Flame Detection for Silane and Other Non-Hydrocarbon Fires

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Engineer Design Brief

- Introduction
- What is Our Goal?
- Code Requirements and Recommendations
- Risk Analysis and its Integration with Codes & Standards
- Fire Alarm Detection and Flame Emission Light Spectrum
- UV/IR/Video Flame Detectors
- Case Scenarios
What is Silane?
Why it is so important in this day and age?
Why it is so interesting for FPEs?
Introduction

**SiH₄**

Silane Gas (SiH₄) in “natural conditions” is a pyrophoric and volatile gas which can spontaneously ignite on contact with air without any external ignition source, and is almost invisible to the human eye (similar to hydrogen). Flames will be visible.

Disilane, TSA (Trisilylamine - H₉N₃Si₃), MCS (Monochlorosilane - SiH₃Cl), Anisole Solvent (C₇H₈O) and Ammonia (NH₃) will also be reviewed
Introduction

Silane

Lower Flammable Limit (LFL) = 0.8% - 1.5%
Upper Flammable Limit (UFL) = 96% - 98%

Silane Mixtures in the 3% - 4% Range can exhibit Pyrophoric Behavior

It is too rich to burn above UFL

SiH$_4$

It is too lean to burn below LFL
Pyrophoric?

Is a substance that will ignite spontaneously in air.

Pyrophoric materials are often water-reactive as well and will ignite when they contact water or humid air.

Let’s get to know more about Silane and other Pyrophoric Substances...
Flame Detection for Silane and Other Non-Hydrocarbon Fires

Introduction

Energy Release
Reaction Speed
Burning Velocity

SiH₄(gas) + 2O₂(gas) → SiO₂(sol) + 2H₂O(gas)

SiH₄(gas) + O₂(gas) → SiO₂(sol) + H₂(gas)

Depending on Oxygen Levels

Hazardous Byproducts

Multi Billion Dollar Industries
Semiconductors
Carbon Fibers
Titanium Implants
Flame Detection for Silane and Other Non-Hydrocarbon Fires

Introduction

SiH₄

UV Band below 0.35 microns

Silane Flame: UV below 0.3 microns
IR near 2.7 microns
Flame Detection for Silane and Other Non-Hydrocarbon Fires

What is Our Goal?

Analyze extremely volatile and toxic gases which can spontaneously ignite on contact with air without any external ignition source; review national and international Codes and Standards; determine the applicability of design concepts and, their implementation in real case scenarios.
Code Requirements and Recommendations

- Storage and Handling of Silane and Silane Mixtures, ANSI/CGA-G-13, 2006 Edition (2015 Ed. is in progress)
- International Building Code (IBC), 2009 Edition
- International Fire Code (IFC), 2009 Edition
- NFPA 72, National Fire Alarm Code, 2010* Edition

*NFPA recently released the NFPA 72, 2013 Edition, but the 2010 edition still referenced in the latest editions of model building codes such as the IBC and NFPA 101
Code Requirements and Recommendations

ANSI/CGA-G-13
Storage and Handling of Silane and Silane Mixtures

- Physical and Chemical properties
- Packaging Information
- Outdoor and Indoor Storage and Use
- System Configuration
  - Cylinder Sources and Bulk Sources
- Piping and Components
Code Requirements and Recommendations

ANSI/CGA-G-13
Storage and Handling of Silane and Silane Mixtures

- Gas and Flame Detection
- Fire Protection Systems
- Ventilation Systems
- Venting and Treatment
- Purge Gas Systems
- Electrical Equipment

Chapter 11: Gas & Flame Detection
ANSI/CGA-G-13
Chapter 11: Gas Monitoring

Outdoor Locations:
Gas Detection is NOT required

Indoor Locations:
Monitor Gas Leaks
Warning Concentrations
Greater than 25% LFL (within exhausted zones)
Less than 5 ppm (outside exhausted zones)
Shutdown Silane Gas Flow
Code Requirements and Recommendations

ANSI/CGA-G-13
Chapter 11: Flame Detection

- Outdoor Locations:
  Optical Flame Detectors Required
  Use proper equipment for Silane
  Weatherproof-Arc Welding-Corrosive Resistant

- Indoor Locations:
  Optical Flame Detectors Required
  Outside and Inside Gas Cabinets
  Inside Valve Manifold Boxes (VMBs)

- Shutdown Silane Gas Flow
Code Requirements and Recommendations

NFPA 318, 2012 Edition
Flame Detection

- Section 4.3.3
  Detector shall respond to Silane Flame Signature
- Where? as per Chapters 7 and 8:
  Pyrophoric Liquid Storage Cabinets
  Gas Cylinder Storage
  Distribution System
- Shutdowns? as per Chapters 7 and 8:
  Shutoff Gas/Liquid Supply Valves

Use official and authenticated copies. Always!
NFPA 318, 2012 Edition
Gas And Smoke Detection Systems

Section 4.3.4
Gas Detection System is Required where the potential exists for flammable gas concentrations exceeding 25% of LFL.

Section 4.3.5
Smoke Detectors shall be provided at the exit of Makeup Units and Air-Handling Units
Code Requirements and Recommendations

NFPA 318, 2012 Edition
Flame Detection - Sequence of Operations

› Activate Suppression System
   Fixed Water Spray - Deluge System
   (Most Commonly Used)
   CO2 Systems

› Activate Gas System Shutdown

› Activate Fire Alarm and Notification System
Code Requirements and Recommendations

NFPA 72, 2010 Edition
Flame Detection

- Radiant Energy (Flame) Detectors
- Flame Detectors Sensitivity
- Video Image Flame Detection
- Fire Characteristics and Detector Selection (Sect. 17.8.2)
- Wavelength Concept (A.3.3.294) Spectrum Ranges (A.17.8.1)
- Proper Coverage/Spacing (Sect. 17.8.3)
Risk Analysis and its Integration with Codes & Standards

Risk Analysis and Basis of Design (BOD)

- Executive Summary
- Describe Each Area
- Identify Anticipated Hazards and Risk
- Recommend Fire Detection and Suppression Systems
- Reference Applicable Codes & Standards
- Involve AHJ and Stakeholders
- Prepare Design Documents
Risk Analysis and its Integration with Codes & Standards

Risk Analysis and Basis of Design (BOD)

<table>
<thead>
<tr>
<th>AREA</th>
<th>HAZARD/RISK</th>
<th>RECOMMENDED DETECTION/ SUPPRESSION</th>
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<tbody>
<tr>
<td>PROCESSING</td>
<td>++++ / $$$</td>
<td>UV-IR-VIDEO / CO₂</td>
</tr>
<tr>
<td>CONTAINMENT</td>
<td>+ / $</td>
<td>UV-IR / WATER SPRAY</td>
</tr>
<tr>
<td>TUBE TRAILER</td>
<td>+++ / $$$</td>
<td>UV-IR-LINEAR / CO₂</td>
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<tr>
<td>TANKS</td>
<td>++++ / $$$$</td>
<td>UV-IR-VIDEO / WATER SPRAY</td>
</tr>
<tr>
<td>SUPPLY PAD</td>
<td>+++ / $</td>
<td>UV-IR / WATER SPRAY</td>
</tr>
</tbody>
</table>

For Illustration ONLY. Not to be considered as Code Summary

Risk Analysis to Be Specific for Each Facility/Area

+++ / $$$

UV-IR-LINEAR / CO₂

UV-IR-VIDEO / WATER SPRAY

UV-IR / WATER SPRAY
Fire Alarm Detection and Flame Emission Light Spectrum

NFPA 72, 2010

Radiant Energy

<table>
<thead>
<tr>
<th>Spectrum</th>
<th>Range</th>
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<tbody>
<tr>
<td>UltraViolet</td>
<td>0.10 - 0.35 microns</td>
</tr>
<tr>
<td>Visible</td>
<td>0.36 - 0.75 microns</td>
</tr>
<tr>
<td>Infrared</td>
<td>0.76 - 220 microns</td>
</tr>
</tbody>
</table>

Table A.17.8.1

Silane Flame: UV below 0.3 microns
IR near 2.7 microns
UV/IR/VIDEO
Flame Detectors

UV/IR Flame Detector Operating Principles

- UV - Geiger-Muller Vacuum Photodiode
- Single or Multiple Wavelengths (UV/IR)
- Provision to Minimize Unwanted Alarms
- Field of View - Area of Coverage
  Sensitivity -vs- Angular Displacement

Spark/Ember Detectors are limited to normally dark environments. Range: 0.5-2.0 microns
UV/IR/VIDEO
Flame Detectors

UV/IR Flame Detector Area of Coverage

Based on NFPA 72, 2012.
Figure A.17.8.3.2.3
UV/IR/VIDEO
Flame Detectors

Video Image Flame Detector (VIFD)
Operating Principles

› Automatic Analysis of Real-Video Images
› Install, Inspect, Test & Maintain based on Manufacturer’s Published Instructions
› Software Components and Analysis
   Brightness - Contrast - Edge Content - Motion
   Could Trace Specific “Fire Signatures”
   Provision to Minimize Unwanted Alarms
› Password Protection Required to avoid Unauthorized Changes
Spectral Emissions - "Fire Signatures"

- Oil
- Coal
- Gas

Relative Intensity

Wavelength (micron)

1 micron = 1000 nanometer
UV/IR/VIDEO
Flame Detectors

Spectral Emissions - “Fire Signatures”

<table>
<thead>
<tr>
<th>Wavelength (micron)</th>
<th>Relative Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
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<tr>
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<tr>
<td>0.4</td>
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<tr>
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</table>

<table>
<thead>
<tr>
<th>Material</th>
<th>UV</th>
<th>Visible</th>
<th>IR</th>
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<tbody>
<tr>
<td>OIL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COAL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GAS</td>
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</table>

Silane Flame:
UV < 0.3 microns
IR ≈ 2.7 microns

1 micron = 1000 nanometer
UV/IR/VIDEO  
Flame Detectors

Response Time

<table>
<thead>
<tr>
<th>DETECTOR TYPE</th>
<th>RESPONSE TIME</th>
<th>HOW TO AVOID NUISANCE ALARMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV</td>
<td>3-4 Milliseconds</td>
<td>2-3 seconds Delay</td>
</tr>
<tr>
<td>IR</td>
<td>3-5 seconds</td>
<td>Software Provisions</td>
</tr>
<tr>
<td>VIDEO</td>
<td>7 seconds</td>
<td>Software Provisions</td>
</tr>
<tr>
<td>SMOKE/PHOTO</td>
<td>4-5 minutes (smoldering fires)</td>
<td>&gt;1 minute (flaming fires)</td>
</tr>
<tr>
<td>SMOKE/ION</td>
<td>&gt;13 minutes (smoldering fires)</td>
<td>10 seconds (flaming fires)</td>
</tr>
</tbody>
</table>

Each Detector response time is affected by multiple elements (e.g., smoke density, visibility, humidity, etc)
UV/IR/VIDEO
Flame Detectors

The Science Behind the Datasheets...

\[ S = \frac{(kP - e\zeta d)}{d^2} \]

- \( S \) = Radiant Power Reaching the Detector
- \( k \) = Detector’s Proportionality Constant
- \( P \) = Radiant Power Emitted by the Fire
- \( e \) = Naperian Logarithm Base (2.7183)
- \( \zeta \) = Air’s Extinction Coefficient
- \( d \) = Distance Between Fire and Detector

Verify that the flame detector is listed for the expected light spectrum.
UV/IR/VIDEO
Flame Detectors

Performance Criteria

Check for UL, FM Global and Manufacturer’s Test Results

Vertical Field of View with Detector at 45° From Horizontal
Case Scenarios
Proper Coverage

Based on CGA G-13-2006

Typical Bulk Source Container Layout
Case Scenarios
Expect Field Coordination

How to get the Job done?

Protection of Bulk Silane Compounds
any?
evega@rjagroup.com
Thank You!

References

Storage and Handling of Silane and Silane Mixtures, ANSI/CGA-G-13, 2006 Edition
International Building Code (IBC), 2009 Edition
International Fire Code (IFC), 2009 Edition

Credits
Rolf Jensen & Associates. New York, Boston and Chicago Offices