Risk Assessment BASF Class Tank Container

Technical University of Berlin | Department of Rail Vehicles

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Motivation & Objectives of the Risk Assessment

• BASF Class Tank Containers are certified and approved since 2015 for the transport of dangerous goods and since 2017 in use without incidents
• In 2018 BASF started a voluntary Risk Assessment according to

**CSM – VO (EU) 402/2013**
## System comparison

<table>
<thead>
<tr>
<th>New System</th>
<th>Conventional Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>B-TC on iCTW</strong></td>
<td><strong>ISO-Tank Container on intermodal car</strong></td>
</tr>
<tr>
<td>Bogies TVP-NBS</td>
<td>Approved bogies Y25</td>
</tr>
<tr>
<td>L-Buffers</td>
<td>A-Buffers</td>
</tr>
<tr>
<td>Strengthened spigots and corner-castings</td>
<td>Tank size up to 26'</td>
</tr>
</tbody>
</table>
Influences of system adaption

Higher forces due to larger container:
- Strengthened spigots and corner-castings
- L-buffers
- Reinforced car-frame
- Hump yard suitability

- Sloshing movements with partially filled container
- Innovative bogie with disc brakes
- Hump yard suitability

- Tightness of container after impact
- Influence of car construction
- Movement of container during impact
Scope of Risk Assessment

Comparison of

- Technical specifications
- Driving behavior
- System limits
- Sloshing movements

Comparison by

- Driving trails
- Simulations
- Impact-tests
- Data analysis

Paper based technical comparison

- System definition
- Risk Analysis & Detection
- Risk Evaluation

Running stability with sloshing impact

- Analysis of sloshing forces on driving behavior
- Measurements and Simulation with increased velocities

Long-term trials and hump investigation

- Shock detection during operation
- Hump yard suitability
- Buffing Simulations

Impact tests

- Container stability during Overriding
- FE Simulations and Tests of occurring damage
Paper based technical comparison

- Based on technical standards / RID requirements
- Identification of critical components
- Comparison of reference values for container materials
- Exposure of identified system modifications:
  - Hazard Identification
  - Hazard Management
  - Risk Evaluation

Train driving and shunting

- Loading
  - Tank construction and mounting
  - Railway operating regulations and events
  - Railway staff
  - Operational tool
  - Environmental conditions

Inspection of carriages and wagons

Maintenance
## Investigation of sloshing movements („Schwall“)

<table>
<thead>
<tr>
<th>Investigation</th>
<th>Test vehicle</th>
<th>Track</th>
<th>Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Experiment</strong></td>
<td>45' B-TC on 45' iCTW (BTC45)</td>
<td>Double S-Curve ( r = 190 ) m</td>
<td>10, 15, 20 and 25 km/h</td>
</tr>
<tr>
<td></td>
<td>45' B-TC on 52' iCTW (BTC52)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2x 20' TC on 40' CTW (TC2x20)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2x 26' TC on 60' CTW (TC2x26)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Simulation</strong></td>
<td>45' B-TC on 45' iCTW (BTC45)</td>
<td>Curve ( r = 500 ) m and S-Curve ( r = 150 ) m</td>
<td>Curve up to 150 km/h</td>
</tr>
<tr>
<td></td>
<td>45' B-TC on 52' iCTW (BTC52)</td>
<td></td>
<td>S-Curve up to 70 km/h</td>
</tr>
<tr>
<td></td>
<td>3x 20' TC on 60' CTW (TC3x20)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Experimental investigation

• Measurement of running stability with evaluating influence of liquid sloshing:
  – Full / partially loaded / empty
  – Different velocities
• Data acquisition for simulation models
• Comparison of different systems

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical Position Sensor</td>
<td>Bogie</td>
</tr>
<tr>
<td>Lateral Position Sensor</td>
<td>Bogie</td>
</tr>
<tr>
<td>Velocity Sensor</td>
<td>Car Body</td>
</tr>
<tr>
<td>GPS Sensor</td>
<td>Container</td>
</tr>
<tr>
<td>Gyroscope</td>
<td>Car Body</td>
</tr>
<tr>
<td>Photoelectric barrier</td>
<td>Car Body</td>
</tr>
</tbody>
</table>
Measurement equipment for lateral and vertical movement

Lateral Position Sensor sy_1R

Vertical Position Sensor sz_1R
Simulation of sloshing movements

- Approximation of critical states at increasing velocities
- Evaluating different operation scenarios

**B-TC on iTCW Wheel Set 1 left \( v = 30 \text{ km/h} \)**

![Graph showing displacement over running time for B-TC on iTCW Wheel Set 1 left at \( v = 30 \text{ km/h} \)]
Sloshing model

- Simplified mechanical models for lateral and longitudinal sloshing: Pendulum / Spring-Mass-System
- Validation with measurements from investigation of sloshing movements
Experimental results of the investigation

Running safety Loc+Wagon (wagon pushed, half loaded state)

Test vehicles:
- BTC52
- TC2x26
- BTC45
- TC2x20

H/H_{max} vs. Velocity [km/h]
Simulation results of investigation

No critical sloshing movements are detected during the measurements and simulations
Long-term trials

- Evaluation of accelerations and forces on critical components (spigots, buffers)
- Comparison of fully and partially loaded B-TC on 45' iCTW with conventional intermodal car
- Testing areas:
  - Shuttle operation Ludwigshafen ↔ Schwarzheide ($\sum 15,000$ km)
  - Hump yard ($\sum 250$ runs / load status)
- Execution of non-destructive testing on spigots and corner-casting to detect failures
- Data processing: LPF 16 Hz (EN 12663-2)
Instrumentation

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>🟦</td>
<td>1-axis Accelerometer at container</td>
</tr>
<tr>
<td>🟢</td>
<td>1-axis Accelerometer at car</td>
</tr>
<tr>
<td>🔳</td>
<td>GPS Sensor</td>
</tr>
</tbody>
</table>

1-axis Accelerometer at container
1-axis Accelerometer at car
GPS Sensor

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# Equipment

<table>
<thead>
<tr>
<th></th>
<th>Set 3</th>
<th>Set 4</th>
<th>Set 5</th>
<th>Set 11</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wagon type</strong></td>
<td>45' iCTW</td>
<td>45' iCTW</td>
<td>45' iCTW</td>
<td>60' CTW</td>
</tr>
<tr>
<td><strong>Container type</strong></td>
<td>45' B-TC</td>
<td>45' B-TC</td>
<td>45' B-TC</td>
<td>2x 26' TC</td>
</tr>
<tr>
<td><strong>Load</strong></td>
<td>Full</td>
<td>Full</td>
<td>Half</td>
<td>Full</td>
</tr>
<tr>
<td><strong>Operation</strong></td>
<td>Shuttle (LU-SH)</td>
<td>Hump yard</td>
<td>Hump yard</td>
<td>Hump yard</td>
</tr>
<tr>
<td><strong>Goods</strong></td>
<td>MEG</td>
<td>MEG</td>
<td>Water</td>
<td>MEG</td>
</tr>
</tbody>
</table>
Shuttle measurements

• No excess of longitudinal (left) and lateral (right) acceleration limits between the destinations

• 16 Runs Ludwigshafen-Schwarzheide and Ludwigshafen-Antwerp
Hump yard measurements and simulations

No critical states during measurements and simulations detected
No damage at examined components detected
Impact tests

Evaluation of damage on overriding cars and derailment collision
## Equipment

<table>
<thead>
<tr>
<th>Investigation</th>
<th>Test vehicle</th>
<th>Velocity [km/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side-on and frontal impact simulation and Frontal impact experiment</td>
<td>45' B-TC (Van Hool) on 45' iCTW (BTC45 VH)</td>
<td>Side on: 25</td>
</tr>
<tr>
<td></td>
<td>45' B-TC (Magyar) on 45' iCTW (BTC45 GM)</td>
<td>Frontal: 15 and 19</td>
</tr>
<tr>
<td></td>
<td>Tank wagon (TW) Zacens</td>
<td>15.0 and 18.6</td>
</tr>
<tr>
<td></td>
<td>2x 26' TC on 52' iCTW (Conventional)</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15.1</td>
</tr>
<tr>
<td>Frontal impact</td>
<td>45' B-TC (Van Hool) on 52' iCTW (BTC52 VH)</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14.0</td>
</tr>
</tbody>
</table>
FEM simulation of impact scenario

- Execution with ANSYS Professional
- Models with up to $2.5 \times 10^6$ elements
- Analysis of material failure
  - Maximal tension
  - Maximal strain
- Execution with different velocities
Side-on impact simulation

- Additional modelling of bogies
- Simplified rail-wheel contact
- Impact velocity: 25 km/h

Simulation up to 0.85 s:
## Material properties of the tank shell

<table>
<thead>
<tr>
<th></th>
<th>Van Hool</th>
<th>Magyar</th>
<th>Tank wagon</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>A₁ [%]</td>
<td>50</td>
<td>48</td>
<td>35</td>
<td>43</td>
</tr>
<tr>
<td>Number of vaccum rings</td>
<td>deleted</td>
<td>deleted</td>
<td>deleted</td>
<td>deleted</td>
</tr>
<tr>
<td>Thickness of vaccum rings [mm]</td>
<td>deleted</td>
<td>deleted</td>
<td>deleted</td>
<td>deleted</td>
</tr>
<tr>
<td>Head Wall Thickness [mm]</td>
<td>7.9</td>
<td>5.65</td>
<td>8.0</td>
<td>5.2</td>
</tr>
<tr>
<td>Shell thickness [mm]</td>
<td>3.4</td>
<td>4.5</td>
<td>6.3</td>
<td>4.2</td>
</tr>
</tbody>
</table>
Plastic strain distribution on the impacted tank

45' B-TC VH/45' iCTW
Max: 0.418

45' B-TC GM/45' iCTW
Max: 0.443

TW
Max: 0.552

2x26' TC/52' iCTW
Max: 0.112
Plastic strain distribution on the impacted tank

Max plastic strain:

45' B-TC VH/45' iCTW – Max 0.418

45' B-TC GM/45' iCTW – Max 0.443

TW – Max 0.552

2x26' TC/52' iCTW – Max 0.112
Plastic strain distribution on the impacted wagon

45' B-TC VH/45' iCTW
Max: 0.332

45' B-TC GM/45' iCTW
Max: 0.232

TW
Max: 0.267

2x26' TC/52' iCTW
Max: 0.330

Advantage of the longitudinal beams of the iCTW against tank wagon
Reasonable impact force ratio of the tank to the wagon
Plastic strain distribution on impacting tank

Most deformation in case of side-on impact between tank wagons
Both tanks failed!
## Simulation results of side-on impact

Safety reserve = 1 - Max. plastic Strain / $A_1$

<table>
<thead>
<tr>
<th>$A_1$/Max. Strain</th>
<th>Investigated tank</th>
<th>Safety reserve of investigated tank</th>
<th>Stationary car body</th>
<th>Impacting tank</th>
<th>Impacting car body</th>
<th>TW-BTC45 VH</th>
<th>TW-BTC45 GM</th>
<th>TW-TW</th>
<th>TW-Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50/41.8</td>
<td>48/44.3</td>
<td>35/55.2</td>
<td>43/12.2</td>
</tr>
<tr>
<td></td>
<td>Investigated tank</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16.4 %</td>
<td>7.8 %</td>
<td></td>
<td>71.6 %</td>
</tr>
<tr>
<td></td>
<td>Safety reserve of investigated tank</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-57.7 %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stationary car body</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20/33.2</td>
<td>20/23.2</td>
<td>20/26.7</td>
<td>20/33.0</td>
</tr>
<tr>
<td></td>
<td>Impacting tank</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>35/7.0</td>
<td>35/23.1</td>
<td>35/35.1</td>
<td>35/4.3</td>
</tr>
<tr>
<td></td>
<td>Impacting car body</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20/25.6</td>
<td>20/26.3</td>
<td>20/12.7</td>
<td>20/30.1</td>
</tr>
</tbody>
</table>
Plastic strain distribution on tank bottom

<table>
<thead>
<tr>
<th>Material</th>
<th>15 km/h Max</th>
<th>19 km/h Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>BTC45 VH</td>
<td>29.5%</td>
<td>56.6%</td>
</tr>
<tr>
<td>BTC45 GM</td>
<td>25.7%</td>
<td>48.2%</td>
</tr>
<tr>
<td>Conventional</td>
<td>20.0%</td>
<td>53.0%</td>
</tr>
<tr>
<td>TW</td>
<td>33.0%</td>
<td>50.0%</td>
</tr>
</tbody>
</table>

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Simulation results of frontal impact

<table>
<thead>
<tr>
<th>Tank Material</th>
<th>Norm</th>
<th>Thickness Head / Shell [mm]</th>
<th>Equiv. Head Thickness [mm]</th>
<th>Equiv. Shell Thickness [mm]</th>
<th>Safety reserve ($V_{imp} = 15$km/h)</th>
<th>Safety reserve ($V_{imp} = 19$km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TW</td>
<td>1.4571</td>
<td>6.3 / 6.3</td>
<td>9.15</td>
<td>9.15</td>
<td>5.71 %</td>
<td>-42.86 %</td>
</tr>
<tr>
<td></td>
<td>DIN 17440</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>1.4404</td>
<td>5.2 / 4.2</td>
<td>9.23</td>
<td>7.46</td>
<td>53.49 %</td>
<td>-23.26 %</td>
</tr>
<tr>
<td></td>
<td>SANS 50028-7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BTC45 VH</td>
<td>1.4402</td>
<td>7.9 / 3.4</td>
<td>15.82</td>
<td>7.07</td>
<td>38.54 %</td>
<td>-17.92 %</td>
</tr>
<tr>
<td></td>
<td>SANS 50028-7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BTC45 GM</td>
<td>1.4402</td>
<td>5.65 / 4.5</td>
<td>11.31</td>
<td>9.01</td>
<td>46.46 %</td>
<td>-0.42 %</td>
</tr>
<tr>
<td></td>
<td>SANS 50028-7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BTC52 VH</td>
<td>1.4404</td>
<td>7.9 / 3.4</td>
<td>15.82</td>
<td>7.07</td>
<td>100 %</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

Safety reserve = 1 - Max. plastic Strain / A1
Impact test execution
Impacting wagon

Flat wagon Rs 671 as an impacting wagon

Appropriately prepared Rs 671 for the impact tests

Weight: 80.2 t
**Instrumentation**

- **Measuring:**
  - Accelerations & velocities
  - Container movement
  - Impact forces

---

**Measurement**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-axis Accelerometer</td>
<td>Car Body</td>
</tr>
<tr>
<td>2-axis Accelerometer</td>
<td>Car Body</td>
</tr>
<tr>
<td>3-axis Accelerometer</td>
<td>Container</td>
</tr>
<tr>
<td>GPS Sensor</td>
<td>Container</td>
</tr>
<tr>
<td>Longitudinal Position Sensor</td>
<td>Car Body</td>
</tr>
<tr>
<td>Vertical Position Sensor</td>
<td>Car Body</td>
</tr>
<tr>
<td>Force transducer</td>
<td>Impacting Buffer</td>
</tr>
</tbody>
</table>

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Measurement equipment on B-TC/iCTW System (front left)

Three-axis Accelerometer
K05C_vl_ax
K06C_vl_ay
K07C_vl_az

Longitudinal Position Sensor
K17C_vl_sx

Three-axis Accelerometer
K05W_vl_ax
K06W_vl_ay
K07W_vl_az

Vertical Position Sensor
K21C_vl_sz
Impact test evaluation

Crack testing per liquid penetrant inspections

Deformation of tank per 3D-Scan
1: Different Systems

<table>
<thead>
<tr>
<th>New System</th>
<th>Conventional System</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>B-TC Van Hool on iCTW</strong></td>
<td><strong>ISO-TC on intermodal wagon</strong></td>
</tr>
<tr>
<td>• Equiv. thickness in mild steel: (calculated acc. RID §6.8)</td>
<td>• Equiv. thickness in mild steel:</td>
</tr>
<tr>
<td>Shell Head</td>
<td>Shell Head</td>
</tr>
<tr>
<td>7.1 mm 15.8 mm</td>
<td>7.5 mm 9.2 mm</td>
</tr>
<tr>
<td>• No leakage</td>
<td>• No leakage</td>
</tr>
<tr>
<td>• Deformation: 90 l</td>
<td>• Deformation: 390 l</td>
</tr>
<tr>
<td><strong>Tank wagon</strong></td>
<td><strong>Tank wagon</strong></td>
</tr>
<tr>
<td>• Equiv. thickness in mild steel:</td>
<td>• Equiv. thickness in mild steel:</td>
</tr>
<tr>
<td>Shell Head</td>
<td>Shell Head</td>
</tr>
<tr>
<td>9.2 mm 9.2 mm</td>
<td>7.5 mm 9.2 mm</td>
</tr>
<tr>
<td>• No leakage</td>
<td>• No leakage</td>
</tr>
<tr>
<td>• Deformation: 100 l</td>
<td>• Deformation: 100 l</td>
</tr>
</tbody>
</table>
1: Different Systems – PT Results

- **New System**
- **Conventional System**

- \( v = 15 \text{ km/h} \)
- No crack on BTC VH
- Cracks on conventional systems
2: Shell thickness

- Shell thickness: 3.4 mm
- Equiv. shell thickness: 7.1 mm
- Equiv. head thickness: 15.8 mm
- Deformation: 90 l

- Shell thickness: 4.5 mm
- Equiv. shell thickness: 9 mm
- Equiv. head thickness: 11.3 mm
- Deformation: 190 l

No deformation at frame and cylinder surface on either containers
Comparable deformation at container bottom
3: Increased velocity

- Shell thickness: 3.4 mm
- Head thickness: 7.9 mm
- Deformation: 90 l

- Shell thickness: 3.4 mm
- Head thickness: 7.9 mm
- Deformation: 210 l

Increasing deformation with increasing velocity - no leakage
4: Increased car length

- Shell thickness: 3.4 mm
- Head thickness: 7.9 mm
- Deformation: 90 l

Impact car stopped by bogie before reaching container with 52' iCTW
Conclusions for running safety

**New System with comparable running stability on straight tracks, curves and at hump yard**

**Detected sloshing movements with no effect to driving safety**
- Specific filling degree for containers in rail transport not recommended → adjust to Rail Tank Cars (RID -chapter 1.6.4.33)

**No damage on new, high-strength spigots**
- New components suitable for all intermodal transport units (EN 12663-2, RID -chapter 6.8.2.1.2)

**No damage on any component after hump yard tests**
- All loaded ICTW suitable for hump yard (EN 12663-2)
Conclusions for failure status / Impact

RTC only vessel with leakage for side impact
- Safety level of conventional system exceeded
- Longitudinal beams of iCTW improve safety for side impacts

Minimum shell thickness with no effect on frontal impact safety
- Amendment of regulations for minimum shell thickness not necessary (RID chapter 6.8.2.1.17; 6.8.2.1.18; 6.8.2.1.19 and 6.8.2.1.20)
- No leakages for all systems – equivalent safety level.

The larger distance between tank-head and buffer of the Rail Tank Car has no positive safety effect compared to the B-TC
- Minimum distance not recommended for TC / B-TC (RID chapter 6.8.2.1.29)

A positive safety effect for both systems can only be reached by a significant distance increase
- Safe replacement for Crash-buffers and overbuffering protection (RID TE25)
Contact Person

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