactory solution for two reasons: First, it is unrealistic to test all the thousands of substances already in use and the new ones rapidly being introduced. Second, there is appreciable lack of confidence in the validity of the existing testing techniques.

The present NEC limits the maximum surface temperature that should be obtained with the equipment used for a particular group (see Chapter 2). This maximum temperature is related to dust-layer ignition temperatures, values that are not well known generally.

Therefore the panel recommends that

- As a temporary measure, NFPA modify the present NEC and classify explosible dusts into Groups E, F, and G through values of electrical resistivity, ρ, as follows:

  Group E, $\rho \leq 10^2$ ohm-cm,

  Group F, $10^2 < \rho \leq 10^8$ ohm-cm,

  Group G, $\rho > 10^8$ ohm-cm.

- The equipment proposed by the Dust Test Equipment Panel in its earlier report, NMAB 353-2,[2] be used in making an extensive round-robin series of tests to support the proposed resistivity levels dividing Groups E, F, and G.

- As a permanent measure, the proposed new classification of dusts, as given in Figure 2, be adopted. In that scheme, the concept of ignition sensitivity and explosion severity is employed. Locations involving combustible dusts with an ignition sensitivity less than 0.2 and explosion severity less than 0.5 should be treated as a weak explosion hazard, as defined by NFPA. The determination of the values of the factors that comprise ignition sensitivity and explosion severity, and hence the overall values for these indices, should be made by the experimental techniques described in Appendix A.

- Layer ignition temperature be determined by the test technique described in NMAB 353-2.[2]

- The maximum surface temperature of the electrical equipment be lower than the specified dust-layer ignition temperature by some differential value, e.g., 25°C. Furthermore, based on experience, an independent upper limit should be specified for the surface temperature of the electrical equipment.

- The same limitations on maximum surface temperature recommended for electrical equipment be applied to other (nonelectrical) equipment.

- Research be supported at a number of locations wherein analytical and experimental studies would be conducted to develop and validate a predictive model of the ignition and explosion hazards of dusts in the working place. These studies should take into account the chemical and physical properties of the dust, including composition; particle shape, size, and distribution; moisture content; apparent density; environmental factors, such as humidity and pressure; and geometry. The propagation of flames and explosions in working places of interest should be studied further. The results of such studies should lead to the classification of many dusts by knowledge of their properties and conditions, to more adequate testing techniques, and to steps that could be taken in the areas of prevention and control. This knowledge would also permit prediction of minimum ignition temperatures for clouds and layers, minimum ignition energies, minimum explosion concentrations, and pressures and rates of pressure rise.

- A laboratory be established to evaluate the explosion hazard of dusts in the working place.* This laboratory should be capable of testing and evaluating 150 to 200 samples each year using the procedure recognized at the time. The laboratory should do comparative testing, i.e., use various experimental techniques. It should determine properties of dusts, as needed. Further, it should be active in some of the research activities described in the previous recommendation. This laboratory should act as a clearinghouse for testing and research results worldwide and thus act in a supporting capacity to the appropriate industries and regulatory bodies.

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* The Bureau of Mines' Dust Explosions Research Laboratory closed operations in this field in the late 1960s.

APPENDIX A

IGNITION AND EXPLOSION HAZARD OF DUSTS

DEFINITION OF IGNITION SENSITIVITY AND EXPLOSION SEVERITY

In Figure 2 the terms ignition sensitivity[4] and explosion severity are used. Definitions of these terms require a somewhat detailed description of the equipment and procedures used to quantify the parameters involved.

The hazard of a dust is related to its ease of ignition and to the severity of the ensuing explosion. Among other parameters, the ease of ignition may be considered a function of the ignition temperature, minimum energy for ignition, and minimum explosion concentration; the severity of an explosion is related to the maximum pressure and the rate of pressure rise. To facilitate evaluation of the explosibility of dusts and to give a numerical rating to the relative hazard, empirical indexes were developed comparing values obtained for these parameters with similar values for a standard Pittsburgh coal dust. The ignition sensitivity and explosion severity of a dust are defined as:

$$\text{Ignition Sensitivity} = (T_c \cdot E \cdot C)_1 / (T_c \cdot E \cdot C)_2$$

$$\text{Explosion Severity} = (P \cdot \dot{P})_2 / (P \cdot \dot{P})_1$$

where subscripts 1 and 2 refer to Pittsburgh coal dust and the test dust, respectively , T_c is the cloud ignition temperature, E is the minimum ignition energy, C is the minimum explosion concentration, P is the maximum explosion pressure, and $\dot{P}$ is the maximum rate of pressure rise. The indexes are dimensionless quantities and have a numerical value of 1 for a dust equivalent to the standard Pittsburgh coal dust. The indexes were not derived from theoretical considerations but provide ratings of explosibility that are consistent with research observations and practical experience.

The relative ignition and explosion hazard of dusts may be further classified by ratings of weak, moderate, strong, or severe. These terms are correlated with the empirical indexes as shown in Table 3.[4]

Table 3 Correlation of Indexes with Relative Degree of Hazard

Degree of Hazard	Ignition Sensitivity	Explosion Severity
Weak	<0.2	<0.5
Moderate	0.2-1.0	0.5-1.0
Strong	1.0-5.0	1.0-2.0
Severe	>5.0	>2.0

Source: Jacobson et al.[4]

The data for Pittsburgh coal dust used in quantifying the ignition sensitivity and explosion severity of dust are as follows:

Cloud Ignition Temperature	610°C
Minimum Ignition Energy	0.06 J
Minimum Explosive Concentration	0.055 g/liter
Maximum Explosion Pressure	83 psig
Maximum Rate of Pressure Rise	2300 psi/s

LABORATORY EQUIPMENT AND PROCEDURES

Preliminary Examination of a Dust Sample

A sample is initially screened through a No. 20 sieve (840 μm); the fraction not passing through the sieve is weighed and discarded. A representative portion of the through-No. 20 sieve dust is then mechanically screened through No. 100 (149-μm) and No. 200 (74-μm) sieves to evaluate the particle-size distribution. The through-No. 200 sieve dust of a homogeneous substance is prepared by sieving. For a nonhomogenous material, the through-No. 200 sieve dust is prepared by grinding all of a representative portion. In practice, if 95 percent or more of the as-received dust passes through a No. 200 sieve, no further size reduction is made. A few tests are performed using the through-No. 20 sieve dust; complete tests are made with the through-No. 200 sieve dust.

The moisture content of the as-received material, except coal, is determined by drying at 75 °C for 24 h. Coal is dried at 105 °C for 2 h in accordance with ASTM Standard Method D271-58. Heat-sensitive materials are dried over a suitable dessicant at room temperature. Explosibility tests are conducted on dusts having 5 percent or less moisture; however, if moisture at this level is observed to affect dispersibility, the dust is further dried before testing.

Each dust is microscopically examined at magnifications of 100X and 400X to ascertain the shape, size, and other physical characteristics of the particles. When requested, the apparent density is determined and samples are sent to other laboratories for chemical analyses and X-ray or spectroscopic examination.

Ignition Temperature of a Dust Cloud

The ignition temperature of a dust cloud is determined in a Godbert-Greenwalt furnace[4] which consists of a 1-7/16-in. vertical Alundum tube, 9 in. long, wound with 21 ft of 18-gauge (0.824-mm^2) Nichrome V wire. The windings are spaced closer together toward the two ends than in the middle to provide a relatively consistent temperature throughout. The tube is mounted between two 1/2-in.-thick transite plates in a 6-in. diameter sheet-metal cylinder with kieselguhr packing between the Alundum tube and the sheet-metal cylinder. The top of the tube is connected by a glass adapter to a small brass chamber with a hinged lid for inserting the dust test sample. A full-port solenoid valve between the dust chamber and a 500-ml air reservoir controls the dispersion of the dust. The air reservoir is pressured to a selected level, indicated by a mercury manometer or any suitable gauge from a compressed-air line. Opening of the solenoid valve disperses the dust in the chamber downward through the furnace. The pressure used for dispersion ranges from 4 to 20 in. of mercury, depending on the density and dispersibility of the dust. Normally, 0.1 g of dust is used in the test, but the weight of the sample may be varied between 0.05 to 1.0 g if the quantity affects the determination.

The temperature of the furnace is measured with a 22-gauge (0.326-mm^2) chromel-alumel thermocouple 1/32 in. from the interior furnace wall at mid-height. The temperature is maintained at the desired value (within ±5 °C) by automatic control. Ignition is indicated by the appearance of flame projecting below the mouth of the furnace. The ignition temperature is the minimum furnace temperature at which flame is observed in one or more trials in a group of four. The nominal test increment is 10 °C.

Minimum Ignition Energy

The minimum electrical energy required for ignition of a dust cloud is determined in the Hartmann apparatus.[4] This consists of a vertically mounted, 2-3/4-in. tube 12 in. long and auxiliary equipment for producing the dust dispersion. The tube, made of Lucite, is attached to a cylindrical metal base or dispersion cup by hinged bolts. The top surface of the cup is machined to an approximately hemispherical shape. The total volume of the chamber is 1.23 liters. Dispersion is accomplished by a single blast of air from a 1.31-liter reservoir. The airflow controlled by a full-port solenoid valve, passes into the chamber through a mushroom-like deflector in the dispersion cup. The air pressure in the reservoir, determined by trial, ranges from 5 to 15 psig. The quantity of dust dispersed ranges from 5 to 10 times the minimum explosion concentration.

The top of the tube is covered with a filter-paper diaphragm held by a retaining ring. The spark constituting the igniting source passes between pointed 20-gauge (0.518-mm^2) tungsten-wire electrodes located 4 in. above the base of the tube. Preliminary trials are made by varying the electrode gap to determine whether this distance affects the minimum igniting value; the normal gap distance is 1/4 in. The spark is obtained from the discharge of capacitors at 100 V (to increase the energy range, the voltage is increased to 400 V). Oil-impregnated, paper-dielectric capacitors ranging from 2 to 100 μF are used. The capacitors discharge through the primary of a luminous-tube (neon) transformer. An electronic timer, with adjustable delay, controls the spark discharge in relation to the dust dispersion. The optimum time is determined during preliminary trials. The energy of the spark (in joules) is calculated as $0.5\ CV^2$, where C is the capacitance in farads and V is the charging potential in volts. The reported minimum energy for ignition of the dust cloud is the least required to produce flame propagation 4 in. or longer in the tube.

Four trials are made at each energy setting; however, if the dust ignites in initial trials, lower energy settings are tried until a minimum is obtained. The value of the minimum ignition energy is approximate, as some electrical energy is dissipated in the transformer circuit and some remains in the capacitors. For this reason, nominal rather than absolute values of energy are obtained. In limited trials with direct condenser discharge at high voltages, comparable minimum ignition energies were obtained for several dusts.

Minimum Explosion Concentration

The minimum explosion concentration or the lower explosive limit of a dust is determined in the Hartmann apparatus, except that an induction spark ignition source is employed rather than a timed capacitor discharge spark.

This test was developed to provide data corresponding to those obtained in large-scale experiments in galleries and in the Experimental Coal Mine using Pittsburgh coal dust.

A weighed quantity of dust is distributed in the dispersion cup. The top of the Lucite Hartmann tube is covered with a filter-paper diaphragm held in place with a retaining ring. A 1/16-in. hole is made in the center of the filter paper to prevent pressure buildup in the tube from the dispersing air. The electrodes are adjusted to a 3/16-in. gap, and when the electric spark is struck the current is set to 23.5 mA. The dust cloud is formed in the Lucite tube by dispersing the weighed dust sample with air released from the reservoir. Optimum dispersing air pressure ranges from 5 to 15 in. of mercury and is determined in preliminary trials.

Following ignition of the dust, sufficient pressure must be developed to rupture the diaphragm to indicate an explosion. The pressure required to burst the filter-paper diaphragm is about 2 to 3 psi, depending on the rate of pressure rise. If propagation occurs for a given weight of dust, the weight is reduced by 5 mg and another trial is made until a quantity is obtained that fails to propagate flame in any of four successive trials. The lowest weight at which flame propagates is used in calculating the minimum concentration. Tests are made with the electrodes at 2 and 4 in. from the bottom of the tube. The average of the two weights is divided by the volume of the tube (1.23 liters) to arrive at the minimum concentration. For materials that tend to agglomerate, 3 to 5 percent of fuller's earth may be admixed to facilitate dispersion.

In this test, a momentary dust cloud is produced by a single blast of air. This cloud is of short duration and is relatively nonuniform. To achieve controlled dust dispersion of known concentration, an apparatus was developed to produce a continuous dust-air stream. By varying the airflow and dust feed rate, a dust cloud of desired concentration was produced for studying the lower explosive limit. The results obtained with the continuous-stream method are similar to those obtained with the single-air-blast method in the Hartmann apparatus.

Explosion Pressure and Rates of Pressure Rise

Pressure and rates of pressure rise developed by a dust explosion are determined in a closed steel Hartmann tube. Dust dispersion is accomplished by releasing air from a 50-cc reservoir at 100 psig, instead of from the 1.31-liter reservoir at 14 psig previously described. The maximum pressure that can develop in the explosion tube from the dispersing air is 6.5 psig; however, because of rapid development of the dust explosion, the pressure from the dispersing air at the time of ignition is generally 2 to 3 psig. A full-port solenoid valve controls admission of the dispersing air, and a check valve prevents the combustion gases from escaping back into the dispersion reservoir. Ignition of the dust cloud is normally produced by the 24-W continuous spark source. For dusts that ignited with difficulty, the heated coil or guncotton source is tried.

The explosion pressure is measured by electronic transducers. The maximum pressure and the average and maximum rates of pressure rise developed in an explosion are determined from the pressure-time records. The dispersion pressure (initial pressure in the tube at time of ignition) is subtracted from the peak explosion pressure to give a corrected maximum pressure. The average rate is obtained by dividing the maximum pressure by the time interval between ignition of the dust cloud and the occurrence of the maximum pressure. The maximum rate is the steepest slope of the pressure-time curve. Normally explosion tests are made at dust concentrations of 0.1, 0.2, 0.5, 1.0, and 2.0 oz/ft^3.

Reproducibility of Tests

In laboratory tests, small quantities of dust (usually 1 g or less) are dispersed in a relatively small volume. Application of the numerical values obtained in the laboratory must be applied to large-scale industrial situations with caution. Factors involved are the generally incomplete and nonuniform dispersion in a large volume, the insufficient or excess dust present, the heat losses to the walls and enclosed equipment, the varying degrees of turbulence, and the intensity of the igniting source. Variations in particle shape and size distribution and the pretreatment of a dust are also important factors.

It is assumed that test samples are identical with regard to ignition and explosibility. The variation in the measurement of the parameters of ignition sensitivity is appreciable. For example, based on 10 repetitive tests, the mean ignition temperature of cornstarch dust clouds is 430°C. Assuming that systematic errors are not involved, the actual test temperature may be 430° ± 11°C at a 95 percent confidence level.

When data obtained in laboratory tests are reported, specific values are given even though they may not be statistically valid. For example, the minimum energy required for ignition of coal dust is reported at 0.06 J. A more complete study might show the probability of ignition at 0.06 J to be 0.25 at a 95 percent confidence level.

Acknowledgement

The section on Laboratory Equipment and Procedures is based on methods described in H. G. Dorsett, Jr. et al.[5]

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