Approval Standard for Flammability Classification of Industrial Fluids

Class Number 6930

April 2009

Foreword

The FM Approvals certification mark is intended to verify that the products and services described will meet FM Approvals' stated conditions of performance, safety and quality useful to the ends of property conservation. The purpose of Approval Standards is to present the criteria for FM Approval of various types of products and services, as guidance for FM Approvals personnel, manufacturers, users and authorities having jurisdiction.

Products submitted for certification by FM Approvals shall demonstrate that they meet the intent of the Approval Standard, and that quality control in manufacturing shall ensure a consistently uniform and reliable product. Approval Standards strive to be performance-oriented. They are intended to facilitate technological development.

For examining equipment, materials and services, Approval Standards:

a) must be useful to the ends of property conservation by preventing, limiting or not causing damage under the conditions stated by the Approval listing; and

b) must be readily identifiable.

Continuance of Approval and listing depends on compliance with the Approval Agreement, satisfactory performance in the field, on successful re-examinations of equipment, materials, and services as appropriate, and on periodic follow-up audits of the manufacturing facility.

FM Approvals LLC reserves the right in its sole judgment to change or revise its standards, criteria, methods, or procedures.

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1. INTRODUCTION

1.1 Purpose

1.1.1 This standard states Approval requirements for the flammability rating for industrial fluids intended for use as, but not limited to, lubricants, hydraulic power transmission, turbine governor control, heat transfer, transformer insulation and cooling fluid.

1.1.2 Fluids intended for use as transformer fluids shall also meet the requirements of Approval Standard 6933, ‘‘Less Flammable Transformer Fluids’’ or Approval Standard 6934, ‘‘Non Flammable Transformer Fluids’’, as appropriate.

1.1.3 Approval criteria may include, but are not limited to, performance requirements, marking requirements, examination of manufacturing facility(ies), audit of quality assurance procedures, and a follow-up program.

1.2 Scope

1.2.1 This standard evaluates the flammability characteristics of fluids intended for use in industrial equipment by determining their chemical heat release rate from spray fires and the fluid’s critical heat flux for ignition, or by determining the critical temperature to sustain combustion. Based on these values, a Spray Flammability Parameter (SFP) or Adiabatic Stoichiometric Flame Temperature ($T_{ad, cr}$) can be calculated. The SFP or the ($T_{ad, cr}$) is then used as the basis for classifying the fluid and is useful in determining acceptable fire protection techniques and requirements applicable to a given installation in accordance with FM Global Property Loss Prevention Data Sheets.

1.2.2 An industrial fluid that meets the requirements of this standard shall be eligible to be flammability rated as FM Approved.

1.2.3 This standard is intended only to evaluate a fluid’s flammability under stated conditions. Environmental considerations, toxicity and the suitability for the end use of the product have not been evaluated.

1.2.4 The tests conducted as part of this examination are intended to simulate conditions that may occur while the fluid is in use. This standard is not intended to be used to determine the protection requirements when containers of the fluid are placed in storage or other conditions.

1.3 Basis for Requirements

1.3.1 The requirements of this standard are based on field loss experience, research and testing, and/or the application standards of FM Approvals and/or other national or international organizations. The advice of manufacturers, users, trade associations, jurisdictions and/or loss control specialists was also considered.

1.3.2 The requirements of this standard reflect tests and practices used to examine characteristics of industrial fluids for the purpose of obtaining Approval. Industrial fluids having characteristics not anticipated by this standard may be FM Approved if performance equal, or superior, to that required by this Standard is demonstrated, or if the intent of the standard is met. Alternatively, industrial fluids which meet all of the requirements identified in this standard may not be FM Approved if other conditions which adversely affect performance exist or if the intent of this standard is not met.

1.3.3 Meeting the requirements of this standard shall result in the eligibility of the fluid to be classified as described in Section 4.4.1 of this document. Approval requirements prohibit component substitution or changes in formulation without prior written authorization by FM Approvals.

1.4 Basis for Approval

Approval shall be based upon a satisfactory evaluation of the product and the manufacturer in the following areas:

- Examination and tests on production samples shall be performed to evaluate the flammability of the product;
- An initial in-house Facilities and Procedures Audit inspection of the manufacturer's quality control program.

1.5 Basis for Continued Approval

Continued Approval is based upon:

- Production or availability of the product as currently FM Approved;
- The continued use of acceptable quality assurance procedures;
- satisfactory field experience;
- Compliance with the terms stipulated in the Approval report;
- Satisfactory re-examination of production samples for continued conformity to requirements;
- Satisfactory Facilities and Procedures Audits (F&PA's) conducted as part of FM Approvals' product follow-up program.

1.6 Effective Date

1.6.1 The effective date of an Approval Standard mandates that all products or services evaluated for Approval after the effective date shall satisfy the requirements of that Standard. Products Approved under a previous edition shall comply with the new version by the effective date or else forfeit their listing. The effective date shall apply to the entire Approval Standard, or, where so indicated, only to specific paragraphs of the Standard.

1.6.2 The effective date of this standard is April 1, 2009 for compliance with all requirements.

1.7 System of Units

Units of measurement used in this Standard are United States (U.S.) customary units. These are followed by their arithmetic equivalents in International System (SI) units, enclosed in parentheses. The first value stated shall be regarded as the requirement. The converted equivalent value may be approximate. Appendix A lists the selected units and conversions to SI units for measures appearing in this standard. Conversion of U.S. customary units is in accordance with the American National Standards Institute (ANSI)/Institute of Electrical and Electronics Engineers (IEEE)/American Society for Testing Materials (ASTM) SI 10-97, ''Standard for Use of the International System of Units (SI): The Modern Metric System.'''

1.8 Applicable Documents

The following are standards, test methods, and practices referenced in the examinations conducted per this standard. Refer to the most current version of the method.

American National Standards Institute

(ANSI) B93.2 ‘‘Glossary of Fluid Power Systems and Products’’

American Society for Testing and Materials

ANSI/ASTM D92 ‘‘Standard Test Method for Flash and Fire Points by Cleveland Open Cup’’

ASTM E203 ‘‘Standard Test Method for Water Using Volumetric Karl Fischer Titration’’

ASTM D240 ‘‘Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter’’

ASTM D808 ‘‘Standard Test Method for Chlorine in New and Used Petroleum Products (Bomb Method)’’

ASTM D1179 ‘‘Standard Test Method for Fluoride Ion in Water’’

ASTM D1480 ‘‘Standard Test Method for Density and Relative Density (Specific Gravity) of Viscous Materials by Bingham Pycnometer’’

ASTM D4052 ‘‘Standard Test Method for Density and Relative Density of Liquids by Digital Density Meter’’

ASTM D4309 ‘‘Standard Practice for Sample Digestion using Closed Vessel Microwave Heating Technique for the Determination of Total Metals in Water’’

ASTM D4327 ‘‘Standard Test Method for Anions in Water by Chemically Suppressed Ion Chromatography’’

ASTM D4868 ‘‘Standard Test Method for Estimation of Net and Gross Heat of Combustion of Burner and Diesel Fuels’’

ASTM D5291 ‘‘Standard Test Method for Instrumental Determination of Carbon, Hydrogen, and Nitrogen in Petroleum Products and Lubricants’’

FM Approvals

FM Approval Standard 6930 ‘‘Flammability Classification of Industrial Fluids’’, 2002

FM Approval Standard 6933, ‘‘Less Flammable Transformer Fluids’’, 1979

FM Approval Standard 6934 ‘‘Non Flammable Transformer Fluids’’, 1983

FM Global Research

FM Global Research Technical Report Project 0T0W3.RC, ‘‘Spray Flammability of Hydraulic Fluids and Development of a Test Method’’

FM Global Research Technical Memorandum to R. G. Bill, Jr., January 17, 2005 ‘‘Calculation of the Sustained Combustion of Hydraulic Fluids – Modification to the Calculation Procedure (alpha 0.31 version)’’

FM Global Research Technical Memorandum to R. G. Bill, Jr., July 15, 2005 ‘‘Determination of Adiabatic Stoichiometric Flame Temperature of Hydraulic Fluids Using the NASA Equilibrium Code’’

National Aeronautics and Space Administration

NASA Combustion Equilibrium and Application Code (CEA).

1.9 Definitions

General terminology shall be in accordance with ANSI B93.2 ‘‘Glossary of Fluid Power Systems and Products’’ unless shown below. For purposes of this Standard, the following terms apply:

Adiabatic Stoichiometric Flame Temperature (T_{ad}) – the critical temperature for sustained combustion

Concentrate Adiabatic Stoichiometric Flame Temperature ($T_{ad, conc}$) – the critical temperature for sustained combustion for the fluid concentrate

Critical Adiabatic Stoichiometric Flame Temperature ($T_{ad, cr}$) – the critical temperature for sustained combustion for the finished fluid at the lowest water content as specified by the manufacturer.

Critical Heat Flux – the maximum heat flux at or below which there is no ignition

Fluid Concentrate – The term as used herein defines the part of the finished fluid submitted for examination containing all the component parts except water, or with water content of 18% or less by mass percent.

Normalized SFP – The term normalized, as used herein, is defined as SFP measured at a unit flow

Spray Flammability Parameter (SFP) – a measure of the degree of flammability of a fluid in a highly atomized condition when pressurized to the stated pressure shown in this standard.

2 GENERAL INFORMATION

2.1 Product Information

2.1.1 Industrial fluids are liquids that may have two or more components in their composition and consist, but are not limited to, aqueous solutions, emulsions, vegetable oils, synthetic fluids, petroleum-based mineral oils, or other types of base stocks that are processed for stability and resilience. Other fluid compositions meeting the criteria of this standard may also be considered for Approval. Industrial fluids are intended for use as, but not limited to, lubricants, hydraulic power transmission, turbine governor control, heat transfer, transformer insulation and cooling fluids. The suitability of the industrial fluid for specific use shall be determined by the manufacturer.

2.2 Approval Application Requirements

To apply for an Approval examination the manufacturer, or its authorized representative, should submit a request to:

Materials, Director
FM Approvals
1151 Boston-Providence Turnpike
PO Box 9102
Norwood, MA 02062
U.S.A.

The manufacturer shall provide the following preliminary information for each fluid with any request for Approval consideration:

- Product trade name or formula designation;
- General description;
- Viscosity, SSU or cSt (mm^2/s) at °F (°C)*;
- Specific gravity at °F (°C)*;
- Flash and Fire point, Cleveland Open Cup, °F (°C) per ASTM D92*;
- Appearance at 77°F (25°C)*;
- Material Safety Data Sheets*.
- The number and location of manufacturing facilities.

*This information is provided to FM Approvals for general information purposes only. These values will not be confirmed or evaluated as part of the examination unless deemed necessary or as required by other portions of this standard.

2.3 Requirements for Samples for Examination

2.3.1 The manufacturer shall provide for each industrial fluid:

- Product general description;
- Product specification;
- Manufacturing flow diagram for each product. Including a written description beginning with receipt of raw materials through packaging and labeling the finished product;
- Product formulation on a proprietary basis. Include amounts by weight and names of raw materials and their suppliers. The formulation sheet must be dated and must have a unique identification number;
- Complete list of all components, CAS numbers, raw material suppliers, molecular weight and molecular distribution, if known;
- Equipment, production requirements and procedures;
- Quality control tests performed on the raw materials and on the in-process and finished products, including test descriptions and tolerance limits for each test;
- All documents shall identify the manufacturer's name, document number or other form of reference, title, date of last revision, and revision level. All documents shall be provided with English translation;
- All documents shall identify the manufacturer's name, document number or other form of reference, title, date of last revision, and revision level. All documents shall be provided with English translation.

2.3.2 Production of all samples submitted for testing for Approval recognition shall be witnessed by a representative of FM Approvals. The witnessed industrial fluids shall be placed in identified containers along with the Material Safety Data Sheets and then shipped to FM Approvals.

2.4 Samples required for testing

2.4.1 Two (2) one gallon (four (4) one L) and one (1) pint (500 ml) of the industrial fluid in identified containers along with their Material Safety Data Sheets and list of physical properties. For flammability based testing, water bearing fluids shall be submitted with the minimum water content specified for their formulation.

2.4.2 For industrial fluids not having a fire point, additional material shall be submitted: one (1) pint (500 ml) of industrial fluid and one (1) pint (500 ml) of the fluid concentrate shall be required for the elemental analysis. The fluid concentrate shall be that used in the manufacture of the sample in paragraph 2.4.1.

2.4.3 For water-in-oil or oil-in-water emulsion type fluids, an additional four (4) 0.26 gal (1 L) containers of fluid shall be required for the Separation Resistance Evaluation. These samples shall be submitted with the maximum water content specified for their formulation.

2.4.4 For quench fluids, an additional two (2) 0.26 gal (1 L) containers of fluid shall be required for the FM Approvals Quench Evaluation test. These samples shall be submitted with the minimum water content specified for their formulation.

2.4.5 All samples submitted for testing shall be shipped prepaid to FM Approvals in sealed containers suitable for shipping and resealing. Upon completion of testing any remaining samples will be disposed in accordance the current regulatory requirements for hazardous waste unless other arrangements have been made in advance with FM Approvals.

3 GENERAL REQUIREMENTS

3.1 Test Requirements

Each industrial fluid submitted shall be screen tested to determine a fire point or verify the fluid will boil prior to obtaining a fire point. The screening test shall be ANSI/ASTM D92.

3.1.1 Industrial fluids submitted for examination having a fire point shall satisfy each of the following performance criteria in order to be eligible for FM Approval or as a FM Specification Tested Product under this standard:

- Determination of the Fire Point by Cleveland Open Cup;
- Determination of the chemical heat release rate, (Q_{ch}), of a highly atomized spray of the industrial fluid;
- Determination of the industrial fluid density per ASTM D1480 or ASTM D4052;
- Calculation of the critical heat flux for ignition of the industrial fluid;
- Calculation of the SFP of the industrial fluid.

3.1.2 Industrial fluids having a fire point and having a normalized SFP of 5×10^4 or less are eligible for Approval.

3.1.2.1 Industrial fluids having a fire point and having a normalized SFP greater than 5×10^4, but no more than 10×10^4 are eligible to be listed as a FM Specification Tested Product. FM Specification Tested industrial fluids, less flammable than mineral oil fluids but may stabilize a spray flame, can be considered less-flammable. Sprinkler protection may still be needed to control a fire involving these fluids.

3.1.2.2 Industrial fluids having a SFP exceeding that allowed for a FM Specification Tested Product classification are not eligible for categorization under this Standard.

3.1.3 Industrial fluids submitted for examination not having a fire point shall satisfy each of the following performance criteria in order to be eligible for Approval under this standard:

- Determination of the chemical heat release rate of a highly atomized spray of the industrial fluid;
- Gross Heat of Complete Combustion Test of the fluid concentrate per ASTM D240, or ASTM D4868;
- Determination of the elemental composition of the fluid concentrate. Testing shall determine the percent mass of: carbon, hydrogen, oxygen, calcium, phosphorous, potassium, nitrogen, bromine, chlorine, fluorine, and sulfur. Should it be determined that the above list does not include all elements in the fluid concentrate, additional testing is required.
- Determination of the water content of the industrial fluid and the fluid concentrate per ASTM E203;
- Calculation of the Adiabatic Stoichiometric Flame Temperature by NASA Combustion Equilibrium and Application Code of the fluid concentrate ($T_{ad,conc}$) and the industrial fluid ($T_{ad,cr}$).
- Emulsion based fluids shall meet the requirements of the Separation Resistance Evaluation.

3.1.4 Industrial fluids submitted for examination not having a fire point are eligible for Approval if they meet the following requirements:

- The industrial fluid chemical heat release rate (Q_{ch}) of a highly atomized spray shall be equal to, or less than, 130 kW.
- The Adiabatic Stoichiometric Flame Temperature adjusted for the total mass of water in the finished fluid ($T_{ad,cr}$), shall be equal to, or less than, 2100 K.
- Testing may not be required for water based fluid having a water content equal to, or greater than, 60% by mass.

Industrial fluids having a chemical heat release rate (Q_{ch}), or an Adiabatic Stoichiometric Flame Temperature ($T_{ad,\,cr}$), exceeding that allowed above are not eligible for categorization under this standard.

3.1.5 Re-Testing of Materials

3.1.5.1 Submission of the fourth Product Revision Report (Form 797) that revises the formulation, raw material, or raw material supplier to an industrial fluid will require testing of the fluid.

3.2 Manufacturer's Responsibilities

3.2.1 All fluids FM Approved under this standard shall be completely blended within authorized manufacturing facilities.

3.2.2 All concentrates delivered to other facilities for further processing or blending shall be subject to the performance, test and quality control audit (initial and follow-up) requirements of this Standard. In cases where the further processing or blending is deemed equivalent to that originally tested and Approved, test requirements may be waived at the sole discretion of FM Approvals.

3.3 Markings

3.3.1 The Approval Mark (see Appendix B) shall be displayed visibly and permanently on the containers of fluids, or in the case of bulk shipments, the shipping documents, that meet the requirements of this standard as appropriate. The manufacturer shall not use this mark on any other product unless such product is covered by a separate report.

3.3.2 The label shall include following information:

- The Approval Mark or Specification Tested verbiage (as appropriate);
- The manufacturer's name and address;
- Manufacturer's product name or designation;
- Fluid type designation (e.g., ''Hydraulic Fluid'', ''Quenchant'');
- Batch, blend or lot number*
- Plant of manufacture, if different from above*

*May be in encoded form.

4 PERFORMANCE REQUIREMENTS AND VERIFICATION

4.1 Determination of Flash Point

4.1.1 ANSI/ASTM D92 shall be used to determine fire point temperature.

4.2 Determination of Chemical Heat Release Rate

4.2.1 The chemical heat release rate of a finely atomized spray of the fluid shall be determined for use in calculation of its Spray Flammability Parameter (SFP) per paragraph 4.5.

4.2.2 The Chemical Heat Release Rate (Q_{ch}) of the industrial fluid shall be determined in accordance to FM Approvals Fire Test Procedure for Determination of Chemical Heat Release Rate of Industrial Fluids in the FM Approvals 200 kW-Scale Fire Products Collector.

4.3 Determination of Fluid Density

4.3.1 Measurement of sample density will also be required for the Spray Flammability Parameter calculation (for industrial fluids having a fire point only). Density at 140°F ± 3°F (60°C ± 2°C) shall be obtained per ASTM D1480 or ASTM D4052.

4.4 Calculation of Critical Heat Flux

4.4.1. The average of three fire point temperatures determined by ANSI/ASTM D92 shall be used to calculate the critical heat flux.

4.4.2 The relationship between critical heat flux (q_{cr}) in kW/m^2, and fire point temperature (T_f) is as follows:

$$q_{cr} = \alpha \times \sigma \times T_f^4$$

Where

α is the fluid surface absorptivity, assumed to be 1,
σ is the Stefan-Boltzman constant, 5.67×10^{-11} kW/m^2 × K^4
T_f is the fire point temperature in units of K (degrees Kelvin)

4.5 Calculation of Spray Flammability Parameter (SFP)

A Spray Flammability Parameter (SFP) shall be calculated for the fluid having a fire point.

4.5.1 Spray Flammability Parameter Equation:

$$SFP_{(normalized)} = 11.02 \times 10^6 \times Q_{ch} / (\rho_f \, q_{cr} \, m_f)$$

where:

Q_{ch} is the chemical heat release rate determined per Section 4.2 and expressed in units of kW,
ρ_f is the density of the fluid, in units of kg/m^3, determined per Section 4.3,
q_{cr} is the critical heat flux for ignition determined per Section 4.4 in units of kW/m^2,
m_f is the fluid mass flow rate during the chemical heat release rate measurement, in units of g/s.

4.5.2 The SFP has been divided by m_f to derive $SFP_{(normalized)}$. This has been done to allow comparison of SFP values in various apparatuses having different hydraulic flow characteristics.

4.5.3 Calculations for determining the normalized SFP shall be rounded to the nearest whole number. For example, a result of 5.5×10^4 shall be rounded down and reported as 5×10^4 (FM Approved). A result of 5.6×10^4 shall be rounded up and reported as 6×10^4 (FM Specification Tested).

FM Approved	Having a normalized SFP of 5×10^4, or less. These industrial fluids are typically unable to stabilize a spray flame
FM Specification Tested	Having a normalized SFP greater than 5×10^4, but no more than 10×10^4. These industrial fluids are less flammable than mineral oil fluids but may stabilize a spray flame. They can be considered less-flammable. Sprinkler protection may still be needed to in order to control a fire involving these fluids.

4.5.4 Fluids having a normalized SFP greater than 10×10^4 (flammability approximating that of mineral oil fluids) shall not be listed as FM Approved or FM Specification Tested.

4.6 Required Testing for Industrial Fluids Not Having a Fire Point

The following testing is required for industrial fluids where a fire point cannot be determined per Section 4.1.

4.6.1 Determination of Chemical Heat Release Rate

The Chemical Heat Release Rate of the industrial fluid shall be determined per Section 4.2.

4.6.2 Determination of Gross Heat of Complete Combustion

The heat of combustion of the fluid concentrate shall be determined by ASTM D240 or ASTM D4868.

4.6.3 Determination of Water Content

The water content of the industrial fluid and the fluid concentrate shall be determined by ASTM E203.

4.6.4 Determination of Elemental Composition

The elemental composition of the fluid concentrate shall be determined by the following methods, or other elemental procedures demonstrated to produce equivalent data at the sole discretion of FM Approvals:

4.6.4.1 The elemental composition by percent mass for calcium, phosphorous, sulfur and potassium shall be determined by Chromatography per ASTM D4327, ASTM D808 and ASTM D4309.

4.6.4.2 The elemental composition by percent mass for carbon, hydrogen, and nitrogen shall be determined by ASTM D5291.

4.6.4.3 The elemental composition for bromine and chlorine shall be determined by ASTM D4327 and ASTM D808.

4.6.4.4 The elemental composition for Fluoride shall be determined by ASTM D1179.

4.6.4.5 The elemental composition for Oxygen measurement shall be determined by Perkin Elmer 240 Elemental Analyzer method, or an equivalent analyzer having similar precession and bias.

4.6.5 Determination of the Adiabatic Stoichiometric Flame Temperature

NASA Combustion Equilibrium and Application (CEA) Code shall be used to determine the Adiabatic Stoichiometric Flame Temperature of the fluid concentrate ($T_{ad,\ conc}$) and industrial fluid ($T_{ad,cr}$).

4.6.6 Separation Resistance Evaluation (Emulsions only)

Emulsion based industrial fluids shall not exhibit more than 3 percent (by volume) separation of oil from the remaining fluid when individual samples are subjected to the following conditions:

4.6.6.1 The separation resistance of an emulsion based fluid shall be evaluated in accordance with FM Approvals Test Method for Emulsion Separation Resistance Evaluation for Industrial Fluids.

4.6.6.2 All samples shall be prepared at the concentration to be listed and using water meeting the manufacturer's specification for hardness.

4.6.7 Quench Fluid Test (Quench Fluids only)

4.6.7.1 Quench fluids shall be evaluated in accordance with FM Approvals Test Method for Evaluation of Quench Fluids.

4.6.7.2 Quench fluids shall not exhibit ignition, flame, or violent boiling during the test duration.

5. OPERATIONS REQUIREMENTS

5.1 Demonstrated Quality Control Program

A quality assurance program is required to assure that each subsequent batch or lot of industrial fluid produced by the manufacturer shall have the same quality and reliability as the specific fluid sample examined and tested.

5.1.1 Documentation/Manual

Producibility of formulation, conformance to formulation recipe, and performance are the areas of primary concern and is determined during the examination, witnessing of test sample production and follow-up Facilities and Procedures Audits. Conformance to formulation is verified by control of quality for at least the following areas:

- existence of corporate quality control guidelines
- incoming assurance, including testing
- in-process assurance, including testing,
- final inspection and test,
- equipment calibration
- formulation and change control
- packaging and shipping
- handling discrepant materials

5.1.2 The manufacturer shall establish a system of product formulation control to prevent unauthorized changes, including, as appropriate:

formulation recipe documents,

engineering change requests,

engineering orders,

change notices.

5.2 Records

5.2.1 To assure adequate traceability of materials and products, the manufacturer shall maintain a record of all quality assurance tests performed, for a minimum period of two years from the date of manufacture.

5.2.2 Formulation and Change Control

The manufacturer shall establish a system of product configuration control that shall allow no unauthorized changes to the product. Changes to critical documents, identified in the Approval Report or FM Specification Tested Product Report, must be reported to, and authorized by, FM Approvals prior to implementation for production.

The manufacturer shall assign an appropriate person or group to be responsible for, and require that, proposed changes to FM Approved or FM Specification Tested products be reported to FM Approvals before implementation. All requests for changes in Approved products shall be agreed to in writing by FM Approvals prior to distribution and sale. The manufacturer shall notify FM Approvals of changes in the product or of persons responsible for keeping FM Approvals advised by means of FM Approvals' Form 797, FM Approved Product/Specification-Tested Revision Report or Address/Main Contact Change Report.

Records of all revisions to all FM Approved products shall be maintained.

5.3 Follow-up Facilities and Procedures Audits (F&PA)

5.3.1 An audit of the manufacturing facility is part of the Approval investigation to verify implementation of the quality assurance program. Its purpose is to determine that the manufacturer's equipment, procedures, and quality program are maintained to insure a uniform product consistent with that which was tested and FM Approved.

5.3.2 All manufacturing facilities that produce an Approved or listed fluid, as well as all facilities that conduct additional or final processing of an Approved or listed fluid, shall be subjected to unannounced, follow up Facilities and Procedures Audits (F&PA).

5.3.3 The purpose of the audit shall be to determine that the manufacture or blending of fluids, equipment, procedures and the manufacturer's controls are being properly maintained to produce a product equivalent to that which was originally tested and Approved or Specification Tested.

5.3.4 Such audits shall be conducted periodically, but at least annually, by FM Approvals or its representatives. Additional audits may be conducted based on jurisdictional requirements or at the sole discretion of FM Approvals.

5.3.5 FM Approved or FM Specification Tested products or services shall be produced or provided at or from the location(s) audited by FM Approvals and as specified in the Approval or Specification Tested Report. Manufacture of products bearing the Approval Mark, or Specification Tested verbiage, is not permitted at any other location without prior written authorization by FM Approvals.

5.3.6 Quality of performance is determined by field performance, re-examination (if required) and test.

APPENDIX A: Units of Measurement

LENGTH:
in. – ‘‘inches’’, ft – ‘‘feet’’
(mm – ‘‘millimeters’’), (m - ‘‘meters’’)
mm = in. × 25.4 m = ft × 0.3048

AREA:
in^2 – ‘‘square inches’’
ft^2 – ‘‘square feet’’
(mm^2 – ‘‘square millimeters’’), (m^2 – ‘‘square meters’’)
$mm^2 = in^2 \times 6.4516 \times 10^2$ m2 = $ft^2 \times 0.0929$

VELOCITY:
ft/s – ‘‘feet per second’’
(m/s – ‘‘meters per second’’)
m/s = ft/s × 0.3048

MASS FLOW:
lb/s – ‘‘pounds per second’’
(g/s – ‘‘grams per second’’)
g/s = lb/s × 454.5

LIQUID VOLUME:
gal – ‘‘gallon’’
(L – ‘‘liter’’)
L = gal × 3.7854

HEAT:
Btu – ‘‘British thermal units’’
(kW/h – ‘‘kilowatt hours’’)
kW/h = Btu × 0.000293

DENSITY:
lb/ft^3 – ‘‘pounds per cubic foot’’
(kg/m3 – ‘‘kilograms per cubic meter’’)
$kg/m3 = 0.0777 \times lb/ft^3$

PRESSURE:
psi – ‘‘pounds per square inch’’
(kPa – ‘‘kilopascals’’)
kPa = psi × 6.8948

TEMPERATURE:
°F – ‘‘degrees Fahrenheit’’
(°C – ‘‘degrees Celsius’’)
°C = (°F – 32) × 5/9

VOLUME FLOW:
gal/min – ‘‘gallons per minute’’
(L/min – ‘‘liters per minute’’)
L/min = gal/min × 3.7854

VISCOSITY:
SSU – ‘‘universal Saybolt seconds’’
(cSt mm^2/s – ‘‘centistokes or square millimeters per second’’)
These measurements are determined through the use of different testing techniques. Hence, no direct arithmetic conversion is possible.

APPENDIX B: FM Approvals Certification Marks

FM Approvals certifications marks are to be used only in conjunction with products or services that have been Approved by FM Approvals and in adherence with usage guidelines.

FM APPROVED mark:
Authorized by FM Approvals as a certification mark for any product that has been FM Approved. There is no minimum size requirement for the mark, but it must be large enough to be readily identifiable. The mark should be produced in black on a light background, or in reverse on a dark background.

Cast-On FM Approvals marks:
Where reproduction of the FM Approved mark described above is impossible because of production restrictions, use these modified versions of the FM Approved mark. There is no minimum size requirement for the mark, but it must be large enough to be readily identifiable.

FM Approved Mark with ‘‘C’’ only:
Authorized by FM Approvals as a certification mark for any product that has been evaluated by FM Approvals in accordance with Canadian codes and standards. There is no minimum size requirement for the mark, but it must be large enough to be readily identifiable. The mark should be produced in black on a light background, or in reverse on a dark background.

FM Approved mark with ‘‘C’’ and ‘‘US’’:
Authorized by FM Approvals as a certification mark for any product that has been evaluated by FM Approvals in accordance with US and Canadian codes and standards. There is no minimum size requirement for the mark, but it must be large enough to be readily identifiable. The mark should be produced in black on a light background, or in reverse on a dark background.

FM Approvals Certification Marks

USAGE GUIDELINES

All FM Approvals certification marks are the sole property of FM Approvals LLC ("FM Approvals") and are registered or the subject of applications for registration in the United States and many other countries. They are for use only according to these guidelines.

FM Approvals certification marks may be used only on FM Approved products and related product packaging, in advertising material, catalogs and news releases. Use of FM Approvals certification marks on such material is not a substitute for use of the complete FM Approvals certification mark on FM Approved products and/or product packaging.

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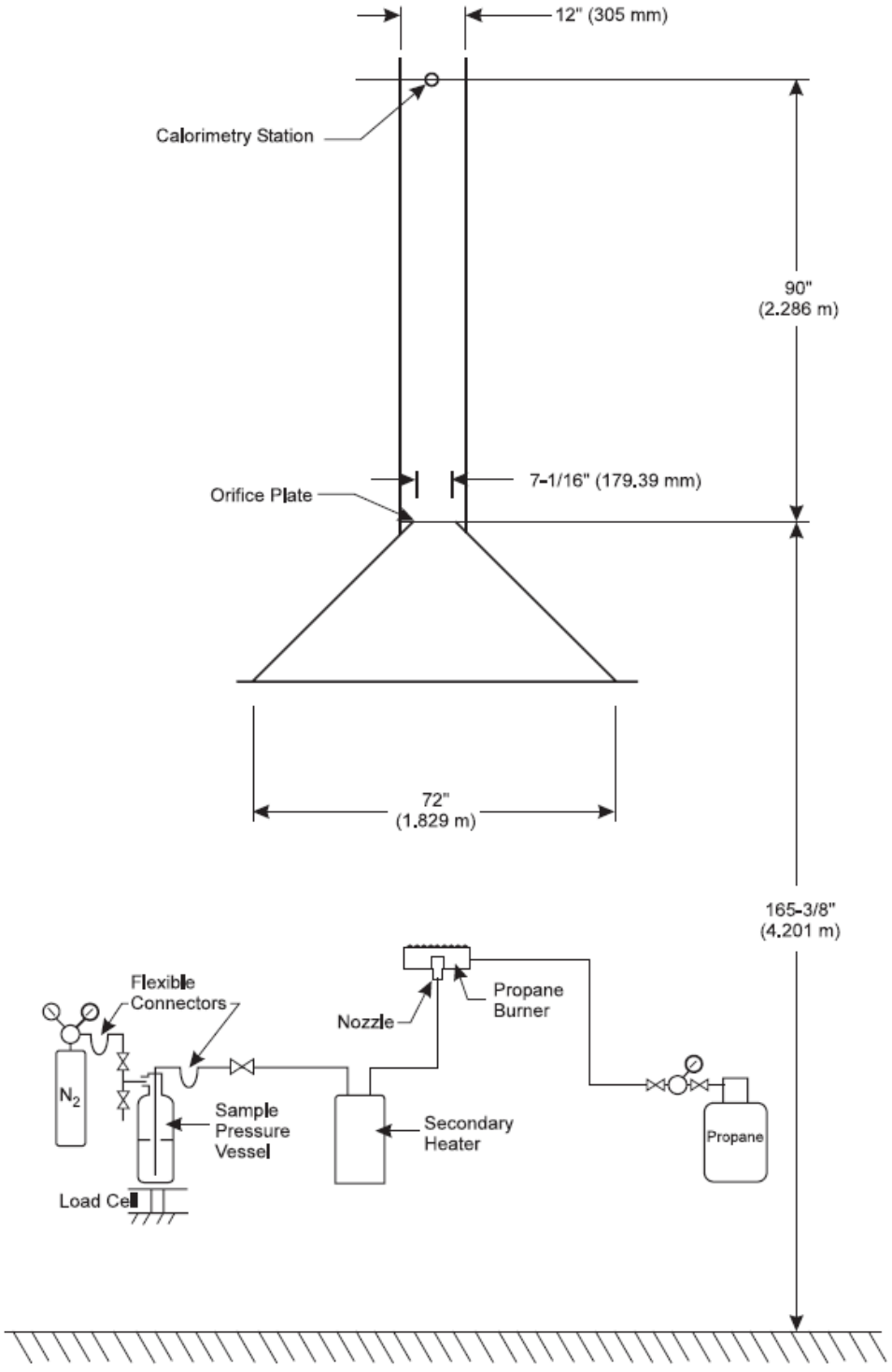
APPENDIX C: The Fire Products Collector

Figure C-1 illustrates the overall configuration of this apparatus. The apparatus consists of a vertical steel duct connected to an air pollution control system. The duct is made up of 12 in. (305 mm) diameter sections, connected to a large collecting funnel of 72 in. (1.829 m) diameter at its widest level. The fire products generated from the fire are captured along with ambient air in the duct by the funnel (cone collector) through a 7-1/16 in. (179 mm) diameter orifice.

Measurements are made at a station several duct diameters above the orifice. In the apparatus, the fire products are diluted and well mixed with ambient air as they are captured in the sampling duct. The following measurements are made in the duct: total mass and volumetric flow rates of the mixture of fire products and air; gas temperature; and concentrations of carbon dioxide, carbon monoxide, and total gaseous hydrocarbons.



FM Heat Release Rate Measurement Apparatus

Fig. C-1. FM Approvals Fire Products Collector

APPENDIX D: Determination of Heat Release Rates

In flaming combustion, heat is released in the production of CO_2 and CO, or in the consumption of O_2. Therefore, the chemical heat release rate Q_{ch} (kW) can be calculated as:

$$Q_{ch} = k_1 \times G_{CO2} + k_2 \times G_{CO} \quad \text{(Eq. D1)}$$

Where,

$k_1 = \Delta H_T / k_{CO2}$ is the net heat of complete combustion (kJ/g) of the fuel per unit mass of CO_2 produced;

k_{CO2} is the theoretical stoichiometric mass of CO_2 produced per unit mass of fuel converted completely to CO_2

$k_2 = (\Delta H_T - \Delta H_{CO} \times k_{CO})/k_{CO}$ is the net heat of complete combustion (kJ/g) of the fuel converted to CO per unit mass of CO produced;

k_{CO} is the theoretical stoichiometric mass of CO produced per unit mass of fuel converted completely to CO,

and ΔH_{CO} is the heat of combustion of CO (10.13 kJ/g);

and G_{CO2} and G_{CO} are the mass generation rate (g/s) of CO_2 and CO, respectively.

Or, $$Q_{ch} = k \times D_{O2} \quad \text{(Eq. D2)}$$

Where,

$K = -\Delta H_T / k_{O2}$ is the net heat of complete combustion of the fuel per unit of mass of O_2 -consumed and D_{O2} is the consumption rate (g/s) of O_2.

With some exceptions the values K, k_1, and k_2 are approximate constants for various types of fluids. Since it is much more difficult to measure the O2 consumption accurately for low heat release rate fires, as compared to CO_2 and CO, Equation (D1) was chosen for the determination of chemical heat release rate, using 13 and 12 for the values of k_1 and k_2, respectively.

. $$Q_{ch} = 13\ G_{CO2} + 12\ G_{CO} \quad \text{(Eq. D3)}$$

When $G_{CO} << 1$, 12 G_{CO} can be neglected.

The values of k_1 and k_2 can be precisely calculated if the exact elemental or chemical formula and ΔH_T, net heat of complete combustion (kg/J), of the fluid are known.

APPENDIX E: Screening of Fluids SFP Approximation Methods

Most fluid manufacturers do not have ready access to either the Fire Products Collector or Critical Heat Flux test apparatuses. However, SFP approximations may be calculated from more commonly available standard ASTM bench tests. FM Approvals maintains that in order to determine SFP, the tests contained in the body of Approval Standard 6930 must be conducted. The correlation between SFP values obtained using the test method contained in the Standard and that shown in this appendix is unknown

$$q_{cr} = \alpha \times \sigma \times T_f^4 \qquad \text{(Eq. E1)}$$

Where,

α is the fluid surface absorptivity, assumed to be 1,

σ is the Stefan-Boltzman constant, 5.67×10^{-11} kW/m^2 × K^{-4}

(kilowatts per square meter-degree Kelvin to the fourth power), and

T_f is the fire point temperature in units of K (degrees Kelvin).

There are no conceptual liabilities to the use of this measurement. However, there are some practical considerations which dictate caution. Some fluids do not exhibit a valid fire point. Two-component fluids, such as water-glycol mixtures, will not exhibit a fire point until all the water has been evaporated. This value is not valid for the mixture. For such fluid, a SFP can not be determined, the flammability of the fluid should be determined using the NASA equilibrium code.

ASTM D240 oxygen bomb calorimeter can be used to determine net heat of complete combustion (ΔH_T). This value can be used as a proxy for chemical heat release rate (Q_{ch}), in kW. Their relationship is as follows:

$$Q_{ch} = \chi_{ch} \times \Delta H_T \, m_f \qquad \text{(Eq. E2)}$$

Where,

χ_{ch} is the combustion efficiency,

ΔH_T is the net heat of complete combustion in units of kJ/g (kilojoules per gram), and

m_f is the mass flow rate of the fluid in units of g/s (grams per second).

A spreadsheet is available from FM Approvals, upon request, to calculate SFP from all of the four possible combinations of ignition energy and heat release measurements. Interested manufacturers can use this tool to assess the likelihood of their products being classified in the flammability group desired prior to sending the fluids to FM Approvals for formal listing evaluation. The equations used in that spreadsheet are discussed below.

The equation used when Q_{ch} has been measured and qcr was calculated:

$$SFP_{(normalized)} = 11.02 \times 10^6 \times Q_{ch}/(\rho_f \times q_{cr} \times m_f) \quad \text{(Eq. E3)}$$

If Q_{ch} and T_f have been measured, then substituting equation E1 into equation E3 provides the appropriate calculation method:

$$SFP_{(normalized)} = 1.94 \times 10^{17} \times Q_{ch}/(\rho_f \times T_f^4 \times m_f) \quad \text{(Eq. E4)}$$

If Q_{ch} has not been measured, but ΔH_T is known, then equation E2 can be substituted into equation E3 to yield the third alternative calculation method. This method is only approximate and will yield an SFP higher than that calculated using equation E3 by a factor of $1/\chi_{ch}$, the combustion efficiency:

$$SFP_{(normalized)} = 11.02 \times 10^6 \times \Delta H_T /(\rho_f \times q_{cr}) \quad \text{(Eq. E5)}$$

Similarly, substituting equation E1 into equation E5 yields the equation to be used when calculating SFP from ΔH_T and T_f. Again this equation renders an approximate result, due to an assumption of a combustion efficiency of 1:

$$SFP_{(normalized)} = 1.94 \times 10^{17} \times \Delta H_T /(\rho_f \times T_f^4) \quad \text{(Eq. E6)}$$

APPENDIX F: Correction Method for Elemental Composition for Fluids Not Having a Fire Point

The elemental composition, i.e., mass% of industrial fluid sample is to determine for carbon, hydrogen, oxygen, calcium, phosphorous, potassium, nitrogen, bromine, chlorine, fluorine, sulfur, metals, etc. Also the water content of the industrial fluid sample is measured by the Karl Fischer method per ASTM E203 is determined. The laboratory elemental composition results will include the presence of the hydrogen and oxygen due to water in the samples. A correction to the elemental composition is necessary to account for the effect of water on the measured mass percent of oxygen (O atom). It is strongly recommended that a concentrate be used in the elemental analysis to minimize the correction. To correct for this overlap the following methodology is developed:

a. Suppose Y_i is the reported mass fraction of element *i*, where I can be carbon, hydrogen, oxygen, calcium, phosphorous, potassium, water content etc.

b. The sum of all elements including the measured water (Y_W) is:

$$\Sigma_i = Y_K + Y_P + Y_C + \ldots\ldots + Y_W \qquad \text{(Eq. F1)}$$

c. The error in the sum is Error = $\Sigma_i - 1$. Note that $E_{error} < Y_W$. This is because the reported oxygen and hydrogen is also included in the measured water mass fraction.

d. The actual mass fraction of hydrogen and oxygen is corrected to account for the measured water as follows:

$$Y_{O,a} = \frac{Y_O - \frac{16}{18} E_{error}}{1 - Y_W} \text{ ; and } Y_{H,a} = \frac{Y_H - \frac{2}{18} E_{error}}{1 - Y_W} \qquad \text{(Eq. F 2)}$$

e. The corrected actual mass fractions of each element in the absence of any water are calculated as:

$$Y_{K,a} = \frac{Y_K}{1 - Y_W}$$

$$Y_{P,a} = \frac{Y_P}{1 - Y_W}$$

$$Y_{Ca,a} = \frac{Y_{Ca}}{1 - Y_W} \qquad \text{(Eq. F 3)}$$

and so on

f. The gross heat of compete combustion per unit mass of the fluid consumed (ΔH_c *in kJ/kg*) is measured per ASTM D4868 or ASTM D240. The corrected gross heat of compete combustion $\Delta H_{c,a}$ is calculated as;

$$\Delta HY_{c,a} = \frac{\Delta H_c}{1 - Y_W}$$

(Eq. F 4)

NASA Combustion Equilibrium and Application Code is used to calculate the Concentrate Adiabatic Stoichiometric Flame Temperature ($T_{ad,\,conc}$) using the $Y_{K,a}$, $Y_{P,a}$, $Y_{C,a}$, ... $Y_{W,a}$,$\Delta H_{c,a}$. A second calculation is then made to determine the Critical Stoichiometric Flame Temperature ($T_{ad,\,cr}$) of the fluid at the desired water content.