Cryogenic Suppression of Liquid Pool Fires and Wooden Crib Fires

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Introduction

- Fire is one of the leading causes of loss of property and life around the world.

- There are inadequacies with current techniques for extinction of challenging fires involving hazardous materials in industrial plants, fuel depots, refineries, powerplants, warehouses, etc.

- Chemical and fuel fires pose some of the most dangerous situations for firefighters. Commonly known as class B fires, they can be unpredictable and depending on the size and intensity of the fire, difficult to extinguish or even contain.

- Firefighters currently use combinations of foam and water in order to prevent such fires from spreading and causing further damage. However, both have limited effectiveness and the foam can contaminate the surrounding land and waterways.

Introduction

The technique presented herein is targeting hazardous chemical fires, fuel pool or fuel spill fires, where expedient suppression or extinction is paramount in order to prevent explosions, avoid release of toxic fumes and avert environmental disasters.

An example of such a fire at the Buncefield oil depot near Hemel Hempstead, England, in Dec.2005

Fire Extinction by Liquid Nitrogen

- **Liquid nitrogen vaporizes readily and is environmentally-benign, causing no additional property damage or groundwater contamination.**
- **As vaporizing nitrogen displaces oxygen, the cryogen should be applied to ventilated locations at the absence of living beings.**
- **Direct application of this cryogen onto a hot pyrolyzing or burning surface induces vaporization and abrupt expansion.**
- **The pyrolyzing gases are inerted, the surface is cooled, which reduces its pyrolysis rate, air is separated from the fuel and the fire extinguishes.**

Fire Extinction by Liquid Nitrogen

- **Calculations show that direct application of a quantity of liquid nitrogen (at 77 K) on a pyrolyzing/burning horizontal surface induces rapid evaporation to gaseous nitrogen still at 77K, which causes an expansion of 175 times** (from 0.807 g/cc to 0.004622 g/cc).

- **Subsequently the nitrogen gas expands to higher temperatures in the flame. At the very least, it expands to room temperature (298 K). Expansion to room temperature would constitute an additional 3.7 times expansion** (from 0.004462 g/cc to 0.00125 g/cc), **or a total expansion of 645 times.**

- **Expansion to even higher temperatures in a flame may generate a total expansion of more than 1000 times.**

- **Such expansion is exceedingly fast with a typical duration in the order of seconds. If abrupt evaporation is realized then the size of the flame that can be extinguished is maximum.**

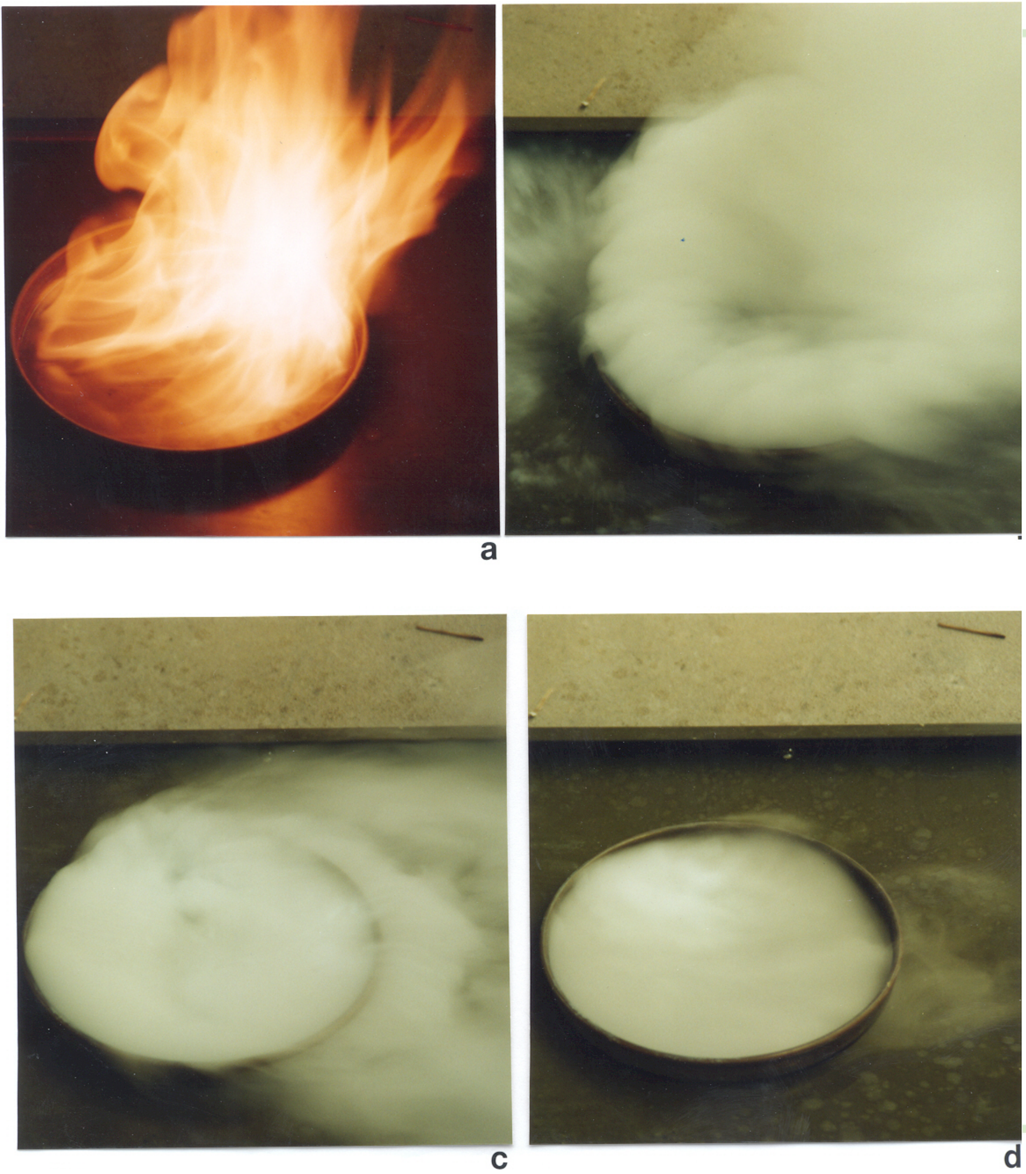
Fire Extinction by Liquid Nitrogen

- Results from experimental work on extinguishing fires with direct application of liquid nitrogen are reported herein.
- There have been some applications of cryogenic liquids in the fire-fighting practice however little, if any, has been reported in the scientific literature.
- While this technique may be applied to a variety of fire types, such as chemical fires, building fires, , etc., this work presents the first systematic results on the use of the cryogen liquid nitrogen to extinguish pool fires.

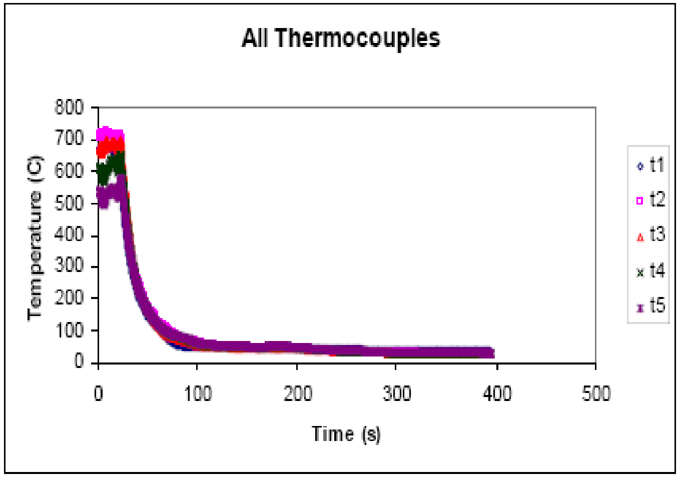
Experiments with Small Alcohol Pool Fires

- The effectiveness of liquid nitrogen was fist demonstrated in bench-scale experiments at **Northeastern University**.
- These preliminary experiments involved a fire over a shallow (1 cm) pool of iso-propyl alcohol, 20 cm in diameter.
- A quantity of 2-3 milliliters of liquid nitrogen, thrown from a distance, successfully extinguished the fire.
- The extinction of this flame appeared to be nearly-instantaneous, i.e., in the order of a second.

Experiments with Small Alcohol Pool Fires



Simultaneous temperature measurements at 5 axial locations in the flame, upon introduction of the cryogen, are also shown below.



Systematic Experiments with Pool Fires

Subsequent work at CSIRO, Australia, involved fires of two different fuels (propanol or diesel oil) in a little under 1 square meter pool, 2.5 cm deep. The fuel pan was placed inside a larger pan which was filled with water, 5 cm deep. The diesel oil fire was ignited with the help of a small quantity of gasoline. Upon ignition the fires were let to burn for a few minutes.

Cryogen quantities of 1 liter (or less) were gently poured from a small height (15 cm above the fire) at three different locations:

(a) at one corner of the fuel pool (inside pan);
(b) in the pool of water (outside pan),
either at its two corners (half and half) or
along its front side (between the two pans);
(c) along the floor, outside of both pans.

Systematic Experiments with Pool Fires

- The first type of experiments were remarkably successful; as the cryogen was poured at one corner of the fuel pool it spread over the entire pool and extinguished the fire instantaneously (in the order of seconds). The cloud of nitrogen then spread over the outside water pool and subsequently over the laboratory floor, covering an area of approximately 3 meters in diameter. The height of the cloud was only 15-20 cm, because of gravity. The coverage of that area by the nitrogen vapors, upon extinguishment of the flame, lasted for a few minutes.

- This technique was also successful at the presence of wind, generated by a fan blowing on the flame, the cryogen being poured at a corner upstream of the flame.

- The second and third types of experiments were not successful in most cases, with one notable exception: the presence of wind.

- Hence the presence of wind may be beneficial in some cases.

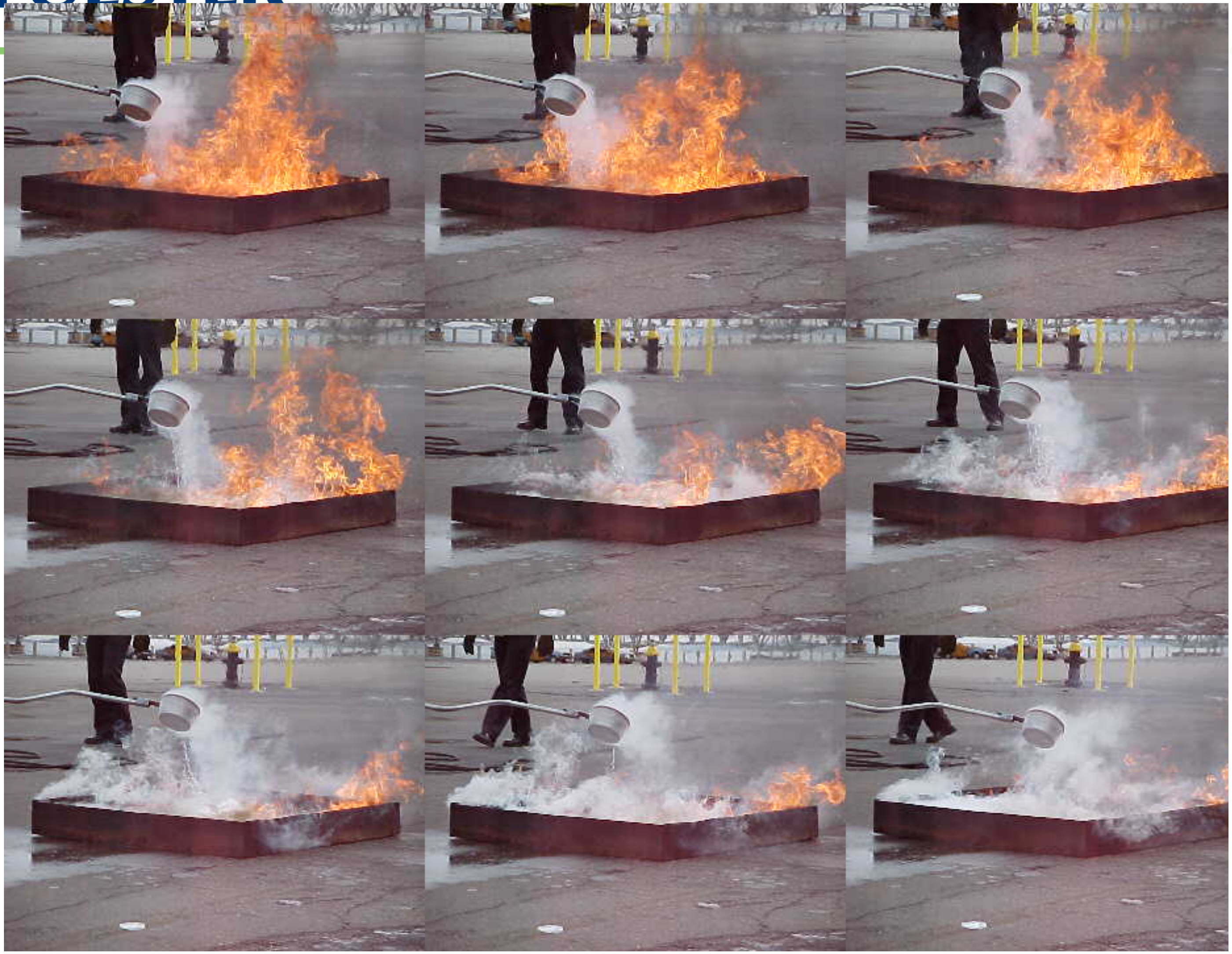
Systematic Experiments with Pool Fires

Demonstrations at Boston's FD

- Demonstrations were performed at the Boston Fire Department's Training Academy. A sizable pool-fire of diesel oil and gasoline was ignited on a thick layer of water (5 cm). The tank size was 1 square meter. The tests were conducted outdoors, at the presence of a strong wind (20-40 mph).
- A bulk quantity (1 liter) of liquid nitrogen was manually distributed over the fire, using a bucket attached to the tip of a horizontal pole. The fire was quickly extinguished.
- A larger quantity (approx. 1.5 liters) was dumped in the center of the fire, some splashed outside. This fire was also extinguished.
- Finally, the fire was extinguished by throwing (tossing) cryogen contained in styro-foam cups (coffee cups) with the lid in place, from a distance of 3 meters away from the edge of the fire. Three cups of the cryogen were needed to extinguish this fire.

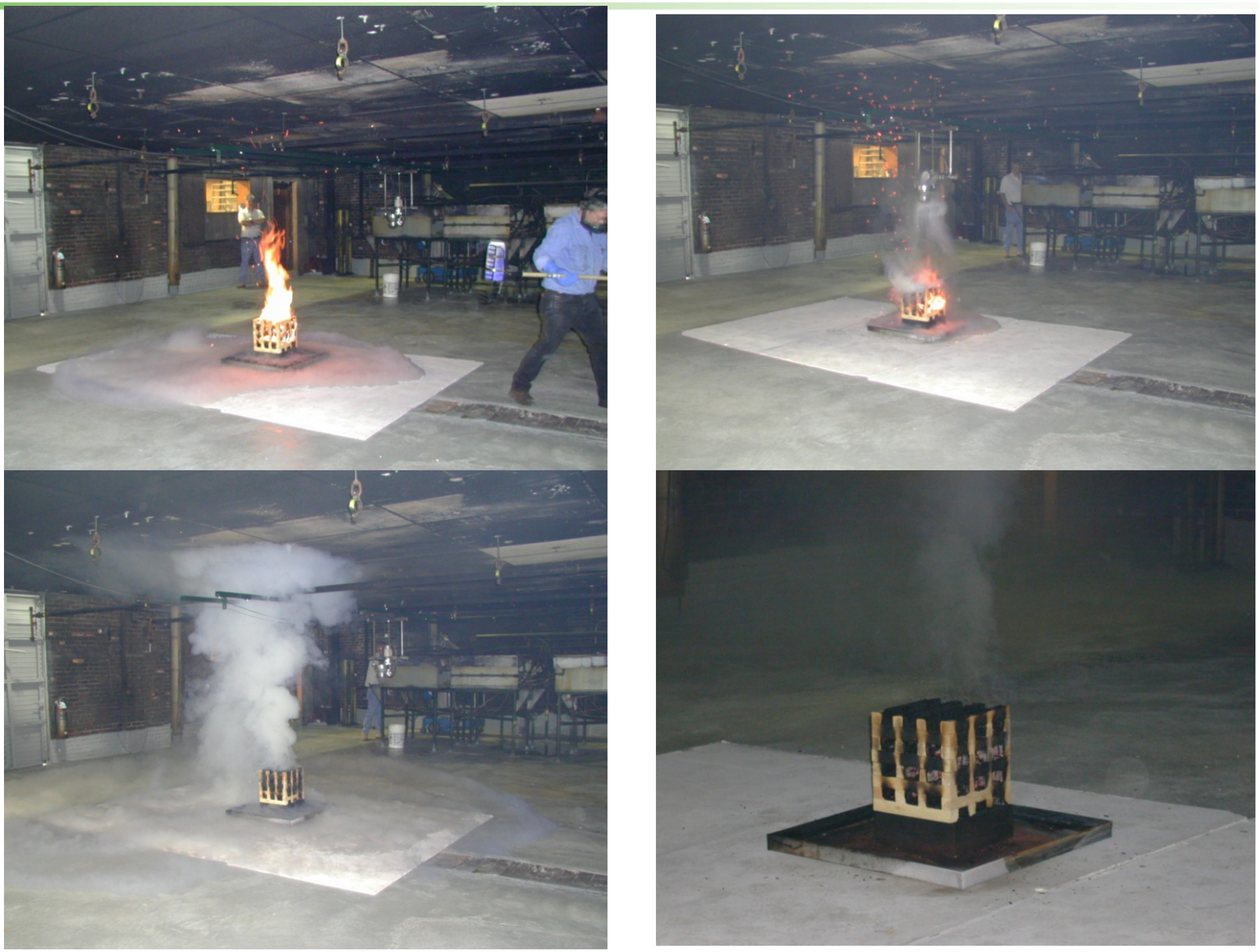
Demonstrations with Diesel Oil Pool Fires

Experiments with Larger Diesel Oil Pool Fires



The next question is how can liquid nitrogen be effectively delivered to fires ?

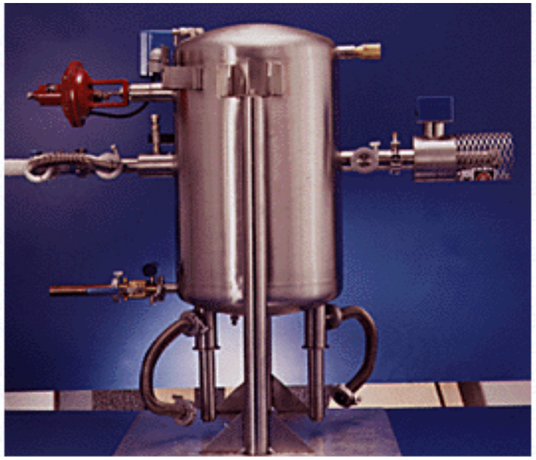
Experiments with Wood Cribs

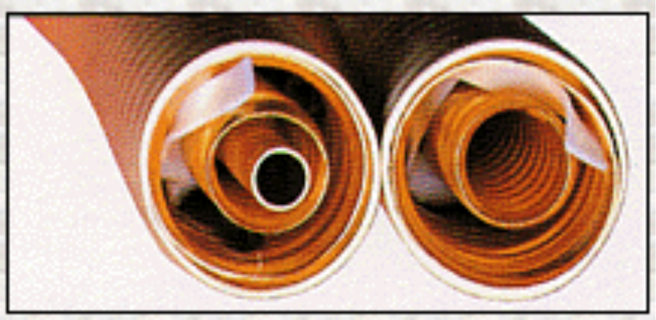


Delivery Methods

Firefighters apply perfluorooctane sulphonate foam by hose to Buncefield Depot fire.

Delivery by Track, Hose, Nozzle



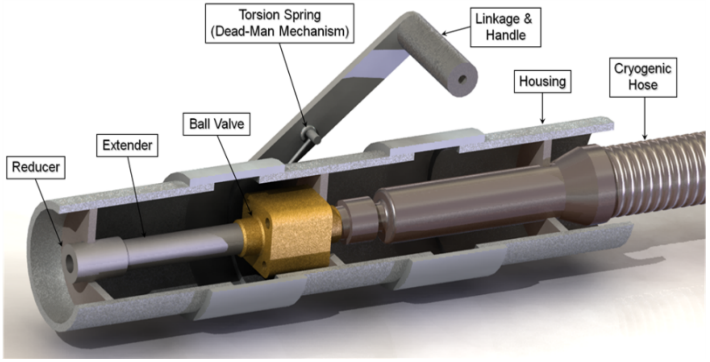


Components:

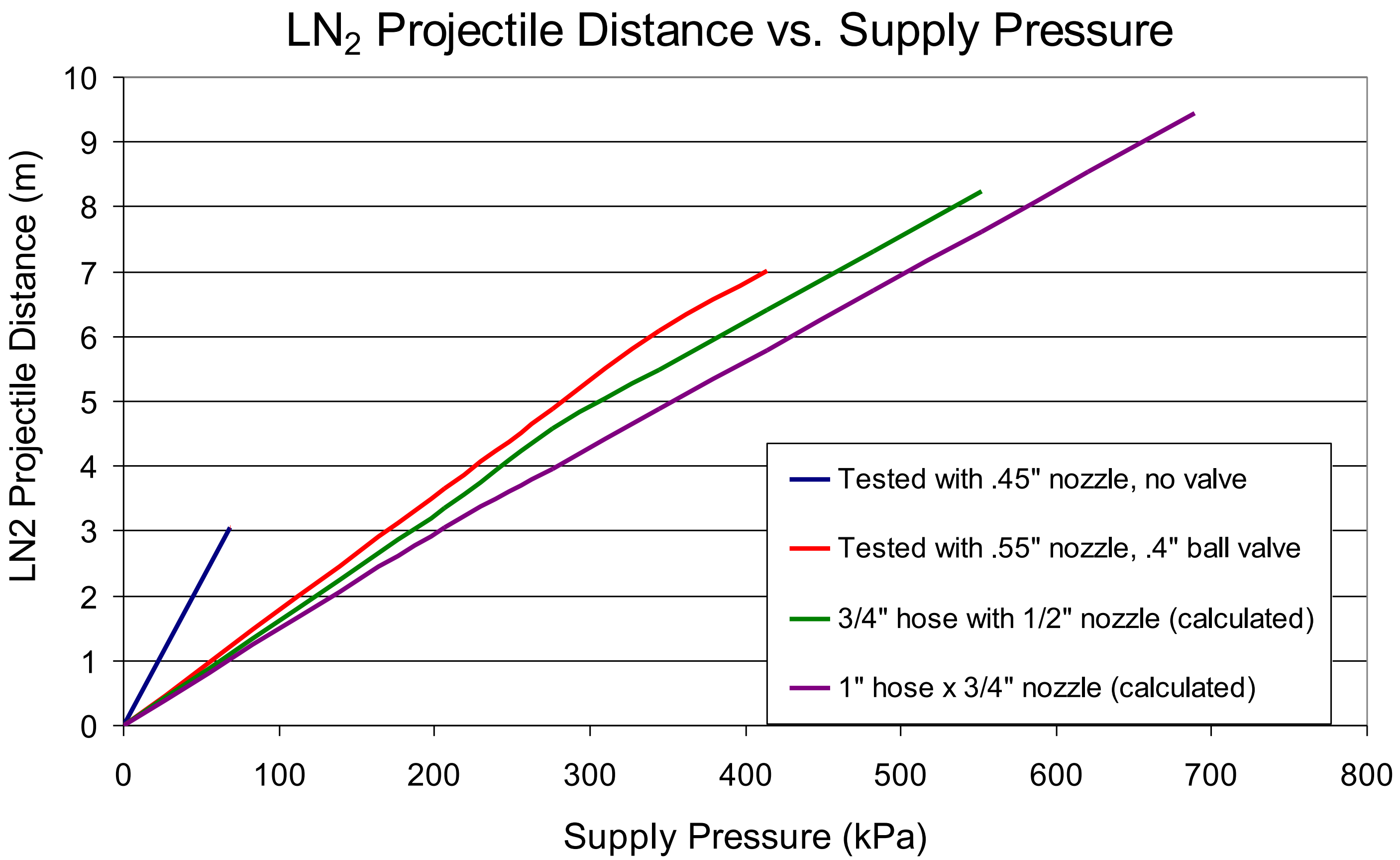
- Reservoir
  - Truck mounted
  - Double walled
  - Vacuum insulated
- Pump
  - Variable pressure
  - Variable flow rate
  - Automatic, mechanical compensation
- Hose
  - Triaxial
  - Vacuum barrier
  - Phase separator
- Nozzle

Hose/Nozzle Application

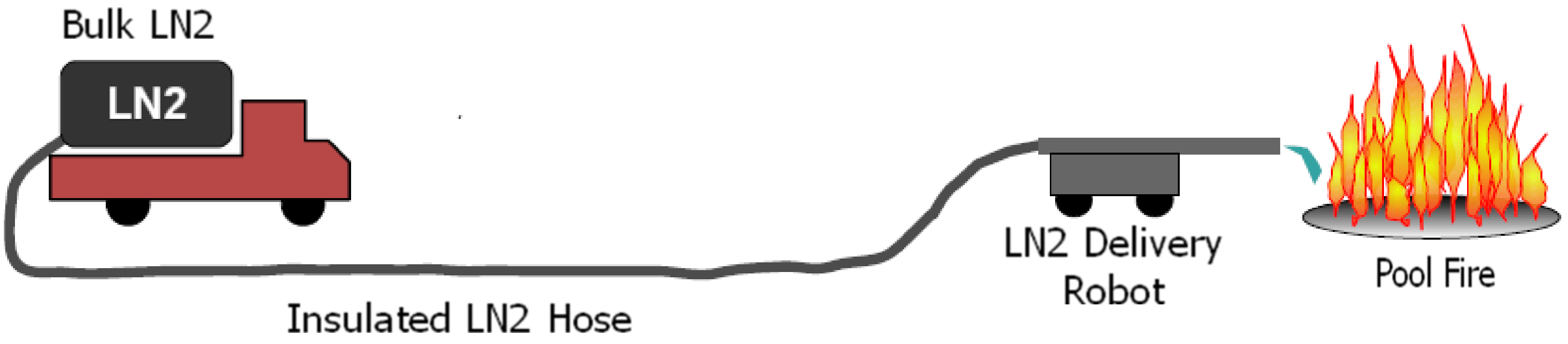
Hose/Nozzle Application



Delivery of LN2 by Hose/Nozzle



Robotic Delivery of LN2



Robotic Delivery of LN2

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- THE USE OF LIQUID GASES TO EXTINGUISH FIRES
- by
- D. J. RASBASH

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- **HAZARDOUS LIQUIDS**

LSMS: UN NOUVEAU MODELE D'ETALEMENT DE NAPPES DE GNL ET AUTRES MATIERES DANGEREUSES

- N.C. Daish, S.B. Dalziel, M.T. Jackson and P.F. Linden
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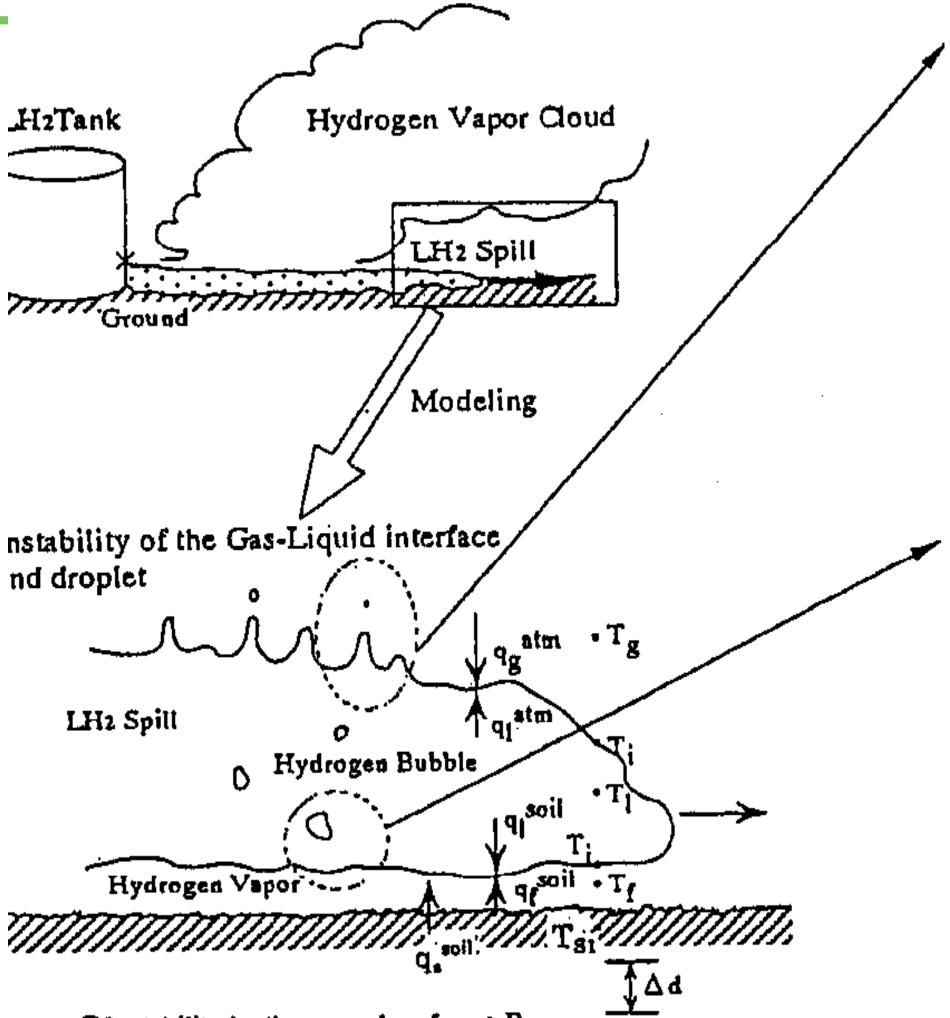

◎Instability by the ground surface : B

Evaporation rate by the heat of atmosphere

$$M^{atm} = \frac{(q_g^{atm} + q_l^{atm})}{\Delta h}$$

$$q_g^{atm} = (\alpha_g^{atm} \cdot A^{atm})(T_g - T_i)$$

$$q_l^{atm} = (\alpha_l^{atm} \cdot A^{atm})(T_l - T_i)$$

$$A^{atm} = \frac{3 \cdot V_l}{\boxed{r_{drop}}}$$

◎Instability of Gas-Liquid interface : r_{drop}
<Parameter>

Evaporation rate by the heat of groudd

$$M^{soil} = \frac{(q_l^{soil} + q_f^{soil})}{\Delta h}$$

$$q_l^{soil} = (\alpha_l^{soil} \cdot \boxed{A^{soil}})(T_l - T_i)$$

$$q_f^{soil} = (\alpha_f^{soil} \cdot \boxed{A^{soil}})(T_f - T_i)$$

$$(\delta \rho_f C p_f) \frac{dT_f}{dt} = q_s^{soil} - q_f^{soil}$$

$$q_s^{soil} = \frac{2}{\frac{\Delta d}{\lambda^{soil}} + \frac{\delta}{\lambda_f} \cdot \boxed{B}} ($$

◎Instability of the Surface of Vaporfilm : A^{soil}

TANK FIRE SUPPRESSION
DIRECT LIQUID NITROGEN SUPPLY SYSTEM