Update to the LNG Dispersion Model Validation Database

Simon Gant and James Stewart

PHMSA Public Workshop on Liquefied Natural Gas (LNG) Regulations, Washington DC, 19 May 2016

This presentation and the work it describes were undertaken by the Health and Safety Laboratory under contract to Oak Ridge National Laboratory. Its contents, including any opinions and/or conclusion expressed or recommendations made, do not necessarily reflect policy or views of the Health and Safety Executive. © British Crown Copyright, 2016
Contents

• Background
• Aims
• Methodology
  – Maximum arc-wise concentrations
  – Additional experimental data: Maplin Sands and Thorney Island
  – BA-Hamburg experiments: errors
• Deliverables
• Timeline
• Possible future work
Background

2007  LNG Model Evaluation Protocol (Ivings et al., 2007)

2008  LNG Model Validation Database, Version 1 (Coldrick et al., 2008)

2009  Review of LNG Source Models (Webber et al., 2009)

2010  LNG Model Validation Database, Version 11 (Coldrick et al., 2010)
      PHMSA Advisory Bulletin PHMSA-2010-0226

2011  Evaluation of DEGADIS 2.1, PHAST v6.6/6.7 and FLACS v9.1r2 by FERC & PHMSA

2012  

...  

2016  LNG Model Validation Database, Version 12 (Stewart et al., 2016)
      LNG Model Evaluation Protocol (Ivings et al., 2016)
Content of the NFPA Database:
Aims of the Update

• To add new features into the database to meet the requirements of PHMSA Advisory Bulletin PHMSA-2010-0226
  – Maximum arc-wise concentrations
  – Point-wise data for Maplin Sands and Thorney Island
  – Concentration Safety Factor, Concentration Safety Factor to LFL, Distance Safety Factor to LFL
  – Experimental uncertainty

• To correct errors
  – BA-Hamburg: incorrect geometry
  – Other small mistakes

• To provide more extensive documentation and guidance
Contents

• Background
• Aims
• Methodology
  – Maximum arc-wise concentrations
  – Additional experimental data: Maplin Sands and Thorney Island
  – BA-Hamburg experiments: errors
• Deliverables
• Timeline
• Possible future work
Max. Arc-wise Concentration

Measured maximum arc-wise concentration

Predicted maximum arc-wise concentration

Cloud centerline

Gas source

Sensors

Experiments

Model

Method used by e.g. Hanna et al. (1993)
Max. Arc-wise Concentration

Predicted maximum arc-wise concentration

PHMSA method: used previously to evaluate DEGADIS, PHAST, and FLACS
Max. Arc-wise Concentration

PHMSA method for max. arc-wise concentrations

PHMSA-2010-0226 Advisory Bulletin states: “The maximum arc wise concentration should be based on the location of the experimental sensor data that produced the maximum arc wise concentration relative to the cloud centerline”

- Precautionary, given uncertainties in ensemble mean concentrations (it will tend to make the ½ LFL exclusion zone larger)
- It accounts for the strong vertical gradient in concentration near the ground
- It accounts for sensors not being aligned to arcs in some experiments
- It encourages development of plume meandering models
Max. Arc-wise Concentration

Does it matter which method is used for maximum arc-wise concentration?

Example:
Maplin Sands 27 experiment

Results summary for Maplin Sands, Burro, Coyote & Falcon:

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean Relative Bias (MRB)</th>
<th>Mean Relative Square Error (MRSE)</th>
<th>Geometric Mean (MG)</th>
<th>Geometric Variance (VG)</th>
<th>Factor of Two (FAC2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hanna et al.</td>
<td>0.31</td>
<td>0.38</td>
<td>1.4</td>
<td>1.6</td>
<td>61%</td>
</tr>
<tr>
<td>PHMSA</td>
<td>0.41</td>
<td>0.59</td>
<td>1.9</td>
<td>15</td>
<td>56%</td>
</tr>
<tr>
<td>Acceptable</td>
<td>-0.4 &lt; MRB &lt; 0.4</td>
<td>MRSE &lt; 2.3</td>
<td>0.67 &lt; MG &lt; 1.5</td>
<td>VG &lt; 3.3</td>
<td>FAC2 &gt; 50%</td>
</tr>
</tbody>
</table>

Results for DRIFT model
Contents

• Background
• Aims
• Methodology
  – Maximum arc-wise concentrations
  – Additional experimental data: Maplin Sands and Thorney Island
  – BA-Hamburg experiments: errors
• Deliverables
• Timeline
• Possible future work
Additional Experimental Data

Maplin Sands (1980) experiments

Time-series data processed for point-wise concentrations

© Shell
Additional Experimental Data

Thorney Island (1982) experiments

Time-series data processed for point-wise concentrations
Contents

• Background
• Aims
• Methodology
  – Maximum arc-wise concentrations
  – Additional experimental data: Maplin Sands and Thorney Island
  – BA-Hamburg experiments: errors
• Deliverables
• Timeline
• Possible future work
Errors in Experimental Data

BA-Hamburg experiments

Incorrect: NFPA database, version 11

Correct: NFPA database, version 12

REDIPHEM (1996)

<table>
<thead>
<tr>
<th></th>
<th>Instantaneous release</th>
<th>Continuous release</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>Height</td>
<td>Diameter</td>
</tr>
<tr>
<td>DA6502</td>
<td>0.4</td>
<td>4</td>
</tr>
<tr>
<td>DA6647</td>
<td>0.4</td>
<td>4</td>
</tr>
</tbody>
</table>

Schatzmann et al. (1991)

Continuous Release.
Obstacles: Semi-circular wall of Height: 2.2 Lcc and Radius 23 Lcc.
Ground-level Concentrations measured downstream from the Source.

Fig. 26: Concentration versus time traces at different locations for a continuous heavy gas release into flat terrain obstructed by a semi-circular wall.

Marotzke (1993)

Ein solcher halbkreisförmiger Schutzzaun kann zum Beispiel dann zur Anwendung kommen, wenn sich nur in einer Richtung von einer potentiellen Schwergasquelle zu schützende Einrichtungen befinden. Es wurden zwei Zäune mit unterschiedlichen Radien verwendet:

- quellnaher Zaun: Radius 2.5 Lcc bzw. 14 Lcc und Zaunhöhe 0.4 Lcc bzw. 2.2 Lcc
- quellferner Zaun: Radius 4 Lcc bzw. 22.4 Lcc und Zaunhöhe 0.4 Lcc bzw. 2.2 Lcc
Contents

• Background
• Aims
• Methodology
  – Maximum arc-wise concentrations
  – Additional experimental data: Maplin Sands and Thorney Island
  – BA-Hamburg experiments: errors
• Deliverables
• Timeline
• Possible future work
Deliverables

1. NFPA Model Validation Database version 12
   a) Microsoft Excel 2010 spreadsheet
   b) ASCII data files (plain text version of spreadsheet)
   c) Database Guide (125 pages)

2. Revised LNG Model Evaluation Protocol
   - Relatively minor changes from version 11
## Deliverables

Excel 2010 Spreadsheet version 12, e.g. Burro 3
Deliverables

Database Guide
Contents

• Background
• Aims
• Methodology
  – Maximum arc-wise concentrations
  – Additional experimental data: Maplin Sands and Thorney Island
  – BA-Hamburg experiments: errors
• Deliverables
• Timeline
• Possible future work
Timeline

• 1 May 2016   Draft database spreadsheet and guide circulated for review
• 27 May 2016  Comments due on database and guide
• End of June 2016 Revised MEP report circulated for review
• End of July 2016 Comments due on MEP report
• End of Aug 2016 Final NFPA Database version 12 issued

Tentative dates
Contents

• Background
• Aims
• Methodology
  – Maximum arc-wise concentrations
  – Additional experimental data: Maplin Sands and Thorney Island
  – BA-Hamburg experiments: errors
• Deliverables
• Timeline
• Possible future work
Possible Future Work

• LNG MEP focuses on spills of LNG (import terminals)
  – Source terms: evaporating pools of cryogenic liquids

• For LNG export terminals, range of other source terms:
  – Flashing jets of pressure-liquefied refrigerant gases, e.g. propane, mixed refrigerants
  – Spills of condensates

• Experimental data could be added to LNG MEP, e.g.:
  – Flashing jets: Lathen (propane releases with obstacles), Desert Tortoise and FLADIS (ammonia), Jack Rabbit (chlorine) etc.
References

- PHMSA Advisory Bulletin, docket PHMSA-2010-0226
- DEGADIS 2.1 evaluation for LNG MEP
- PHAST v6.6 and v6.7 evaluation for LNG MEP
  - http://www.regulations.gov/#!docketDetail;D=PHMSA-2011-0075
- FLACS 9.1r2 evaluation for LNG MEP
  - https://www.regulations.gov/#!docketDetail;D=PHMSA-2011-0101
- Hanna et al. (1993)
- Witlox et al. (2013)
- REDIPHEM
- Schatzmann et al. (1991)
- Marotzke (1993)
Acknowledgements

- Julie Halliday (PHMSA)
- Simon Rose (Oak Ridge National Laboratory)
- David Rosenberg (FERC)
- Michael Schatzmann (Hamburg University)
- Lorenzo Mauri (GexCon)
- Steven Hanna (Hanna Consultants)
- Joseph Chang (US Department of Homeland Security)
- Henk Witlox (DNVGL)
- Morten Nielsen and Søren Ott (Technical University of Denmark)
- Gert König-Langlo (Alfred Wegener Institute Polar & Marine Research)
- Shell, for permission to use Maplin Sands images

- Daniel Gorham, Kathleen Almand and Janna Shapiro (NFPA)
- Jay Jablonski (HSB)
- Richard Hoffmann (Hoffman-Feige)
- Leon Bowdoin (Hess LNG)
- Frank Katulak (GDF Suez)
- Kevin Ritz (BGE)
- Jeff Beale (CH IV International)
- David Butler (City of Everett, MA)
- Andrew Kohout (FERC)
- Filippo Gavelli (GexCon)
- Phani Raj (DOT)
- Anay Luketa (Sandia National Laboratories)