CLASSIFICATION OF DUSTS RELATIVE TO ELECTRICAL EQUIPMENT IN CLASS II HAZARDOUS LOCATIONS

Report of the
Committee on Evaluation of Industrial Hazards

NATIONAL MATERIALS ADVISORY BOARD
Commission on Engineering and Technical Systems
National Research Council
National Academy of Sciences

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ABSTRACT

This document combines material presented in earlier National Materials Advisory Board reports and revises it to account for changes in the National Electrical Code that were made in 1981 and that reflect some of the recommendations of the Committee on Evaluation of Industrial Hazards.

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's (NRC) National Materials Advisory Board (NMAB)* classify several hundred gases, vapors, and dusts in accordance with the groupings in Article 500 of the National Electrical Code.** The committee's expertise is comprised of chemistry; combustion phenomena; knowledge of codes, standards, and regulations; electrical engineering; and industrial practices.

The committee established two panels to deal with combustible dusts--one to classify the dusts and one to recommend the test methods needed to determine dust classification parameters. The conclusions of the Panel on Dust Test Equipment, amended and approved by the committee, were presented in 1979 in Test Equipment for Use in Determining Classifications of Combustible Dusts (Report NMAB 353-2). The classification of dusts by the Panel on Classification of Combustible Dusts, amended and approved by the committee, was published in 1980 in Classification of Combustible Dust in Accordance with the National Electrical Code (Report NMAB 353-3). This document combines the material presented in these earlier reports and revises it to account for changes in the NEC that were made in 1981 and that reflect some of the recommendations of the committee. Thus, this report supersedes Reports NMAB 353-2 and NMAB 353-3.

The work of the committee relative to gases and vapors resulted in two reports: Matrix of Combustion-Relevant Properties and Classifications of Gases, Vapors, and Selected Solids (Report NMAB 353-1) was published in 1979 and classified certain chemicals based on physical and flammability data. Classification of Gases, Liquids, and Volatile Solids Relative to Explosion-Proof Electrical Equipment (Report NMAB 353-5) was published in 1982 and classifies additional chemical compounds. In addition, the committee is preparing another report, Rationale for Classification of Combustible Gases, Vapors, and Dusts with Reference to the National Electrical Code, (Report NMAB 353-6) which reviews the classification procedures for gases and vapors and for dusts and recommends changes to improve the procedures.

The chairman of the committee expresses his sincere thanks to all those participating in the study as well as to Stanley M. Barkin of the National Materials Advisory Board who provided staff support. Special thanks are given to Ernest C. Magison who prepared the first draft of this report and to Leland J. Hall and Peter J. Schram, respective chairmen of the Panel on Classification of Combustible Dust and the Panel on Dust Test Equipment.

Homer W. Carhart, Chairman

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* The National Materials Advisory Board is a unit of the Commission on Engineering and Technical Systems of the National Research Council. Its general purpose is the advancement of materials science and engineering in the national interest. It fulfills that purpose by providing advice and assistance to government agencies and private organizations on matters of materials science and technology affecting the national interest, by focusing attention on the materials aspects of problems and opportunities, and by making appropriate recommendations for the solution of such problems and the exploitation of the opportunities.

**The chemicals and materials to be classified originally included those subject to an earlier NRC study for the U.S. Coast Guard and those listed by OSHA in the Federal Register on June 27, 1974 (pp. 23541-3). The list subsequently was expanded (with additional support from the National Institute for Occupational Safety and Health) to include the gases and vapors listed in Fire Hazard Properties of Flammable Liquids, Gases, Volatile Solids, Manual 325M issued by the National Fire Protection Association (NFPA) in 1977. The dusts to be classified were those listed in 1976 in the NFPA's Fire Protection Handbook (pp. 3-107 to 3-114).

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Chapter 1

SUMMARY OF RECOMMENDATIONS

The present method of grouping combustible dusts (i.e., the 1981 NEC 500) is based solely on electrical resistivity. In addition, 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 committee, based on its study and the work of its panels, recommends that:

1. Dusts having an ignition sensitivity less than 0.2 (i.e., a low probability of ignition) and an explosion severity less than 0.5 (i.e., a low consequence) should be considered as constituting only a weak explosion hazard, and electrical equipment suitable for Class II locations should not be required for these dust atmospheres.

2. Dusts with an ignition sensitivity equal to or greater than 0.2 or an explosion severity equal to or greater than 0.5 should be classified solely on the basis of resistivity into two arbitrary groups, E and G.

3. The specification of maximum permitted surface temperatures, such as is presently done in the National Electrical Code, should be continued. However, to provide for safe use of electrical apparatus in the presence of dusts with layer ignition temperatures lower than these maximum permitted temperatures, the maximum surface temperature of electrical equipment should be required to be lower than the layer ignition temperature by a fixed differential (e.g., 25°C).

4. The test procedures for measuring resistivity and layer ignition temperature should be those described in this document.

5. There is a need for consistency in dealing with the hazard of hot surfaces, and those responsible for safety in locations made hazardous by the presence of combustible dusts should apply the same limitations on maximum surface temperature to all equipment, not only electrical equipment.

6. Analytical and experimental research should be undertaken to develop and validate a predictive model that can be used as a basis for classifying the ignition and explosion hazards of a dust in the workplace based on its properties and conditions. Such research also could lead to development of more adequate testing techniques and could suggest new methods for preventing and controlling dust explosions. (A potential approach is described in NMAB 353-6.)

7. A laboratory should be established to evaluate the explosion hazard of dusts in the workplace.* This laboratory should be capable of testing and evaluating 150 to 200 samples each year using the current standard procedures. The laboratory also should perform comparative testing (i.e., use various experimental techniques) and should determine properties of dusts, as needed. Further, it should be active in some of the research activities recommended in item 6 above and should act as a clearinghouse for domestic and foreign testing and research results in support of affected industries and regulatory bodies.

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

Chapter 2

RATIONALE FOR 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 (Palmer 1973). Since that time, dust explosions also have occurred persistently in a wide variety of other industries (e.g., agriculture, mining, chemicals, and plastics). The possibility of such explosions often is unrecognized because a material may present little or no explosion hazard in bulk form and becomes extremely hazardous only when in the form of a dispersible dust.

Until the 1981 edition was published, the National Electrical Code (NEC) classified dusts in three general categories: agricultural, carbonaceous, and metallic. Selection and installation rules for electrical equipment recognized that the hazards posed by electrically conductive dusts and electrically nonconductive dusts were different, but it was not until the 1981 edition was published that the NEC quantified the boundary values of electrical resistivity for Groups E, F, and G dusts and explicitly stated a value of resistivity below which a dust must be considered electrically conductive. These 1981 amendments to the NEC resulted, at least in part, from the earlier work of this committee and particularly its Panel on Classification of Combustible Dusts.

The work of the Panel on Classification of Combustible Dusts was initiated after the Occupational Safety and Health Administration (OSHA) requested that this committee classify a submitted list of several hundred gases, vapors, and dusts in accordance with the groups presented in Article 500 of the NEC. In work previously conducted for the U.S. Coast Guard by the NRC Committee on Hazardous Materials (1970, 1971, 1973, 1974), a method to classify flammable gases and vapors had been established, and this method was used by the committee to prepare a matrix of combustion-relevant properties and classifications of gases, vapors, and selected solids (Committee on Evaluation of Industrial Hazards 1979). However, neither the NEC nor other standards give a rationale for classifying combustible dusts in Class II, Groups E, F and G as defined in NEC Article 500. Although many test methods for determining parameters of dusts that are relevant to classification were known, none were generally accepted and recognized by common use. Accordingly, the committee established the Panel on Dust Test Equipment to recommend needed test methods.

PREMISES FOR CLASSIFYING DUSTS INTO GROUPS E, F, AND G

The committee considered the following four premises prior to classifying dusts into Groups E, F, and G:

1. The classification method must be closely related to the standards for selection and installation of electrical apparatus in Class II locations mandated by the NEC.

2. The classification method need not encompass the classification of dusts with such inherently high fire or explosion potential that the incremental hazard caused by the presence of electrical apparatus is insignificant. Such dusts require special consideration and handling beyond the scope of the NEC.

3. The classification method should permit classification of any unclassified dust based on easily determined parameters but also must allow, if available data permit, the identification of dusts that are a fire hazard but not a serious explosion hazard. Such dusts need not be classified according to the NEC guidelines.

4. The classification method must permit classification of plastic and chemical dusts as well as agricultural, carbonaceous, and metallic dusts.

CONSEQUENCES OF THESE PREMISES

Premise 1

NEC selection and installation requirements for Class II locations specify use of dust-ignition-proof enclosures or dust-tight enclosures, depending on the type of equipment enclosed and the relative hazard of the location. In addition, the NEC specifies maximum surface temperatures for electrical apparatus. Underlying these rules is the assumption that the tight enclosures will prevent dust from entering so that arcs, sparks, or hot surfaces inside the enclosure cannot ignite the dust, and the external surfaces of the apparatus will not reach a temperature sufficiently high to ignite a dust cloud or a layer of dust which may accumulate.

The use of an enclosure to prevent ignition permits a dust to be classified using only the resistivity limits specified by the NEC. Ignition energy, explosive limits, and other combustion parameters need not be known.

As explained below, the requirement that the surface temperature of apparatus be low enough not to ignite a layer of dust deposited on the apparatus demands a knowledge of the layer ignition temperature of the dust. This parameter is used in selecting apparatus for safe use, not for classifying a dust according to the NEC guidelines.

Premise 2

The objective of the NEC is to provide guidance concerning the selection and installation of electrical equipment to minimize danger from electrical shock, fire, and explosion resulting from the use of electrical equipment. Stated differently, the goal is to ensure that the risk of shock, fire, or explosion is not significantly greater when electrical apparatus is used than it would be if there were no electrical equipment present.

Given this objective, it is not meaningful to classify materials that inherently pose a high fire and explosion hazard because the incremental risk resulting from the presence of electrical apparatus is low. Pyrophoric materials, strong oxidizers, and explosives that demand special precautions in use and handling need not be classified.

Premise 3

As explained above, a combustible dust can be classified in Group E, F, or G if only the resistivity of the dust is known. The test for determining resistivity is simple, easy to use, and accurate enough for safe classification. However, some dusts (e.g., cereal grass, cotton linters and some plastics dusts) can be fire hazards but are only weak explosion hazards because they are relatively difficult to ignite and, if ignited, produce relatively weak explosions. The classification of these dusts based on resistivity alone would impose economic penalties on the user of electrical apparatus (i.e., the user would have to select and install special electrical apparatus despite the fact that, in practice, the hazard level is so low that general-purpose apparatus could be used safely). Therefore, the method of classifying dusts based on pertinent combustion parameters permits the identification of low hazard potential dusts, so that they need not be classified. Classification of a low hazard potential dust is always safe, but may be uneconomic.

The apparatus for use in determining the parameters needed to evaluate the severity of hazard is much more expensive to construct than that required for the resistivity test and the test methods require much greater skill than that required for the resistivity test. Also the parameters needed to evaluate the severity of hazard are much more controversial.

Premise 4

The NEC requirement that the surface temperature of electrical apparatus be limited to prevent ignition of deposited layers of dust, or dust clouds, presently is implemented by imposing maximum surface temperature limits on

electrical apparatus, depending on the type of apparatus and the group classification of the dust. If NEC rules are to be applied to dusts other than metallic, carbonaceous, and agricultural dusts, a provision must be made for dusts that might ignite in cloud or layer form at a temperature lower than the maximum surface temperatures presently stipulated in the NEC.

A review of published data (Dorsett and Nagy 1968, Jacobson et al. 1961, 1962, and 1964, Nagy et al. 1965 and 1968) indicated that, with some exceptions (approximately 50 out of 1500), the temperature of a heated surface required to cause ignition was always lower for a layer of dust on the surface than it was for a dust cloud in a heated chamber. In those cases in which the cloud ignition temperature was lower than the layer ignition temperature, it was apparent that either:

1. There was a change in state of the dust from a solid to a gas (a typical example would be asphalt),

2. The material in the cloud ignition temperature test was somewhat different from that in the layer ignition temperature test because of oxidation of each particle (an example would be atomized aluminum), or

3. The difference in temperature was within the test tolerance and, as such, is probably not significant.

The committee reasoned that dust cloud ignition temperatures need not be considered in the basic classification scheme because of the small number of dusts having cloud ignition temperatures lower than their layer ignition temperatures. (See Appendix D for a list of dusts that have been found, under test conditions, to have cloud ignition temperatures lower than the layer ignition temperatures.) Although the cloud ignition temperature is required to determine ignition sensitivity, it need not be considered in characterizing a combustible dust once the decision has been made that the dust is combustible and therefore needs classification. The layer ignition temperature is defined to include not only observation of ignition but also any observable change in physical state during the test.

Because the layer ignition temperature may be lower than the maximum surface temperature now permitted by the NEC, the committee recommends that, for safe selection of equipment for use in the presence of such dusts, the maximum surface temperature should be required to be lower than the layer ignition temperature by a fixed differential (e.g., 25°C).

Although dust characteristics such as particle size and shape, thermal insulating properties, abrasiveness, previous history (of metallic dusts), and moisture content may affect explosion parameters significantly in laboratory tests, these effects are not judged to be significant enough to change the classification of a dust. Particle size and shape are known to affect the critical properties of dust, but the availability of a relatively simple and specific test method to determine resistivity and layer ignition

temperature permits the specific dust available in the area under consideration to be evaluated should there be any question as to the group classification.

The thermal insulating properties of a dust will have some effect on the surface temperature of the electrical equipment on which it collects, particularly equipment that generates considerable heat such as lighting fixtures and motors, however, this effect is judged to be relatively minor for most combustible dusts. The abrasiveness of a dust is not pertinent to its classification. An abrasive dust speeds wear of moving parts (e.g., motor bearings) and allows dust to enter the equipment; therefore, abrasiveness is a parameter to be considered in equipment design, inspection, and maintenance, not a parameter related directly to explosion properties of the dust.

The previous history of a dust, particularly metal dusts, is judged to be a critical factor with respect to electrical resistivity. The committee felt that for such highly conductive dusts the electrical resistivity of the solid from which the dust is formed generally should be considered to be the electrical resistivity of the dust itself.*

Although moisture content is known to have an effect on the ignition properties of dust, the major effect appears to be to accelerate spontaneous ignition of non-metallic dusts when the dust is in deep layers. The effect of moisture content on ignition properties was judged to be of only minor significance with respect to ignition by the heated surface of electrical equipment because the heat of the surface would drive off the moisture.

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*In special situations, the method recommended in this report can be used if the samples tested are representative of those actually present in the workplace. That samples are representative is, of course, subject to agreement by the responsible code-enforcing authority. The resistivity also must be measured under conditions comparable to those to which the dust is present in practice. The test for resistivity must be conducted at the high voltage to which the dust may be exposed to ensure that high resistivity surface coatings do not break down when subjected to a voltage gradient in equipment that is higher than that used during measurement.

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Chapter 3

DUST CLASSIFICATION METHODS

CLASSIFYING USING THE 1981 NEC RESISTIVITY GUIDELINES

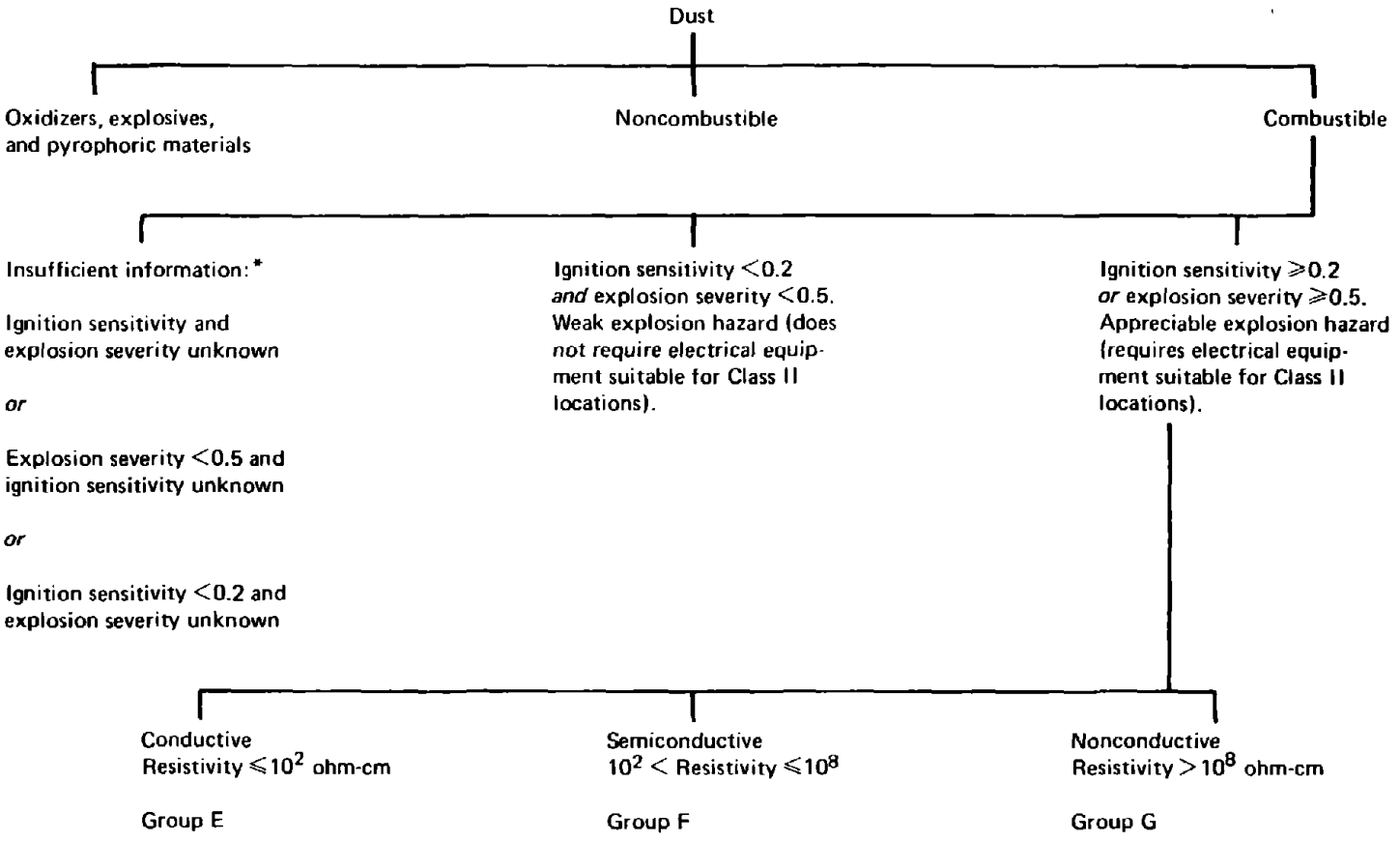
Dust is classified into Group E, F, or G according to the 1981 NEC resistivity guidelines by using the decision tree approach shown in Figure 3-1.

It is first determined whether a specific material is an oxidizer, an explosive, or a pyrophoric material; a noncombustible material; or a combustible material. If the dust is an oxidizer, explosive, or pyrophoric material, it may require safeguards beyond those required for atmospheres in which equipment designed for use in Class II locations as defined in the NEC can be used and the electrical equipment should not be utilized without further testing or evaluation. If the dust is noncombustible, classification need not proceed further since electrical equipment suitable for Class II locations is not required.

If the dust is combustible, the next step is to consider whether the data needed to determine ignition sensitivity and/or explosion severity (see Appendix A for definitions) are available. If ignition sensitivity data and/or explosion severity data are not available, the 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.

It is not always necessary to test a dust to determine resistivity in order to classify it. Resistivity can be estimated for purposes of classification except in doubtful cases. Metal dusts should be presumed to be Group E unless tests have been conducted. Plastic and chemical dusts and agricultural dusts can usually be classified as Group G because of their similarity to other dusts that have been classified. If it is desirable to assess the relative hazard of the dust, the data required to determine ignition sensitivity and explosion severity should be acquired.

A dust that has an ignition sensitivity less than 0.2 and an explosion severity less than 0.5 poses a weak explosion hazard and does 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 requires electrical equipment suitable for Class II hazardous locations.



*Treat as if ignition sensitivity were ≥0.2 *or* explosion severity were ≥0.5 and base group classification on resistivity or on best judgment.

FIGURE 3-1 Classification of dusts (using the 1981 NEC resistivity guidelines).

Test procedures for quantifying ignition sensitivity and explosion severity are described in Appendix A, and were used to derive the values presented in Table 4-1. It is recognized, however, that any change in test equipment may affect the numerical values for explosion severity or ignition sensitivity (e.g., in a chamber larger than that of the Hartmann apparatus, the values of the maximum pressure and the rate of pressure rise may be different).

Ignition sensitivity and explosion severity are not fundamental combustion parameters of a combustible dust but are apparatus dependent values. If, in the future, standard test methods different from those discussed in Appendix A are adopted for use, the values of ignition sensitivity and explosion severity used in classifying dusts must be re-established. It should be emphasized that the values are not sacred. What is important is that dusts from such materials as chlorinated rubber, milled antimony, Pennsylvania anthracite, egg white, and cereal grass (indicated in Table 4-1 by d) are not explosion hazards. The criteria in Figure 3-1 and in Figure 3-2 have been established based on experience with such dusts, and if new test methods yield different values, the criteria must be changed accordingly.

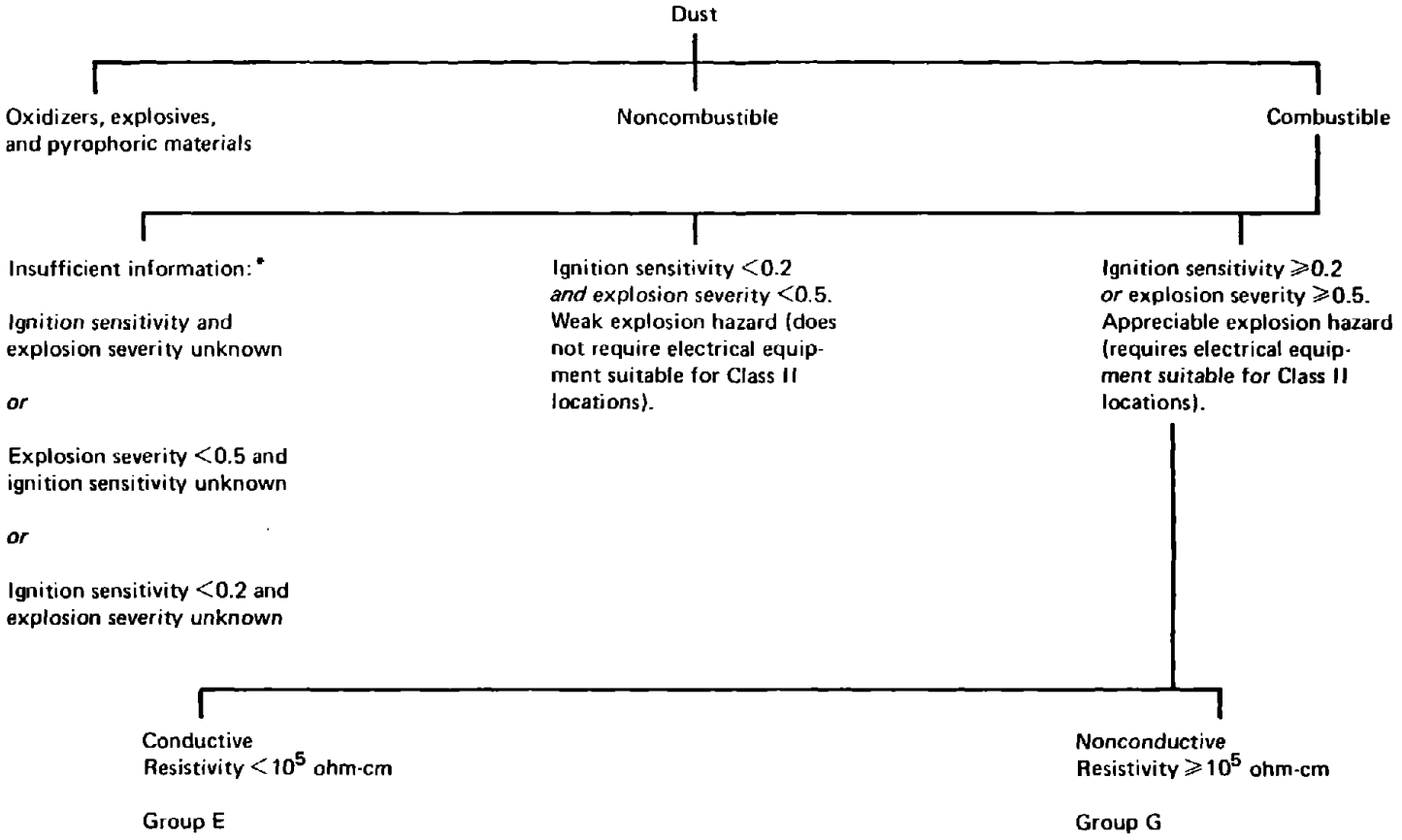
PROPOSED NEW CLASSIFICATION OF DUSTS

The committee proposes that future classifications be made as outlined in Figure 3-2. This proposal separates dusts into two rather than three groups. Group F is considered unnecessary and undesirable in the proposed new classification scheme. It now includes dusts with electrical resistivities both greater and less than the dividing line between conductive and nonconductive combustible dusts, and electrical equipment selected and installed according to the 1981 NEC is essentially the same for atmospheres containing Group E and electrically conductive Group F dusts. Therefore, under the proposed scheme, Group F is eliminated and equipment selection is restricted to Group E and Group G dusts.

The committee believes, however, that equipment operated at over 600 V may present a problem if electrically semiconductive dust is present on uninsulated live parts. It therefore recommends that if Group F is eliminated in some future edition of the NEC, consideration be given to requiring:

1. That equipment containing uninsulated live metal parts operating at greater than 600 V comply with the requirements for equipment for use in Division 1 locations and

2. That plugs and receptacles connected to circuits rated over 600 V be considered unacceptable where conductive dusts are present.



*Treat as if ignition sensitivity were ≥0.2 *or* explosion severity were ≥0.5 and base group classification on resistivity or on best judgment.

FIGURE 3-2 Proposed new scheme for classification of dusts.

This recommendation is based on reports to the committee indicating that plugs and receptacles in mines have short-circuited when operating in excess of 600 V.

Because dust settles and forms layers on operating equipment, the present NEC states that the maximum surface temperatures under actual operating conditions should not exceed those shown in Table 3-1. The committee proposes that a different approach be considered.

TABLE 3-1 Maximum Surface Temperatures

			Equipment (e.g., Motors or Power Transformers) Subject to Overloading			
			Normal Operation		Abnormal Operation	
Class II Group	Equipment Not Subject to Overloading °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

The method employed to measure dust layer ignition temperature parallels what happens to dust that has settled on electrical equipment that generates heat. It is realized that surface temperature and ignition temperature depend on layer thickness and dust compactness; therefore, the committee 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 committee believes that such a safety factor is appropriate and will give the user some flexibility in judgment. Furthermore, the committee recommends that the NEC continue to specify an independent upper limit, based on experience, for the surface temperature of the electrical equipment.

*Field experience or other special conditions may dictate use of another differential value in some specific cases.

TEST APPARATUS

Based on the rationale given in Chapter 2 of this report, only data for layer ignition temperature and resistivity are essential for the classification of a combustible dust. The Panel on Dust Test Equipment reviewed the methods presently used to determine the layer ignition temperature and the electrical resistivity of dusts. Based on the panel's findings, the committee recommends use of:

1. A modified version of the proposed International Electrochemical Commission hot plate method to determine the layer ignition temperature, and

2. A modified version of the method presented in the Instrument Society of America's Area Classification in Hazardous Dust Locations, ISA-S12.10-1973, to determine electrical resistivity.

These recommended methods and the panel's rationale are described in detail in Appendixes B and C.

The panel initially considered methods of testing for thermal and oxidative stability as well as layer ignition temperature and electrical resistivity. A review of the literature disclosed several different techniques for the determination of long-term stability, including thermogravimetric analysis, an active oxygen method, a modified ASTM oxygen bomb method, differential scanning calorimetry, and pressure differential scanning calorimetry. It appeared, however, that no single standardized analysis technique was suitable for all types of material and that no such technique could be established. The panel, therefore, decided that the method recommended for determining the ignition temperature of a dust layer would provide sufficient information on short-term thermal and oxidative stability and that no technique should be recommended at this time for determining long-term thermal and oxidative stability.

TESTING AND RESEARCH

The U.S. Bureau of Mines' Dust Explosions Research Laboratory closed operations in the late 1960s and there now is no laboratory available to conduct routine determinations of the combustion parameters of dusts. Such a laboratory is needed to evaluate the explosion hazard of dusts found in the workplace using currently recognized testing methods. This laboratory also could carry out research needed to specify more adequate testing techniques and to develop methods of classifying dusts in accordance with the severity of explosion hazard based on the properties and physical condition of the dust.

This laboratory also could act as a clearinghouse for other domestic and overseas research and testing results in support of affected industries and regulatory bodies.

Chapter 4

CLASSIFICATION OF VARIOUS DUSTS

OSHA requested that the committee classify dusts according to the NEC. The materials considered are listed in Table 4-1, which was taken from Table 3-8A of the NFPA's Fire Protection Handbook, 14th edition. The next to last column of Table 4-1 lists the classifications of these materials according to the 1981 edition of the NEC. The methodology used in classifying the dusts is described in Chapter 3 of this report. The last column of Table 4-1 lists classifications according to the recommended scheme described in Chapter 3 and illustrated in Figure 3-2.

It is recognized that the materials tabulated in Table 4-1 do not include all of 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 4-1 Classification of Dusts by National Electrical 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 1981	NEC Classification Recommended
I 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	0.2	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 (cereal)	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	460	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 4-1 Classification of Dusts by National Electrical Code (cont'd)

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 1981	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[f]	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[e,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[f]	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	35.0[f]	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
Pheny, 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 4-1 Classification of Dusts by National Electrical Code (cont'd)

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 1981	NEC Classification 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 basic 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	L+[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 4-1 Classification of Dusts by National Electrical Code (cont'd)

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 1981	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	[i]
Tin, atomized (96% Sn 2% Pb)	0.2	0.3	37	1,500	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		[k]	E	E[h]
Uranium	37.2	0.9	53	3,400	20	100	0.045	0.060	E	[i]
Uranium hydride	336	1.5	43	6,500	20	20	0.005	0.060	E	[i]
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	[i]
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]	E[e]
Ferromanganese, medium carbon	0.4	1.0	47	4,200	450	290	0.080	0.130	E[e]	E[e]
Ferrosilicon (88% Si, 9% Fe)	< 0.1	1.6	87	3,600	860	800	0.400	0.420	E[e]	E[e]
Ferrotitanium (19% Ti, 74.1% Fe, 0.06% C)	0.5	2.6	53	2,200	370	400	0.080	0.140	E[e]	E[e]
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 vanicide	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 4-1 Classification of Dusts by National Electrical Code (cont'd)

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 1981	NEC Classification 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 (7/20/10)	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	1.6	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. maximum	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 4-1 Classification of Dusts by National Electrical Code (cont'd)

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 1981	NEC Classification 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	-	[c]	[c]	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, nemuresinous	-	< 0.1	18	200	460	-	[c]	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 4-1 Classification of Dusts by National Electrical Code (cont'd)

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 1981	NEC Classification 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.

Appendix A

IGNITION AND EXPLOSION HAZARD OF DUSTS

DEFINITION OF IGNITION SENSITIVITY AND EXPLOSION SEVERITY

Definition of the terms "ignition sensitivity" and "explosion severity" requires 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 that compare 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:

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

and

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

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; $\dot{P}$ is the maximum explosion pressure; and 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. They 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 index as shown in Table A-1.

TABLE A-1 Correlation of Indexes with Relative Degree of Hazard

Degree of Hazard Severity	Ignition Sensitivity	Explosion
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. 1961.

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 Explosion Concentration	0.055 g/l
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 then is screened mechanically 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 D3176 and D3180. 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 dried further before testing.

*Based on methods described in Dorsett et al. 1960.

It is recommended that each dust be microscopically examined at magnifications of 100X and 400X to ascertain the shape, size, and other physical characteristics of the particles. When applicable, the apparent density should be determined. Chemical analyses and X-ray or spectroscopic examination then may be desirable. This physical and chemical data will aid in interpretation of differing test results for similar materials.

Ignition Temperature of a Dust Cloud

The ignition temperature of a dust cloud is determined in a Godbert-Greenwalt furnace that 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 (Dorsett et al. 1960). The windings are spaced closer together toward the two ends than in the middle to provide a relatively constant temperature throughout the tube. 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 betweeen 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 $\pm 5^{o}C$) 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 $10^{o}C$. Appearance of excessive smoke is an indication that the quantity of dust placed in suspension or the pressure used for dispersion may need to be adjusted.

Minimum Ignition Energy

The minimum electrical energy required for ignition of a dust cloud is determined in the Hartmann apparatus which 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 l. Dispersion is accomplished by a single blast of air from

a 1.31-l 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, which must be determined by trial.

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 to determine minimum energy. 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 since 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 capacitor 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 l) 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 disperson is accomplished by releasing air from a 50-ml reservoir at 100 psig, instead of from the 1.31-l 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 normally is produced by the 23.5 mA continous spark source. For dusts that ignited with difficulty, a 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 to large-scale industrial situations must be done with caution. The 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 also are 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 $\pm$ 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.

REFERENCES

Dorsett, H. G., Jr., Jacobson, M., Nagy, J., and Williams, R. P., Laboratory Equipment and Test Procedures for Evaluating Explosibility of Dusts, Report of Investigations 5624, U.S. Bureau of Mines, Pittsburgh, Pennsylvania, 1960.

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Appendix B

LAYER IGNITION TEMPERATURE

BACKGROUND

The committee's Panel on Dust Test Equipment considered five methods for determining the layer ignition temperature of combustible dusts:

1. The hot plate method of the U.S. Department of the Interior, U.S. Bureau of Mines (private communication, M. Jacobson, U.S. Bureau of Mines, 1977).

2. The modified Godbert-Greenwald furnace method of the U.S. Department of the Interior, Bureau of Mines (Dorsett et al. 1960).

3. The standard method of test for ignition properties of plastics of the American Society for Testing and Materials (ASTM designation D 1929-68).

4. The hot plate method developed by the British Fire Research Station (private communication from the International Electrotechnical Commission SC 31H/WG2, February 1975).

5. The hot plate method proposed as the International Electrotechnical Commission (IEC) test method by IEC Subcommittee 31H, Working Group 2 (IEC 1975).

It was the consensus of the panel that the test method to be recommended should be a hot plate method because of the simplicity and availability of the equipment involved. Available test data indicate that similar test results are obtained when using different hot plate test methods, when different laboratories use the same method, and when repeated tests are performed in the same laboratory.

It also was noted that the difference in results between the U.S. Bureau of Mines' hot plate method and furnace method is about $\pm 20^{\circ}C$. The proposed IEC test method was chosen by the panel as the foundation of its recommended method because there is a relatively wide data base for this method that indicates that it produced results as reproducible as any method studied. The method recommended by the panel for determining the layer ignition temperature of combustible dusts is described below, and the differences between it and the IEC test method are discussed.

Most of the data readily available in the United States on the ignition temperature of combustible dusts layers is the result of tests by the U.S. Bureau of Mines using dust passing through a 0.074-mm (200-mesh) sieve. The

test method recommended by the IEC requires that the dust pass through a 0.2-mm (70-mesh) sieve, with an exception if it is necessary to test coarser dust. There are no reported data correlating the layer ignition temperatures using dust samples identical to each other except for the particle size. Although most experts believe that the difference in layer ignition temperature between dusts passing through 0.2-mm and 0.074-mm sieves is minimal, the panel decided to recommend use of the 0.074-mm sieve because of the lack of reported correlation data and the mass of information already available on layer ignition temperatures using dust passing through a 0.074-mm sieve. This decision errs, if at all, on the side of safety.

Other relatively minor changes from the IEC recommended test method (e.g., thickness of dust layer) also have been made by the panel to reduce the likelihood of differences between layer ignition temperatures obtained using the test method recommended and layer ignition temperatures reported by the U.S. Bureau of Mines.

The panel's recommendation that the melting temperature be considered the ignition temperature if the material melts before an ignition is observed is based on the behavior of molten material, which is different from the behavior of material in the form of dust. Electrical equipment evaluated and found acceptable for use in the presence of dust may not be acceptable when exposed to molten material.

RECOMMENDED TEST METHOD FOR IGNITION TEMPERATURES OF DUST LAYERS

Scope

This test method is intended to determine the minimum temperature of a hot surface that will result in the ignition of a layer of particulate solid, or dust, of specified thickness deposited on it. The test is not suitable for use with substances having explosive properties.

Definitions

For the purpose of this recommendation the following definitions apply:

1. Ignition--The initiation of combustion in the material under test. Ignition should be considered to have taken place at the minimum hot plate temperature at which: (a) there is visible evidence of combustion such as a red glow or flame, (b) the slope of the temperature-time curve for a thermocouple in the center of the dust layer continues to increase, (c) a 50°C temperature rise above hot plate temperature in the dust occurs, or (d) the dust melts.

2. Ignition Temperature of a Dust Layer--The lowest temperature of a hot surface, rounded to the nearest integral multiple of 10°C, at which ignition occurs in a dust layer of given thickness on the hot surface when the procedure in this recommendation is followed.

Preparation of Dust Sample

The dust should be able to pass a 0.074-mm (200-mesh) sieve. If necessary, any dust passing a 0.84-mm (20-mesh) but not a 0.074-mm (200-mesh) sieve should be ground to reduce the particle size until all of the dust passes a 0.074-mm (200-mesh) sieve. The ground and unground (fine dust) samples then should be mixed. The sample must be representative of the dust received and the dust used in the test should be well mixed. Any changes caused in the properties of the as-received dust samples (e.g., by sieving or grinding) should be reported.

General Description of Apparatus

The apparatus is shown schematically in Figure B-1. Essential details and performance requirements are described below.

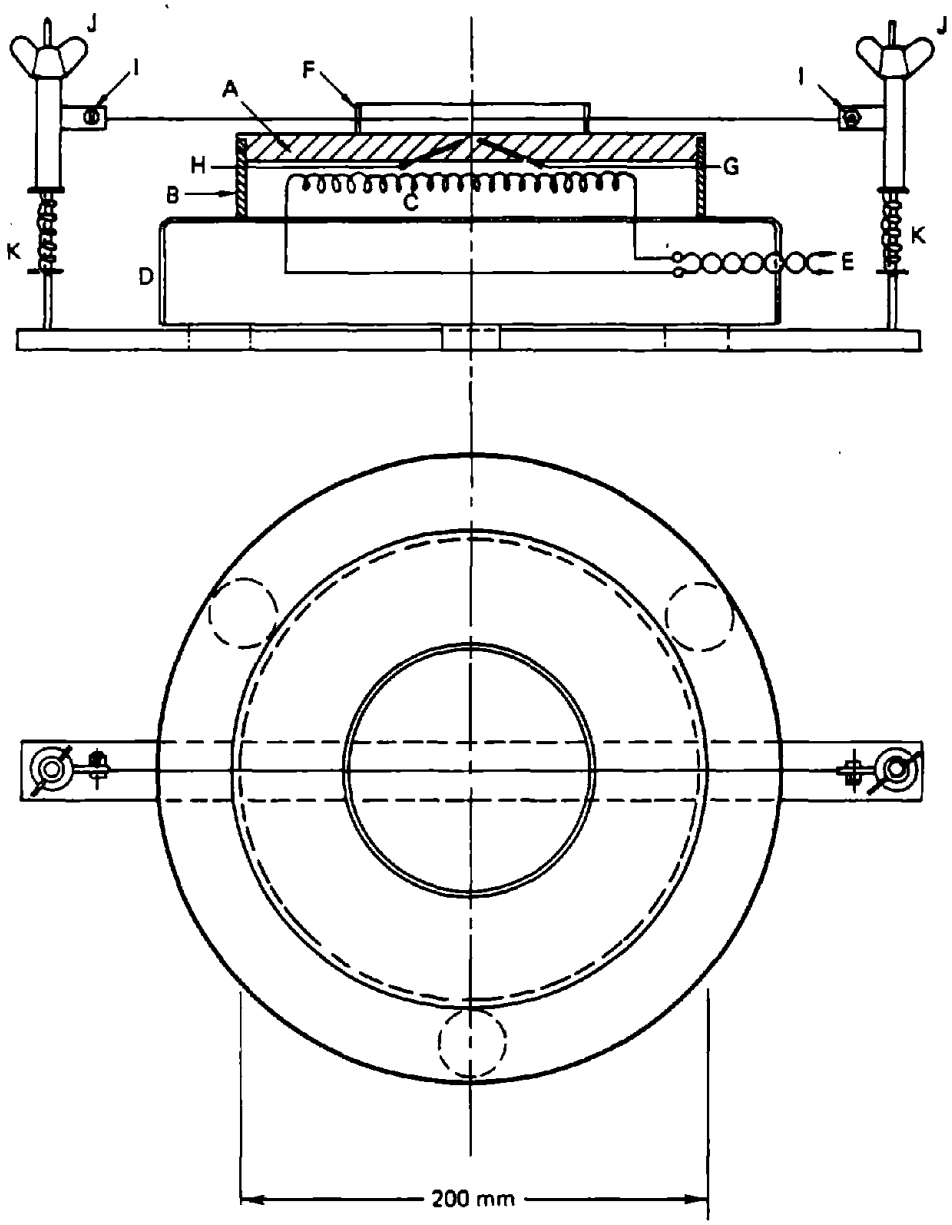
Heated Surface. The heated surface should consist of a circular stainless steel plate 200 mm in diameter and not less than 20 mm thick. The plate should be heated by an electrical heating element and its temperature should be controlled by a device for which the sensing element is a thermocouple mounted in the plate at the center and with its junction in contact with the plate and within 1 ±0.5 mm of the upper surface. The same thermocouple should be connected to a temperature recorder for recording the temperature of the plate during a test. The heated plate and its controller should satisfy the following performance requirements:

1. The plate should be capable of attaining a maximum temperature of 400°C without a dust layer in position.

2. The temperature of the plate must be constant to within ±5°C throughout the period of the test.

3. When the temperature of the plate has reached a constant value, the temperature across the plate should be uniform to within ±5°C when measured across two diameters at right angles using a procedure like that illustrated in Figure B-5 (this requirement shall be satisfied at plate temperatures of 200 ±5°C and 350 ±5°C measured at the center of the plate).

4. The temperature control should be such that the recorded plate temperature will not change by more than ±5°C during the placing of the dust layer and will be restored to within 2°C of the previous value within 5 min of placing the dust layer.



A – Heated Plate
B – Skirt
C – Heater
D – Heater Base
E – Heater Connection to Power Supply and Controller
F – Ring for Dust Layer
G – Plate Thermocouple to Controller
H – Plate Thermocouple to Recorder
I – Dust Layer Thermocouple to Recorder
J – Screw Adjustment for Thermocouple Height
K – Coil Spring

FIGURE B-1 General arrangement of hot plate (not to scale).

5. Temperature control and measurement devices should be calibrated and should be correct to within $\pm 3^{o}C$.

Test Thermocouple. A fine thermocouple (0.20 to 0.25 mm in diameter) should be located so that the junction is at the geometric center of the dust sample. The thermocouple should be stretched across the heated plate parallel to the surface. This thermocouple should be connected to a temperature recorder for observing the behavior of a dust layer during tests.

Temperature Measurement. Temperature measurements with the thermocouple should be made either relative to a fixed reference junction temperature or with automatic cold junction compensation. In either case, calibration should satisfy the above $\pm 3^{o}C$ accuracy requirement.

Ambient Temperature. The ambient temperature should be measured by a thermometer placed in a convenient position within 1 m of the hot plate but shielded from heat convection and radiation from the plate. The ambient temperature should be within the range of 10 to $30^{o}C$.

Dust Layers. Dust layers should be prepared by filling the cavity formed when a stainless steel ring is placed on the surface of the hot plate and by leveling the layer to the top of the ring (Figure B-2). The ring should be 100 mm in diameter and should have slots at opposite ends of the diameter to clear the test thermocouple (Figure B-3). The ring should be left in place during a test. A given dust should be tested in a layer that is 12.5 mm deep. A ring of the appropriate depth will be required.

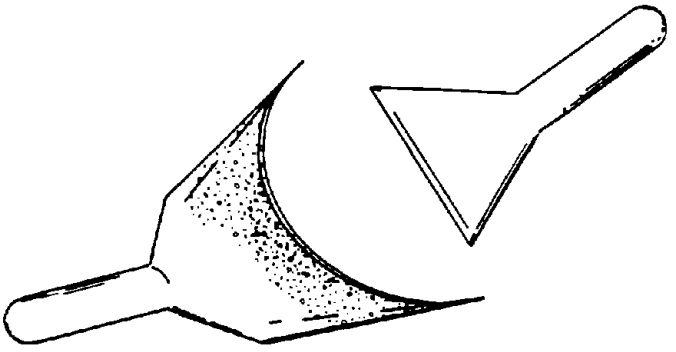


FIGURE B-2 Scoops recommended for forming dust layers. The scoop with the concave edge supports the ring and collects excess dust swept toward it in leveling the layer formed inside the ring.

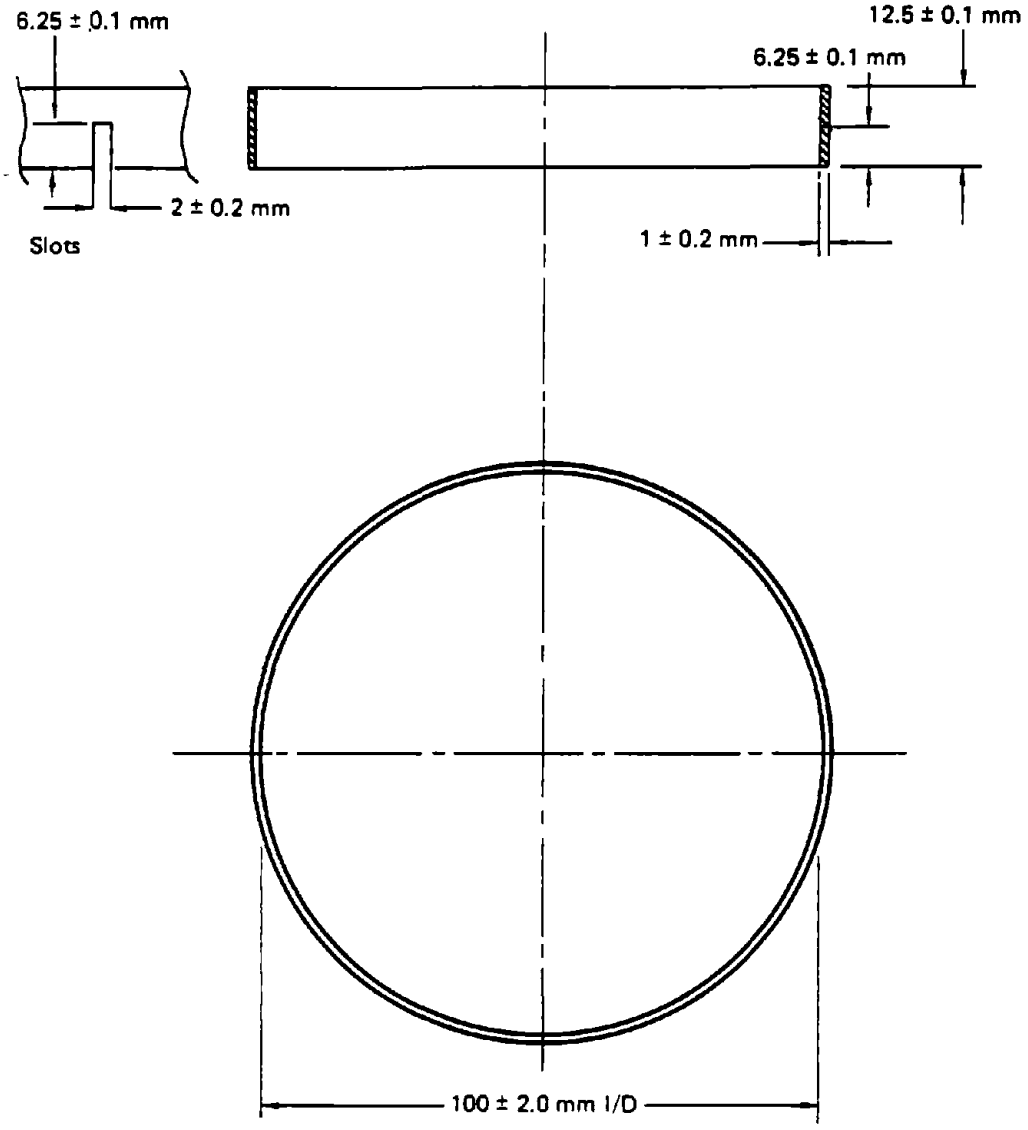


FIGURE B-3 Ring for forming dust layers.

Density of Dust Layer. The dust layer should not be compressed unduly (i.e., the dust should be put into the ring with a spatula and distributed mainly with sideways movement of the spatula until the ring is slightly over-filled; the layer then should be leveled by drawing a straight edge across the top of the ring and the excess dust should be swept away). To minimize spillage, it is convenient to form a pan around one half of the ring and then to draw the straight edge towards the pan.

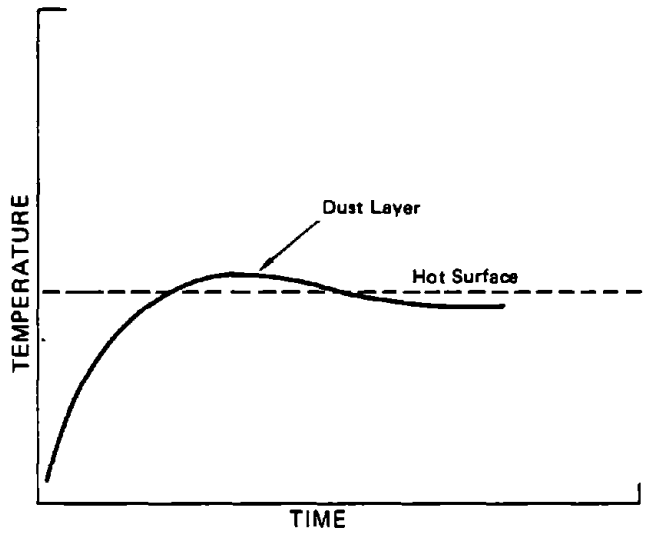
A layer of each dust should be formed in the above manner on a tared sheet of paper and weighed. The apparent density should be calculated from the weight of the dust and the filled volume of the ring and should be reported. These data are only to provide a reference should data on a similar material yield significantly different results.

Procedure

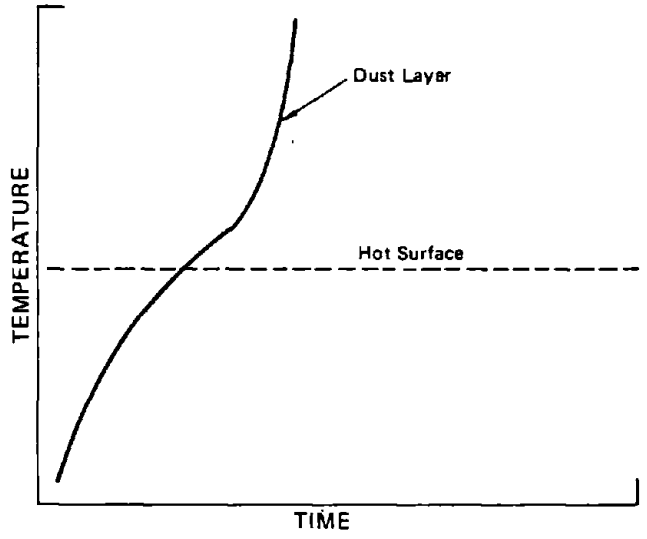
General Basis. Ignition in particulate or porous solids exposed to elevated temperatures generally is preceded by a more or less protracted period of self-heating (usually due to atmospheric oxidation). Depending on the temperature of exposure, self-heating may result in no more than a transient, although sometimes substantial, rise in temperature within the solid that does not lead to the propagation of combustion. Further, the "induction period" for ignition at temperatures near the minimum required for ignition is usually many times greater than for ignition in dust clouds or in gases and vapors. For these reasons, recognition of the minimum ignition temperature for layers is less straightforward than for dust clouds or for gases and vapors, and it is necessary to be certain that failure to ignite at a given temperature is not merely a result of premature termination of a test.

The occurrence of ignition in a layer of dust on a surface at a given temperature depends critically on the balance between the rate of heat generation (self-heating) in the layer and the rate of heat lost to the surroundings. The temperature at which ignition of a given material occurs therefore depends on the thickness of the layer. Values determined for two or more thicknesses of a given dust may be used for predictive purposes (see the section below on application of results).

If the dust is seen to flame or glow, this is sufficient evidence of ignition. If flaming or glowing is not seen, the behavior of the dust layer is to be observed by means of a fine wire thermocouple supported within it and connected to a temperature recorder. It usually will be found that, provided the temperature of the plate is high enough, the temperature in the layer will increase slowly to a maximum value that may be in excess of the temperature of the hot surface and then fall slowly to a steady value below the temperature of the hot surface. This behavior is evidence of self-heating in the dust layer and may often be accompanied by a discoloration of the dust but not by active and visible combustion of the layer. Discoloration shall not be considered to be ignition. If the temperature of the hot surface is slightly higher, it will be found that the temperature measured in the dust layer will continue to rise (instead of passing through a maximum) and lead to ignition. Simple temperature-time curves illustrating this behavior are shown in Figure B-4. If there is no ignition within 30 minutes, the test can be considered concluded. With organic dusts, combustion usually will take the form of charring followed by



A. Self-heating without ignition



B. Ignition

FIGURE B-4 Typical temperature-time curves for ignition of dust layer on hot surface.

smoldering and glowing that will progress through the layer and leave a residue of ash. Sugars, starches, and some other dusts turn dark, melt, expand, foam, and sometimes char with or without ignition. For these dusts, visible observations and notes should be included with the temperature-time curve. With dust layers composed of certain divided metals, ignition may be characterized by the relatively sudden appearance of highly incandescent smoldering combustion progressing rapidly through the layer.

In determining the ignition temperature for a layer of given thickness, repeated trials should be carried out using a fresh layer of dust each time and adjusting the temperature of the hot plate until a temperature is found that is high enough to cause ignition in the layer but that is no more than 10°C higher than a temperature which fails to cause ignition. Temperatures at which ignition fails to occur must be confirmed by continuing a test long enough to establish that any self-heating is definitely decreasing in rate (i.e., the temperature at the point of measurement in the layer is decreasing to a steady value lower than the temperature of the plate).

Method. The apparatus should be set up in a position free from drafts and under a hood capable of exhausting smoke and fumes. An angled mirror some distance above the test sample or equivalent means for visual observation of the dust during the test should be provided.

The temperature of the hot plate should be adjusted to a desired value and should be allowed to become steady within the prescribed limits. A ring of the required height should be placed centrally on the surface of the plate and should be filled with the dusts to be tested and leveled off within a period of 2 min. The test thermocouple recorder then should be started. The surface of the heated plate and the ring should be cleaned after each test.

Results. Tests should be repeated with fresh layers of dust until an ignition temperature has been determined. This should be the lowest hot plate temperature, rounded to the nearest integral multiple of 10°C, at which ignition occurs in a layer of a given thickness. At least two observations of ignition at temperatures differing by no more than 20°C should be recorded. The temperature at which ignition does not occur also should be recorded. This temperature should not be more than 10°C lower than the temperature at which ignition does occur and should be confirmed by at least two more tests.

The test should be discontinued if ignition of a dust layer does not occur below a hot surface temperature of 400°C. This fact and the maximum duration of the test should be reported.

Time to ignition, or time to the maximum temperature in the case of no ignition, should be measured to the nearest 2 minutes from the time of placing the dust layer on the hot surface and should be reported. If melting occurs, this fact and the melting temperature should be recorded and

the test should be discontinued. The melting temperature should be considered to be the ignition temperature.*

If flames appear above the surface of the dust but the dust itself does not ignite, the temperature at which flames appear above the dust should be considered to be the ignition temperature.** If foaming of the dust layer occurs, this fact should be recorded and the testing should be continued until ignition, flaming, or melting is observed.***

Validity of Test Results

Repeatability. Duplicate results obtained by the same operator on different days should be considered unsatisfactory if they differ by more than 20°C. The tests should be repeated.

Reproducibility. Results obtained in different laboratories should be considered to be unsatisfactory if they differ by more than 20°C. The tests should be repeated.

Difficult Materials. Repeatability and reproducibility sometimes may be very poor for reasons associated with the physical nature of the dusts and the behavior of layers during the testing. When this occurs, it should be reported and all results should be accepted as equally valid. The test report should include a brief description of the nature of the combustion following ignition, noting especially behavior such as unusually rapid combustion or violent decomposition. Factors likely to affect the significance of the results also should be reported; these include difficulties in the preparation of layers, distortion of layers during heating, decrepitation, and melting.

Reporting of Results

The test report should include the name, source, and description (if not implicit in the name) of the material tested; the date and serial number of the test; the room temperature; and the apparent density of the material as tested. The report should state that the determination of ignition temperature has been carried out in accordance with this recommended method.

The ignition tests should be reported in the manner shown in Table B-1 (showing results in descending order of temperature rather than in the order in which tests were performed). All test data should be reported (e.g., the

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* Some materials, such as sulfur dusts, melt prior to ignition.
** This phenomenon may occur with some hydrides, for example.
*** Some dusts, such as starch dusts, may foam when heated.

ignition temperature for the 12.5 mm layer described in Table B-1 would be recorded as 170°C). Trials in which the hot surface differed by more than ±20°C from the recorded ignition temperature need not be reported unless unusual observations were noted at temperatures higher than the recorded ignition temperature.

TABLE B-1. Typical Table of Test Results

Depth of Layer, mm	Set Surface Temperature, °C	Result of Trial	Time to Ignition or Maximum Temperature, min
12.5	180	Ignition	16
	170	Ignition	26
	160	No Ignition	30
	160	No Ignition	30
	160	No Ignition	30
	150	No Ignition	30

Application of Results

The values of minimum ignition temperature determined in accordance with this recommended test method apply to layers having the thickness used in the tests. It is possible to estimate minimum hot surface temperatures for the ignition of layers of a given dust of lesser or greater thickness by linear interpolation or extrapolation of the experimental results plotted as the logarithm of the thickness versus the reciprocal of the ignition temperature in degrees Kelvin. This is the simplest predictive procedure that has some theoretical justification. More elaborate treatment based on thermal ignition theory will permit estimates of the ignition temperatures of layers in other configurations (e.g., layers on curved surfaces); however, if accurate predictions of ignition temperature under widely different conditions of exposure (in particular, exposure to a symmetrical high-temperature environment rather than to an unsymmetrical environment like that on a hot plate) are desired, it is preferable to use results obtained for an experimental procedure matching the different environment more closely (e.g., ignition in an oven). When extensive prediction is intended, it is recommended that ignition temperatures be determined for at least three layer thicknesses and that thicker layers be emphasized.

Construction of Heater Surface

Provided the requirements presented above in the section describing the heated surface are satisfied, the detailed construction of the heated surface is not critical. It should consist of a circular plate of stainless

steel provided with a "skirt" (Figure B-1) and may be mounted on any suitable electrically heated hot plate commercially available. Aluminum and ordinary steel are not recommended for the heated surface because of the potential for corrosion problems and the possibility that an aluminum surface could be destroyed when metal powders are being tested.

There are two ways of achieving a sufficiently uniform temperature distribution across the heated plate, the choice of which depends primarily on the heating device available. If the heater consists, for example, of exposed coiled filaments intended to run at red heat, there should be an air gap of about 10 mm between the heater and the plate so that heat transfer occurs by radiation and convection. If, however, the heater is designed for direct contact and heat transfer occurs mainly by conduction, the plate needs to be much thicker if hot spots are to be avoided. A thickness of not less than 20 mm is recommended.

The general arrangement shown in Figure B-1 is self-explanatory. It is preferable to insert indicating and controlling thermocouples in holes drilled radially from the edge of the plate and parallel to the surface at a depth of 1 mm from the surface.

The base of the hot plate should be provided with feet in order to clear the support for a thermocouple stretched horizontally across the surface. This thermocouple is to be mounted between spring-loaded carriers on threaded vertical rods and height adjustment should be provided, e.g., by means of wing nuts.

Measurement of Temperature Distribution on Hot Plate

A suitable piece of apparatus for measuring the temperature distribution across the hot plate is illustrated in Figure B-5. The measuring element should consist of a fine thermocouple with the junction flattened and brazed to a disc of copper or brass foil (5 mm) in diameter. This should be placed at a measuring point and covered with a piece of insulating material (asbestos millboard) 5 mm in thickness and 10 to 15 mm in diameter, held by a vertical glass rod that moves freely in a tubular guide and to which a fixed load is applied.

Temperature measurements should be made along two diameters at right angles and at points 20 mm apart and recorded as in Figure B-6. The thermocouple must be allowed to reach a steady temperature at each point.

The measured surface temperature usually will be lower than the set point temperature of the plate depending on the detailed construction of the thermocouple. This is immaterial and can be ignored. The essential requirement is an accurate measurement of temperature differences rather than of absolute values.

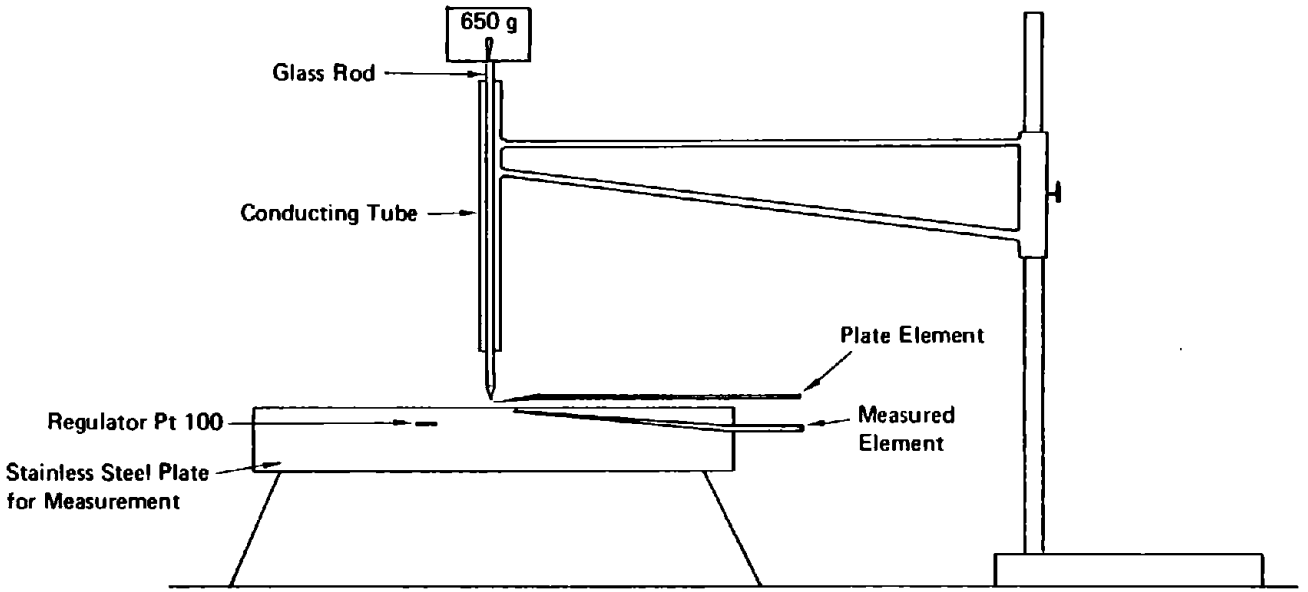

FIGURE B-5 Measurement of surface temperature.

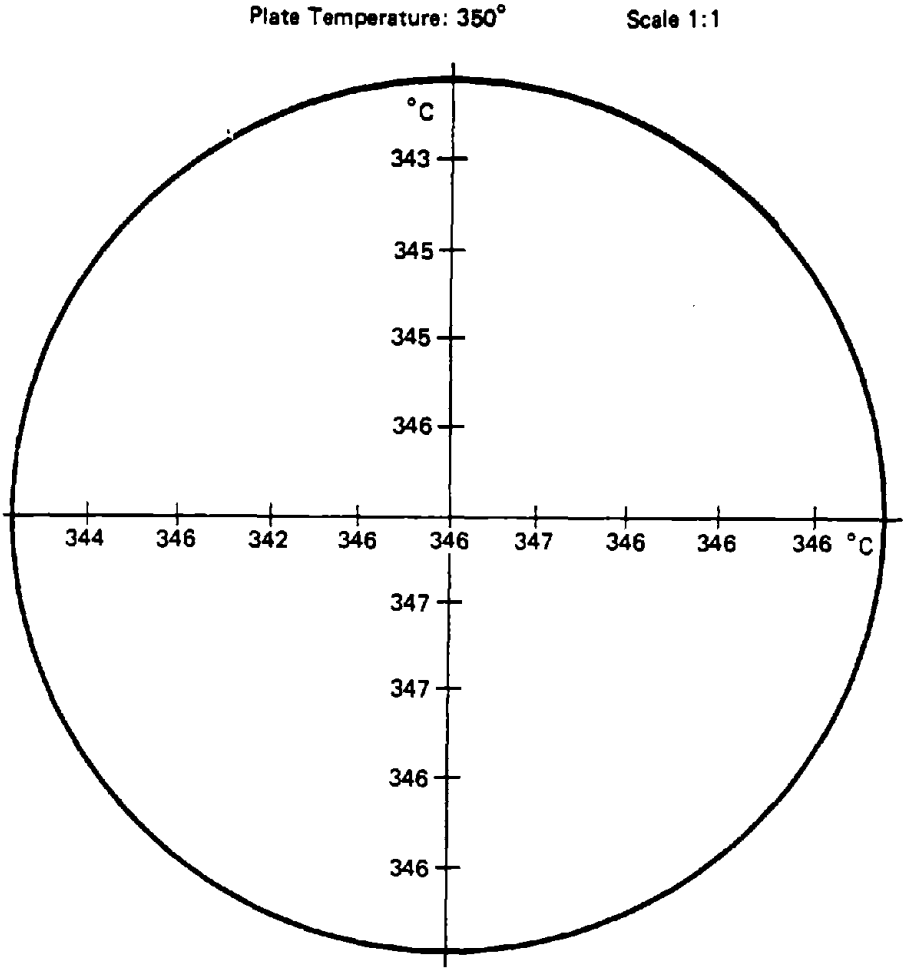

FIGURE B-6 Variation of surface temperature over entire plate--5°C (maximum difference from desired temperature--8°C).

REFERENCES

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International Electrotechnical Commission, An Apparatus and Method for Determining the Self-Ignition Temperature of a Dust Layer, Report IEC/31 H/WG2, Geneva, Switzerland, 1973.

Appendix C

ELECTRICAL RESISTIVITY

BACKGROUND

The committee's Panel on Dust Test Equipment reviewed two reports describing equipment used to determine the electrical resistivity of combustible dusts: (1) a paper on the measurement of electrical conductivity and resistivity of dust samples prepared by S. H. Chiang in 1976 and submitted to the committee in 1977 and (2) a Recommended Practice of the Instrument Society of America (ISA)(1973). The method proposed is essentially the same as the ISA method except that a direct-current rather than an alternating-current power supply is used to reduce the likelihood of instrument error and reactance effects.

RECOMMENDED METHOD OF MEASUREMENT OF DUST RESISTIVITY

Scope

The objective of this test method is to provide a convenient, albeit not precise, determination of the resistivity of dust layers for the purpose of classifying dusts with regard to fire and explosion hazards. The results are used to determine whether dusts have resistivities similar to metallic dusts or to agricultural dusts; therefore, minor differences in measurement technique and experimental conditions are not likely to lead to differences in classification.

Sample Chamber

The sample chamber should be of open construction with rectangular electrodes similar to the chamber described in the Instrument Society of America report (1973). This chamber uses stainless steel bars approximately 14 by 14 mm and 100 mm long, placed approximately 12.5 mm apart (Figure C-1). The exact dimensions of the cell are not crucial. Smaller cells are not recommended because they are difficult to fill and clean. A rectangular cell is recommended because it is simpler to construct than a cell made from concentric tubes and because calculations of resistivity can be made more easily. The open, rectangular cell construction also may be filled and cleaned with less difficulty.

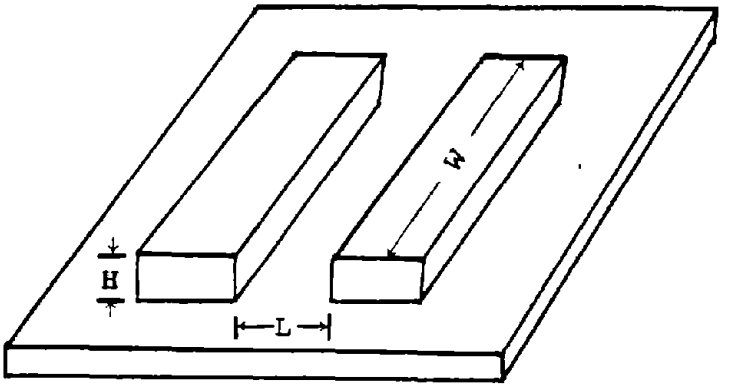

FIGURE C-1 Sample chamber.

The electrodes should be mounted on a material so that the empty cell resistance will be higher, by at least a factor of 10, than that of the cell filled with sample. Any metallic mounting screws should be recessed or countersunk to avoid shunting effects of table tops, etc., during measurement.

The dimensions of the cell are not standardized (i.e., they are left to the discretion of the laboratory making the resistivity determination). Direct-current measurement is recommended to avoid possible complications of capacitance effects. The measurement of resistance can be carried out with any convenient instrumentation suitable for resistance measurement in the range of 10^4 to 10^{11} ohms, depending upon specific cell dimensions. The method of resistance determination may be based either on voltage and current measurement or use of a dc ohmmeter. If voltage and current are measured, the internal resistance of the voltmeter or ohmmeter must be considered in calculating the cell resistance. (Note the following exception. If metallic dusts with oxidized surfaces are being measured the voltage gradient applied to the cell should be higher than the highest voltage gradient to which the dusts may be exposed in use (see page 7)).

Preparation of Dust Sample

The sample should be dry sieved through a 200-mesh sieve to exclude large particles and should be representative of dust that may deposit on the surface of electrical apparatus. No drying or other pretreatment of the sample is required, however, if drying is necessary to facilitate sieving, the sample should be allowed to equilibrate at ambient humidity for at least 24 h. For this purpose, the sample should be exposed in a thin (less than 6 mm) layer.

Procedure

The procedure involves the following steps:

1. The resistance, R_o, of the empty sample chamber should be measured.

2. The dust should be poured into the sample chamber and the sample chamber tapped several times to settle the dust. Excess dust should be removed by running a straightedge along the top of the sample chamber. If the dust does not remain in place at the ends of the sample cell, tape may be used to keep the dust in place. If tape is used, the measurement of R_o should be made with tape in place.

3. The resistance, R_s, of the filled sample chamber should be measured.

4. If R_o is greater than 10 R_s, dust resistivity should be computed from the equation:

$$\rho = R_s \frac{HW}{L}$$

where H, W, and L are cell dimensions in cm (see Figure C-1), R_s is measured resistance of the sample-filled cell in ohms, and is resistivity of the dust sample in ohm-cm.

5. If R_o is less than 10 R_s, dust resistivity should be computed from the equation:

$$\rho = \frac{R_s R_o}{R_o - R_s} \cdot \frac{HW}{L}$$

VALIDATION OF TEST METHOD

Since there is no data base for the recommended test method for determining electrical resistivity of dust, two panel members constructed three different test cells and tested four dusts (cornstarch, powdered sugar, activated charcoal, and powdered graphite) under various conditions to validate the method. Except for some differences in treatment before the test, the dust samples were the same. The results obtained are given in Table C-1.

The results of the retommended method might be considered subject to excessive error when compared to the well-controlled laboratory experiments. However, the intent of the testing is to be able to group dusts of similar resistivity. Data in ISA-S12.10 of the Instrument Society of America (1973) and the panel's tests do not indicate that the effect of moisture, aging, testing, test voltage, etc., are likely to be sufficiently great to cause misclassification of dusts.

TABLE C-1 Resistivity of Test Dusts Under Various Conditions

Dust	Resistivity, ohm-cm		
	Test Cell 1	Test Cell 2	Test Cell 3
As Received			
Cornstarch[a]	2×10^6	2×10^{11}	$10^{11} - 10^{12}$
Powdered sugar[b]	6×10^{14}	10^{14}	$10^{12} - 10^{13}$
Activated charcoal[c]	1.2×10^4	g	2×10^3
Graphite[d]	10^3	g	10^4
Dry[e]			
Cornstarch[a]	4×10^{12}	5×10^{12}	g
Powdered sugar[b]	8×10^{13}	0^{15}	g
Activated charcoal[c]	8×10^3	10^5	g
Graphite[d]	2×10^3	4×10^3	g
Moisture[f]			
Cornstarch[a]	6×10^8	7×10^{10}	g
Powdered sugar[b]	7×10^7	6×10^6	g
Activated charcoal[c]	6×10^3	7×10^3	g
Graphite[d]	6×10^1	8×10^2	g

NOTE: On Test Cell 3 only, voltage varied 10 to 1000 volts dc for cornstarch and powdered sugar. Test Cells 1 and 2, testing cornstarch and powdered sugar, used General Radio No. 1644A Megohm Bridge at 500 volts dc; Test Cells 1 and 2, testing activated charcoal and graphite, used Fluke digital ohmmeter. Test Cell 3, testing charcoal and graphite, used Triplett multimeter.

a Argo "pure cornstarch."
b Domino "confectioners 10-X powdered sugar."
c Apache Chemicals No. 1599 carbon powder, activated decolorizing, Lot No. 10077.
d Wickes Engineered Materials No. 205 "lubricating graphite."
e Dried in dessicator at least 24 h.
f Stored over water in closed container at room temperature at least 24 h.
g Not tested.

REFERENCES

Instrument Society of America, Area Classification in Hazardous Dust Locations, Report ISA-S12.10, Pittsburgh, Pennsylvania, 1973.

APPENDIX D

DUSTS WITH CLOUD IGNITION TEMPERATURES LOWER THAN THEIR LAYER IGNITION TEMPERATURES

Bureau of Mines Report of Investigations Reference Number	Line Number in Reference	Material	Ignition Temperature, °C Cloud	Layer
6	59	Asphalt, blown petroleum resin	510	550
8	9	Dextrin, USP	410	440
8	59	Detergent	540	570
8	70	Soap powder	430	600
8	88	Anthracene and potassium perchlorate	530	700
8	149	Aluminum	550	660
4	60	Monochlorotrifluoroethylene polymer	600	720
4	93	Styrene-hydrocarbon monomer copolymer	460	470
4	122	Vinyl multipolymer containing monomeric vinylidene cyanide	500	510
4	143	Urea-formaldehyde molding compound	490	530
4	182 & 183	Phenol-formaldehyde derivative	460	480
4	201	Gum, manila	360	390
4	208	Sodium resinate	380	480
4	228	Styrene-maleic anhydride copolymer	470	490
4	273	Para oxybenzaldehyde	380	430
5	1	Aluminum, atomized	650	760
5	5	Aluminum, atomized	550	840
5	6	Aluminum, atomized	700	740
5	7	Aluminum, atomized	640	770
5	8	Aluminum, atomized	640	750
5	12	Aluminum, atomized	790	860
5	29	Aluminum, atomized	830	900
5	33	Aluminum, atomized	700	830
5	35	Aluminum, atomized	700	900
5	84	Aluminum, fluid milled	550	630
5	123	Iron, carbon reduced	450	500
5	124	Iron, carbon reduced	450	530
5	167	Manganese, electrolytic	450	470
5	176	Silicon, milled	780	950
5	77	Silicon	850	900
5	190	Thorium	270	280
5	194	Titanium	330	510
5	195	Titanium	470	480
5	202	Titanium	380	660
5	204	Titanium, hydride	440	500
5	205	Titanium, hydride	480	540
5	241	Aluminum-iron alloy	870	900
5	249	Aluminum-magnesium alloy, milled	430	480
5	266	Calcium silicide	690	800
5	281	Ferrotitanium, low carbon	370	400
5	311	Manganese ore, sulfide	330	350
7	4	Aluminum acetate	560	640
7	7	Benzoic acid	560	680
7	44	Stearic acid	420	440
7	55	Sulfur	210	260
7	56	Sulfur	190	220
7	61	Alkylarylsulfonate, sodium	540	570
7	63	Amino acids	670	700
7	77	2-Amino-5-nitrothiazole	400	410
7	83	Ducmycin fermentation residue	550	600
7	101	Vitamin B_2 powder	500	510
7	112	Diazotized meta-nitro-para toluidine coupled with beta naphthol	380	410
7	132	Benzethonium chloride	380	410
7	140	Dichlorodiphenyltrichloroethane (DDT)	650	700
7	171	Sodium 2,4-dichlorophenoxyethyl sulfate	580	600
7	174	3,4,5,6-Tetrahydro-3,5-dimethyl-2H-1,3,5-thiadiazine-2-thione	310	330
3	178	Sucrose, chemically pure	420	470
3	179	Sugar, powdered	370	400
3	180	Sugar, raw, light brown	350	460

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