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Field experiments on high expansion (HEX) foam application for controlling LNG pool fire

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ABSTRACT

Previous research suggests that high expansion foam with an expansion ratio of 500 to 1 is one of the best options for controlling liquefied natural gas (LNG) pool fire on land. However, its effectiveness heavily depends on the foam application rate, foam generator location, and the design of LNG spill containment dike. Examination of these factors is necessary to achieve the maximum benefit for applying HEX on LNG pool fires.

While theoretical study of the effects of foam on LNG fires is important, the complicated phenomena involved in LNG pool fire and foam application increase the need for LNG field experimentation. Therefore, five LNG experiments were conducted at Texas A&M University's Brayton Fire Training Field. ANGUS FIRE provided Expandol solution to form 500 to 1 high expansion foam (HEX) and its latest LNG Turbex Fixed High Expansion Foam Generators.

In this paper, data collected during five experiments are presented and analyzed. The effectiveness of high expansion foam for controlling LNG pool fires with various application rates at two different types of containment pits is discussed. LNG fire behaviors and the effects of dike wall height are also presented and discussed.

1. Introduction

Liquefied natural gas (LNG) is cryogenic. It readily receives heat from its surroundings. When LNG is spilled into a concrete containment pit, concrete acts as a warming source to the LNG. This causes the LNG to evaporate at an initially fast rate creating LNG vapors. Initially, LNG vapors are heavier than air, so when they escape, they hug the ground. It is only as the LNG vapors mix with the warmer air that they begin to rise slowly. It is near the ground where most ignition sources exist, so when the gas dilutes to its flammable range of 5–15% volume by volume in the air, vapor ignition is likely to occur. Fire burns back to the LNG pool where an intense fire is started and creates an LNG pool fire.

Expansion foam has been used as a fire extinguisher for non-liquefied hydrocarbon pool fires. Expansion foam provides an insulating effect that protects the fuel surface from the heat radiation of the fire; it also blocks free air movement crucial to prolong the fire. Water content in the foam absorbs the heat from the fire and forms steam. It provides a cooling effect and reduces the burning rate due to the heat radiation of the fire. Steam dilutes air around the fire and reduces the air necessary to sustain the fire. Based on these phenomena, expansion foam is able to extinguish non-liquefied hydrocarbon pool fire.

On the other hand, similar phenomena do not happen when expansion foam is applied to LNG, which usually leaks at its boiling point of −162 °C. The differences can only be understood by having knowledge of how expansion foam works for both LNG vapor dispersion and LNG pool fire suppression, not as an extinguishment agent. Fig. 1 illustrates expansion foam application on LNG vapor dispersion and pool fires.

Water in a limited amount in the expansion foam plays an important role as the LNG vapors' warming agent. As part of the expansion foam behavior, water content slowly degrades, releasing limited amounts of water downward, until it reaches the LNG pool surface. While draining to the LNG pool surface, the water is in contact with LNG vapors that move upward finding ways to the open air. During this contact, the LNG vapors are warmed, the vapor density is reduced, and LNG vapors become more buoyant (less dense); thus, they are dispersed more upward instead of downwind. At the same time the water is cooled down creating ice tubes along the LNG vapor pathways, which are open to the air. When drained water

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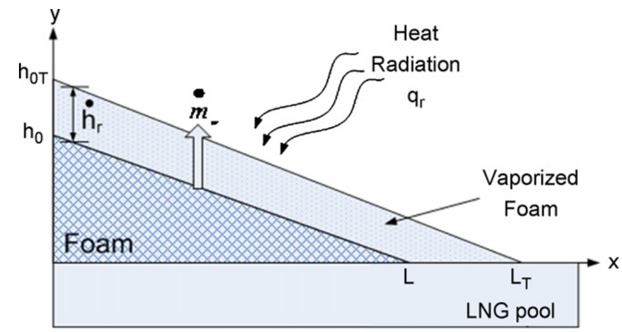
Nomenclature

h_{0T}	initial foam height (m)
h_0	foam height after drained (m)
m'_w	water evaporated (kg/(m^2 s))
L	initial foam front length (m)
L_T	foam front length after drained (m)
q_r	heat radiation (kW/m^2)
D	LNG pool fire base diameter (m)
L_f	flame length (m)
S	distance between object and the center of the fire (m)
E	surface emissivity (W/m^2)
z	z-axis direction
q''	LNG pool fire heat flux (kW/m^2)
τ	atmospheric transmissivity
θ	tilted angle (°)

reaches the LNG surface, ice or hydrate is formed in a honeycomb structure. These phenomena occur at an initially fast rate, commonly before ignition takes place. Hence, during LNG pool fires, expansion foam cannot completely insulate air movement because of the limited amount of vapors leaving the foam blanket through the ice tubes to the open air. In addition, water also participates in engaging a cooling effect by absorbing radiant heat from fire and being converted into steam. However, at the same time, expansion foam application on LNG shows unique behavior compare to the application on non-cryogenic liquid. Due to temperature difference between LNG pool surface and the sprayed expansion foam, water content in the expansion foam is considered as heat source to the LNG pool surface. This Additional heat from water increases LNG vapor generation. As fire size depends on the amount of the vapor, water introduction leads to fire size increase. Therefore, there is a need to balance the cooling effect and the fire size. Based on previous research, high expansion foam of 500:1 expansion ratio was found to be the optimum expansion foam. A lower expansion ratio means lighter foam and that means wind can easily destroy the foam layer reducing foam thickness. A higher expansion foam ratio means higher water content.

The behavior discussed above is the reason expansion foam cannot extinguish LNG pool fires. A common strategy on LNG pool fire



Source: Modified from [2]

Fig. 2. Foam layer exposed to heat radiation from fire.

is to use high expansion foam to control and reduce the fire's radiant heat significantly to make the fire more approachable to the fire fighter. Dry chemicals are then used to extinguish the fire if needed. One of the strategies that could be used includes extinguishing the fire while the LNG pool does what (to eliminate radiant heat) and then provide a foam blanket to control LNG vapor dispersion.

While the effectiveness of high expansion foam application depends heavily on the thickness of the foam blanket, water drainage causes the blanket to collapse over time. Therefore, regular foam top-ups are required by pulsing the LNG Turbex generators on and off to keep the pit full and to keep fresh fluid foam at the surface in order to maximize the LNG pool fire control.

When high expansion foam is applied during an LNG pool fire, some important phenomena occur on the interface between the foam blanket and the LNG pool surface. Fig. 2 shows the initial application of high expansion foam on an LNG pool surface during a fire occurrence. In addition to its natural water drainage downward, water in the high expansion foam is heated and forms steam. This contributes to the expansion foam's collapse by reducing its thickness, and therefore, its effectiveness.

Based on previous studies, high expansion foam application on LNG pool fire can be summarized as follows [3]:

- A certain amount of high expansion foam can prevent air, as oxygen source, from reaching the fire.
- Water in the high expansion foam is heated, boiled, and converted into steam when it comes in contact with the flame. This reduces

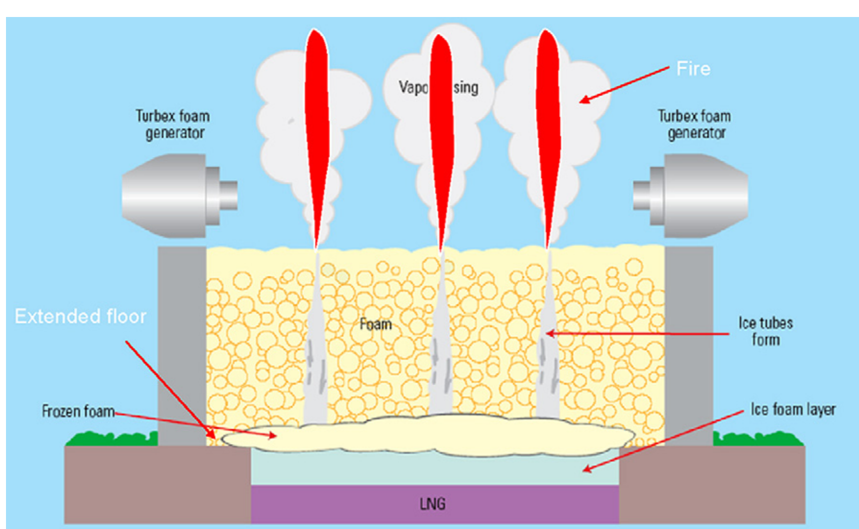


Fig. 1. HEX application on LNG liquid pool and pool fire.