The Role of Basic Design Data in Preventing Explosions within Fired Equipment: A Case Study

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AGENDA

- Facility Background
- Problem – Solution – Benefit
- Collection of Basic Design Data (BDD)
- Incident Description
- Lessons Learned
- Summary and Conclusions
- Questions
**Facility Background**

- Manufactures Expandable Polystyrene (EPS)-type product
- Isopentane ($i$-$C_5$) is used as the blowing agent
- Isopentane emissions from multiple sources throughout the process
  - Reactors
  - Hold Tanks
  - Packaging Operations
Expansions planned for the facility to increase production capacity ~800% over 3 – 4 year period

Isopentane emissions would have to be collected and destroyed for compliance with Environmental emissions permitting
Two classes of i-C₅ streams in the process:

- **Contaminated Air Stream** (LVOC)
  low levels of Isopentane mixed in air

- **Contaminated Inert-Gas Stream** (HVOC)
  variable levels of Isopentane mixed in nitrogen

- LVOC: Continuous, Steady Concentration
- HVOC: Intermittent, Variable Concentration
Catalytic Thermal Oxidizer (TOx) technology chosen

Well suited for moderate-to-high Volatile Organic Compound (VOC) concentrations

Well suited for processes that frequently cycle on and off

Estimated Destruction and Removal Efficiency (DRE) >99% on a continuous basis
AGENDA

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Questions
<table>
<thead>
<tr>
<th>Property</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
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<tbody>
<tr>
<td>Molecular Weight</td>
<td>72.2</td>
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<tr>
<td>Boiling Point</td>
<td>82 deg F / 28 deg C</td>
<td>-60 deg F / -51 deg C</td>
<td>800 deg F / 426 deg C</td>
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<tr>
<td>Flash Point</td>
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<td>Autoignition Temp</td>
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<td>LFL, v% fuel in air</td>
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<td>UFL, v% fuel in air</td>
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<td>MOC, v% oxygen</td>
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HVOC & LVOC Mixing Region

Catalytic Thermal Oxidizer

Natural Gas

Nitrogen Packaging Bin

Vent Filter

Nitrogen Packaging Bin Exhaust

Blower Discharge

FRESH AIR INTAKE

OXIDIZER FAN

Primary Heat Exchanger

Preheated Chamber

Oxidizer Fan

Fresh Air Intake

Bag House

Vent
Combustion Chamber (288 – 350 deg C)
Catalyst Bed (300 – 600 deg C)
<table>
<thead>
<tr>
<th>Source</th>
<th>Type</th>
<th>Reactor Vent/Purge</th>
<th>Conveyor Exhaust</th>
<th>Packaging Vent</th>
<th>Packaging Exhaust</th>
<th>Oxidizer Design Basis</th>
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<tr>
<td>Max Flow (SCFM)</td>
<td>Avg Conc (% i-C5)</td>
<td>Max Conc (% i-C5)</td>
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<td>Reactor Vent/Purge</td>
<td>Batch</td>
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TOx Feed Analysis (Design Basis)
Figure 35.—Limits of Flammability of Pentane in Mixtures of Air and Nitrogen, and of Air and Carbon Dioxide.
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- Oxygen in original atmosphere, percent
- Added inert gas in original atmosphere, percent

- Theoretical mixtures
- Carbon dioxide
- Nitrogen

Pentane in mixture, percent
Minimum Oxygen Concentration
Figure 35.—Limits of Flammability of Pentane in Mixtures of Air and Nitrogen, and of Air and Carbon Dioxide.
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Extrapolates to 4.5% Isopentane in Nitrogen

Figure 35.—Limits of Flammability of Pentane in Mixtures of Air and Nitrogen, and of Air and Carbon Dioxide.
HVOC Design Data
approximately 6.7% Isopentane in Nitrogen

Figure 35.—Limits of Flammability of Pentane in Mixtures of Air and Nitrogen, and of Air and Carbon Dioxide.
HVOC Stream designed to mix with the LVOC stream, and enter Combustion Chamber at ~20% Oxygen.
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Incident Description – What Happened?

- Initial Startup was performed using Reactor Venting (HVOC) Stream

- IMMEDIATELY upon venting the reactor, the HVOC flow rate was 600 SCFM!

- **Recall**: Basic Design Data specified an HVOC flow rate of ONLY 55 scfm

- How did this happen?
Reactor Venting Rates as a Function of Time

Average value of 55 scfm used for Design Basis

Reactor Vents (HVOC) at 600 scfm at Startup
Incident Description –
Event Sequence

- 600 scfm from Reactor Vent led to a flameout condition in the Burner Chamber
- Damper inlet interlocked to close upon flameout
- Second damper valve closed, and valve sequencing caused an over-pressure
- Rupture panel on Bag House burst, introducing atmospheric air to the system!
600 SCFM = FLAMEOUT!

CATALYTIC THERMAL OXIDIZER

NITROGEN

VENT FILTER

PACKAGING BLOWER DISCHARGE

TO ATM

PACKAGING BIN EXHAUST

TO ATM

BLOWER DISCHARGE

TO ATM

NITROGEN

FROM REACTOR 1

FROM REACTOR 2

FROM HOLD TANK

Natural Gas

PREHEATED CHAMBER

OXIDIZER BED

PRIMARY HEAT EXCHANGER

STACK

FRESH AIR INTAKE

OXIDIZER FAN

FIRE

BAG HOUSE

DRUM

% O2

% NO

% HC

% LEL
Interlocking Action....
Valve sequencing leads to over-pressure....
....and Rupture Panel BURSTS from overpressure

CATALYTIC THERMAL OXIDIZER

NITROGEN

VENT FILTER

PACKAGING BLOWER DISCHARGE

TO ATM

PACKAGING BIN EXHAUST

TO ATM

BLOWER DISCHARGE

FROM REACTOR 1

FROM REACTOR 2

FROM HOLD TANK

Natural Gas

PREHEATED CHAMBER

OXIDIZER FAN

FRESH AIR INTAKE

OXIDIZER BLOW

% LEL

% O2

% NO

% HC
Incident Description –

Event Sequence

Burst Rupture Panel went undetected by Operations

HVOC gases trapped in the header MIXED TOx was re-started minutes later

Combustion Chamber

with atmospheric air upstream of the Chamber

resulted CONFINED DEFLAGRATION
Unburned Fuel + Air Ingress = Explosion

CATALYTIC THERMAL OXIDIZER

NITROGEN

VENT FILTER

PACKAGING BLOWER DISCHARGE

TO ATM

PACKAGING BIN EXHAUST

TO ATM

BLOWER DISCHARGE

NITROGEN

FROM REACTOR 1

FROM REACTOR 2

FROM HOLD TANK

Ingress of fresh air

Natural Gas

Primary Heat Exchanger

Oxidizer Fan

FRESH AIR INTAKE

Vent

% O2

% CO

% HC

% LEL

Primary Heat Exchanger

Oxidizer Fan

Stack
HVOC Stream mixed with ambient air; ENTERED COMBUSTION CHAMBER AT 13.5% OXYGEN

Figure 35.—Limits of Flammability of Pentane in Mixtures of Air and Nitrogen, and of Air and Carbon Dioxide.
Lessons Learned

- HVOC flow rate from Reactor must be measured and controlled, independent of Reactor pressure

- The maximum concentration of Isopentane in Nitrogen that can be safely diluted with air without passing through the flammable envelope is 4.5%

- Bag House rupture panel failures must have remote indication and alarming
Loss Prevention Standards

- Basic Design Data (BDD) must be auditable, i.e., the data and its source must be documented and made available in a format that allows easy retrieval.
- Critical BDD should be confirmed independently.
- Persons responsible for collecting experimental BDD should ensure the data has been interpreted correctly by designers.
Loss Prevention Standards

Measures to prevent explosions in Fired Equipment must include minimizing accumulations of unburned fuels during combustion upsets – particularly on the fired-side of the equipment.

Flammability Diagrams must be used when designing Fired Equipment, such as Vent Collection and Destruction Systems (VCDS).
Questions?