Review of US Early Experiences with LNG

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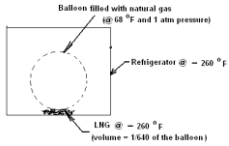
1

Basic LNG Properties

- When natural gas is cooled to -260 ºF it forms LNG.
- Natural Gas at atmospheric pressure and temperature is lighter than air
  (Density is 0.558 that of air)
- The volume reduction from natural gas to LNG is 640:1
- LNG vapor at -260 ºF is heavier than air (density 1.5 times that of air).
- Natural gas @ -168 ºF is neutrally buoyant



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Important LNG Properties

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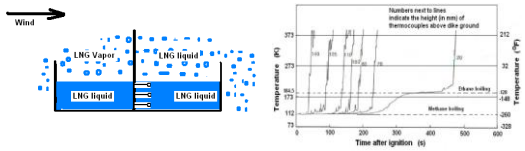
LNG boiling & distilling on ground or on water

LNG is spilled on land or water evaporates rapidly due to its significantly lower temperature compared to that of land or water.



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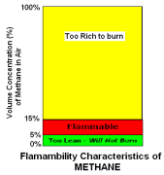
Flammability Characteristics of LNG Vapor

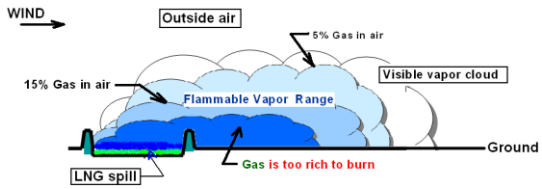


Flamambility Characteristics of METHANE

- Vapor is flammable in air in the range 5% (LFL) to 15% (UFL) concentration.

6

LNG Vapor Cloud Characteristics



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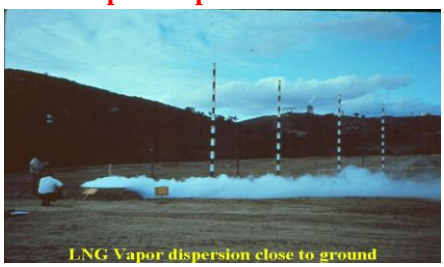
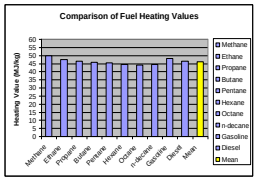
LNG Vapor Dispersion Test Result



8

Comparison of Fuel Heating Values



9

Other important properties of LNG & its vapor

- **LNG floats on water (LNG = 3.7 lb/gal, water = 8.3 lb/gal).**
- **LNG spill on land or on water results in the formation of cold vapor due to LNG boiling (@ -260 ºF).**
- **LNG vapor, when mixed with atmospheric air, condenses water vapor making the "cloud" visible like a fog.**
- **LNG vapor generated by LNG boiling is 1.5 times heavier than air; hence, it hugs the ground or water surface when dispersing in the atmosphere.**
- **LNG pool (liquid) can sustain a fire. LNG vapor in a cloud is flammable (and sustain a flash fire) for vapor concentrations in the 5% to 15% range.**

10

Laboratory & Field Tests & Results

11

Partial List of Experiments

- Shell tests in 1968 (Rapid phase transition)
- Bureau of Mines tests in 1969 (spills on water)
- Tests on LNG jettisoning from ships – Shell, 1972
- Spill tests on land funded by AGA 1972-73 (vapor dispersion and pool fire)
- MIT laboratory tests to understand Rapid Phase Transition phenomenon, 1975-76
- USCH funded China Lake LNG Spill tests 1976-79 (Vapor dispersion, pool fire, vapor fire, vapor cloud explosion)
- US Department of Energy tests 1978-82 (vapor dispersion, pool fire)
- British Gas, Shell & Gaz de France's tests in Europe (1980s and 1990s). Vapor dispersion, fire radiation and cloud explosion type tests.
- Maplin Sands tests by Shell, 1981-82. Spills on water, vapor dispersion and vapor fire. Largest liquid pool spread on water = 30 m
- Montoir tests by a consortium (headed by Gaz-de France). Pool fire tests on land. Largest land pool size test to date, 35 m (115 ft) diameter

12

CHINA LAKE LNG POOL FIRE TESTS

13

Vapor generated by LNG spill on water and dispersion impeded by a barrier

14

Fire ball produced from high concentration vapor cloud ignition

Result of early (accidental) ignition of vapor cloud formed in FALCON Test # 5

15

LNG Pool Fire (~15 m dia) on water China Lake, CA tests 1976-78

Fire on an unconfined pool of LNG spreading on water

16

LNG Fire Characteristics at Different Burn Stages

17

Montoir 35 m Pool Fire Tests

18

Characteristics of 35 m dia LNG Fire

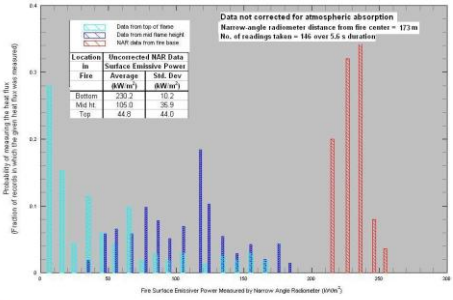
- Very large fires are sooty because of oxygen starvation in the fire center.
- This reduces the radiative output from the fire.
- Also reduces effective hazard area around the fire.

19

Similarities in burning characteristics in 35m dia LNG Pool Fire & an Oil Fire

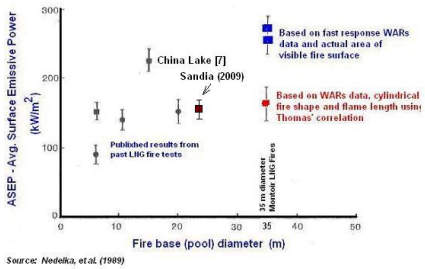
20

NAR Data: Statistical Distribution



21

Mean Emissive Power vs. Fire Diameter



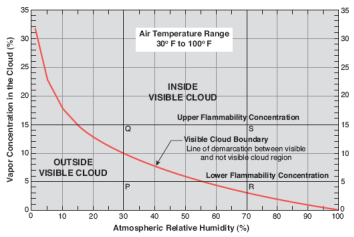
Source: Nedelka, et al. (1989)

22

China Lake Vapor Fire Test

23

Flammable concentration is within the cloud only when atmospheric relative humidity > 55%



24

GdF Vapor Fire Test

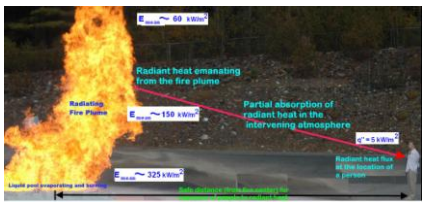
25

LNG Vapor Cloud Ignition

- Vapor cloud fire is a deflagration fire. No over pressures have been recorded.
- Progression of a vapor fire may be impeded by ground level obstructions

China Lake VCE Tests

Important parameters in radiant heat effect calculation



Parameters

1. Physical size of fire (description by idealized geometry)
2. Mean surface emissive power of an idealized fire shape
3. Variation of surface emissive power with height
4. Spectral character of the IR emission from the fire
5. Atmospheric absorption by water vapor, CO2 and scattering
6. Total energy flux incident on a person at any distance, and its spectral characteristics
7. Heat absorption, reflection and thermal inertia properties of human skin
8. Effect of obstructions and clothing on the heat flux incident on skin

LNG related Myths (cont'd)

MYTH 6: People exposed to radiant heat flux levels of 5 kW/m^2 (1600 Btu/hr ft^2) suffer extreme burns or even fatalities.

FACT 6: Human subject exposed to LNG fire radiant heat in field tests did not suffer any burn

Human Exposure to LNG Pool

Exposure of a Person to Radiant Heat from LNG Pool Fire©

Tests Conducted by
Technology & Management Systems, Inc.
Burlington, MA 01803

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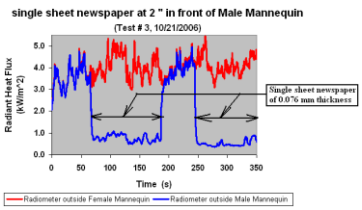
Effect of newspaper shade



Conclusions

Conclusions

- LNG is a hazardous/flammable material. However, LNG is not very much different in its hazards from other hydrocarbon fuels that society uses in very large quantities.

Current Work

- U. S. Department of Energy is funding LNG spill tests
  - Work being done at Sandia Labs in New Mexico
  - Extensive secrecy, results anticipated later this year
- Latest test
  - The is 120m diameter pool, with about 200 m3 LNG released
  - LNG formed an 80 m diameter pool
  - Fire about 40 m diameter, 3 – 4 diameters high
  - black smoke was observed, but not excessive. see more.
  - Fire lasted about 4 minutes

Conclusions

Field Scale Tests indicate that:

- Large LNG fires are similar in physical and radiative characteristics to other oil fires.
- Unconfined vapor clouds when ignited form only a slow deflagration vapor fire. No detonations have been observed.
- Significant propane and other higher hydrocarbon mixture and a strong ignition is needed to initiate vapor cloud explosion
- A human being clothed in normal civilian clothing can withstand a radiant heat intensity of 5 kW/m^2 for 30 seconds without incurring any burns or severe pain.

Dr. Raj and I Thank you for your attention and interest

Questions?