Dust Explosion Propagation Through Small Diameter Pipes: A Review

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NFPA 654, 7.1.6.1

• “Where an explosion hazard exists, isolation devices shall be provided to prevent deflagration propagation between connected equipment in accordance with NFPA 69.”

NFPA 654, 7.1.6.2

• “The requirement of 7.1.6.1 shall not apply where all of the following conditions are met:
  • (1) The material being conveyed is not a metal dust or hybrid mixture.
  • (2) The connecting ductwork is smaller than 4 in. (100 mm) nominal diameter.
  • (3) The maximum concentration of dust conveyed through the duct is less than 25 percent of the minimum explosive concentration (MEC) of the material.
  • (4) The conveying velocity is sufficient to prevent accumulation of combustible dust in the duct.
  • (5) All connected equipment is properly designed for explosion protection by means other than deflagration pressure containment.”
Roser (1998)

“Investigation of dust explosion phenomena in interconnected vessels”, p. 15-22

- 1 m³ vessel connected to a 9-m long, **100 mm diameter pipe**
- Maize starch ($K_{st} = 190$ bar.m/s), wheat flour ($K_{st} = 80$ bar.m/s)
The maximum explosion over-pressure at different locations during the explosion event

<table>
<thead>
<tr>
<th></th>
<th>P2 in the 1 m³ [bar]</th>
<th>P3 at 2.5 m [bar]</th>
<th>P4 at 4.5 m [bar]</th>
<th>P5 at 6.5 m [bar]</th>
<th>P6 at 8.5 m [bar]</th>
</tr>
</thead>
<tbody>
<tr>
<td>750 g/m³ maize starch;</td>
<td>&gt;1.84</td>
<td>1.23</td>
<td>1.19</td>
<td>1.15</td>
<td>0.83</td>
</tr>
<tr>
<td>venting area A = 0.031 m²</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>750 g/m³ maize starch;</td>
<td>3.27</td>
<td>2.58</td>
<td>2.88</td>
<td>3.1</td>
<td>3.94</td>
</tr>
<tr>
<td>venting area A = 0.031 m²</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000 g/m³ wheat flour;</td>
<td>1.31</td>
<td>1.38</td>
<td>2.05</td>
<td>1.46</td>
<td>1.47</td>
</tr>
<tr>
<td>venting area A = 0.031 m²</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>750 g/m³ maize starch;</td>
<td>6.15</td>
<td>4</td>
<td>3.3</td>
<td>2.7</td>
<td>3.36</td>
</tr>
<tr>
<td>closed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000 g/m³ wheat flour;</td>
<td>4.07</td>
<td>2.23</td>
<td>2.03</td>
<td>1.67</td>
<td>1.45</td>
</tr>
<tr>
<td>closed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>750 g/m³ maize starch;</td>
<td>5.95</td>
<td>3.7</td>
<td>3.32</td>
<td>2.87</td>
<td>1.97</td>
</tr>
<tr>
<td>closed</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

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Vogl et al. (2005)

“Explosionsübertragung durch dünne Rohrleitungen”

- (1) The material being conveyed is **not a metal dust or hybrid mixture**. **CORNSTARCH AND WHEAT FLOUR**
- (2) The connecting ductwork is **smaller than 4 in. (100 mm)** nominal diameter. **82 MM, 42 MM AND 27 MM PIPES**
- (3) The maximum concentration of dust conveyed through the duct is **less than 25 percent of the minimum explosive concentration (MEC)** of the material. **NO DUST IN THE PIPE**
- (4) The conveying velocity is **sufficient to prevent accumulation** of combustible dust in the duct. **0 TO 30 M/S PROCESS FLOW**
- (5) All connected equipment is properly designed for explosion protection by means **other than deflagration pressure containment**. **VENTED 1M³ VESSELS**
DUST EXPLOSION PROPAGATION THROUGH SMALL DIAMETER PIPES: A REVIEW

1 m³

(5)

82 mm
42 mm
27 mm

(2)

dust free pipe

(3)

0-30 m/s

(4)

cornstarch (200 bar.m/s)
wheat flour (120 bar.m/s)

(1)

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82 mm pipe diameter experiments:
- 6 experiments led to full length flame propagation (12 m) with cornstarch (0.19 bar < $P_{red}$ < 2.77 bar)
- 5 experiments led to full length flame propagation with wheat flour (0.12 bar < $P_{red}$ < 1.47 bar)

42 mm pipe diameter experiments:
- 3 experiments led to full length flame propagation with cornstarch ($P_{red}$ = 0.15 bar, 0.41 bar and 2.26 bar)
- 5 experiments led to full length flame propagation with wheat flour (0.08 bar < $P_{red}$ < 1.18 bar)

27 mm pipe diameter experiments:
- 2 experiments led to full length flame propagation with cornstarch, for $P_{red}$ = 0.57 bar and 2.19 bar
- 1 experiment led to full length flame propagation with wheat flour, for $P_{red}$ = 1 bar

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• Other experiments in 42 mm and 27 mm diameter pipes led to shorter flame propagation (< 12 m)

• Note that 12 meters for 42 mm and 27 mm diameter pipes lead to L/D of 286 and 444 respectively!

• While the likelihood of full length (12 m) flame propagation decreases with pipe diameter, it always occurred at least once per series for moderate P_{red}, meaning that it remains a possibility even for very small diameter pipes.

• In all experiments, the air flow in the pipes was varied from 0 m/s to 30 m/s, but did not show any influence on the flame propagation according to the authors.
Vogl et al. (private communication)

4.4 m³ vented vessel connected to a 1 m³ vented vessel

- 20-m long, **100 mm diameter pipe diameter**
- cornstarch (200 bar.m/s)
- ignition at the center of the 4.4 m³ vessel
- dust concentration: 1,000 g/m³ in each vessel
- $P_{red} \sim 1$ bar, $V_{max} \sim 300$ m/s
DUST EXPLOSION PROPAGATION THROUGH SMALL DIAMETER PIPES: A REVIEW

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Vogl et al. (private communication)

**Bucket elevator**

- Vented bucket elevator connected to a vented cyclone by a 15-m long, **100 mm diameter pipe**
- Malt (150 bar.m/s)
Conclusions

- There is no experimental evidence that conditions stated in NFPA 654 (§7.1.6.2) could prevent explosion propagation between two protected vessels.
- On the opposite, there is experimental data showing that explosion propagation between two vented vessels through dust free, ≤ 4-in pipes with St1 fuels, under normal process conveyance (0 to 30 m/s) does occur.
- Therefore, it is proposed to remove §7.1.6.2 from NFPA 654.
Dust Explosion Propagation Through Small Diameter Pipes: A Review

P0 – P9 Druckaufnehmer
F1 – F10 Flammenmelder
Rohrdurchmesser d = 82 mm, 42 mm, 27 mm

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82 mm pipe - Cornstarch

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82 mm pipe - Wheat flour
42 mm pipe - Cornstarch

Distance (m) vs Flame Arrival Time (ms) graph.
42 mm pipe - Wheat flour
27 mm pipe - Cornstarch and wheat flour

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Pineau (1982)

“Propagation of Dust Explosions in Ducts”, in “The Control and Prevention of Dust Explosions”

- 1 m³ and 0.1 m³ contained vessels
- 25 mm, 50 mm or 100 mm duct
- 10 m, 25 m or 40 m long
- wheat flour, wood flour
**TABLE II**

Flame propagation tests in duct with wheat flour.

<table>
<thead>
<tr>
<th>Volume of explosion vessel (m³)</th>
<th>Diameter of duct (mm)</th>
<th>Length of duct (m)</th>
<th>Frequency of flame propagation to the end of duct (on number of tests)</th>
<th>Maximum propagation distance for flame (m)</th>
<th>Maximum explosion overpressure (*) (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>25</td>
<td>3/3</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td>1</td>
<td>60</td>
<td>40</td>
<td>5/6</td>
<td>45, 3</td>
<td>40</td>
</tr>
<tr>
<td>1</td>
<td>50</td>
<td>10</td>
<td>1/2</td>
<td>50</td>
<td>≈ 10</td>
</tr>
<tr>
<td>1</td>
<td>30</td>
<td>25</td>
<td>0/2</td>
<td>0</td>
<td>≈ 10</td>
</tr>
<tr>
<td>1</td>
<td>50</td>
<td>40</td>
<td>0/2</td>
<td>0</td>
<td>≈ 20</td>
</tr>
<tr>
<td>1</td>
<td>25</td>
<td>10</td>
<td>0/3</td>
<td>6</td>
<td>&lt; 7</td>
</tr>
<tr>
<td>0.1</td>
<td>100</td>
<td>25</td>
<td>5/7</td>
<td>71</td>
<td>25</td>
</tr>
<tr>
<td>0.1</td>
<td>50</td>
<td>25</td>
<td>0/3</td>
<td>0</td>
<td>&lt; 15</td>
</tr>
<tr>
<td>duct bend at 15 m</td>
<td>1</td>
<td>100</td>
<td>25</td>
<td>2/2</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The number between brackets is the distance from the sensor to the connecting point of the duct with the vessel.

(*) abnormally high value.
**TABLE 1.1: Flame propagation tests in duct with wood flour.**

<table>
<thead>
<tr>
<th>Volume of the explosion vessel $V$ $(m^3)$</th>
<th>Diameter of duct $D$ (mm)</th>
<th>Length of duct $L$ (m)</th>
<th>Frequency of flame propagation to the end of duct $(F)$ (on number of tests)</th>
<th>Maximum propagation distance for flame $(m)$</th>
<th>Maximum explosion overpressure $(\text{bar})$</th>
<th>Detonation frequency in duct</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>25</td>
<td>4/4</td>
<td>100</td>
<td>25</td>
<td>7.4</td>
</tr>
<tr>
<td>1</td>
<td>100</td>
<td>40</td>
<td>7/6</td>
<td>67.5</td>
<td>40</td>
<td>7.5</td>
</tr>
<tr>
<td>1</td>
<td>50</td>
<td>10</td>
<td>7/9</td>
<td>77</td>
<td>10</td>
<td>7.95</td>
</tr>
</tbody>
</table>

**Straight duct**

| 1                                        | 50                        | 25                     | 4/8                                              | 50                                      | 25                             | 8.25                          |
| 1                                        | 50                        | 40                     | 3/7                                              | 43                                       | 40                             | 7.95                          |
| 1                                        | 25                        | 10                     | 0/3                                              | 0                                       | $< 7$                           | 8                             |
| 0.1                                      | 100                       | 25                     | 1/6                                              | 16.6                                    | 25                             | 4.5                           |
| 0.1                                      | 50                        | 10                     | 2/6                                              | 50                                      | 16                             | 6.25                          |
| 0.1                                      | 50                        | 25                     | 0/9                                              | 0                                       | $< 15$                          | 6.75                          |

**Duct bend at 6 m**

| 1                                        | 90                        | 10                     | 4/6                                              | 66.6                                    | 10                             | 6.9                           |
| 1                                        | 25                        | 25/46                 | 25                                               | 25                                      | 7.5                           |
| 1                                        | 25                        | 25/46                 | 25                                               | 25                                      | 7.5                           |

**Duct bend at 15 m**

| 1                                        | 100                       | 25                     | 2/2                                              | 100                                     | 25                             | 7.05                          |

*The number between brackets is the distance from the sensor to the connecting point of the duct with the vessel.

[**] abnormally high value.

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Matsuda (1982)


• “Matsuda has in fact been able to show that, in a 75-mm-diameter pneumatic conveyor, a coal dust explosion flame could be propagated over a length exceeding 50 m.”
- rotary blower, dust feeder and 1.3 m³ dust filter
- ignition in the pipe: explosion flame of acetylene-air mixture or continuous induction spark at 11 m or 10 m away from the dust feeder
- test A: 37-m long 4-in diameter pipe / test B: 51.5-m long 3-in diameter pipe fitted to 35-m long 4-in diameter pipe
- dusts: polystyrene, ABS resin, wood and coal
- vent ratio: 0.56 m⁻¹
Figure 2.
Explosibility of polystyrene dust with change of conveying air velocity.
○ : explosion, △ : propagation part of pipe length, ● : no propagation.

Figure 3.
Explosibility of ABS resin dust with change of conveying air velocity.
○ : explosion, △ : propagation part of pipe length, ● : no propagation.

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Figure 4.
Influence of conveying air velocity on explosibility of wood dust.
Test (A) ○: explosion, ●: no propagation,
Test (B) △: explosion with gas ignition source,
Test (B) ▽: no propagation with an electric spark ignition.

Figure 5.
Influence of conveying air velocity on explosibility of coal dust.

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Van Wingerden et al. (1992)

“Dust Explosion Propagation in Connected Vessels”, VDI Berichte 975, p. 507-528

- “At low and medium concentrations the explosion accelerates through the duct leading to high peak pressures in the duct and the connected vessel. **High dust concentrations reduce the acceleration and it becomes very difficult to obtain flame propagation through the duct.**”
Fike Corporation

Vented dust collector (demo)

- 2.4 m³ vented dust collector
- 4-in (front) and 6-in (back) pipes
- cornstarch (200 bar.m/s)
- dust concentration: 500 g/m³ in the vessel, 100 g/m³ in each pipe
- 0.4 m² vent