



EXPERIMENTATION ON THE EFFECTIVENESS OF POOL FIRE SUPPRESSANT FOR LNG POOL FIRES

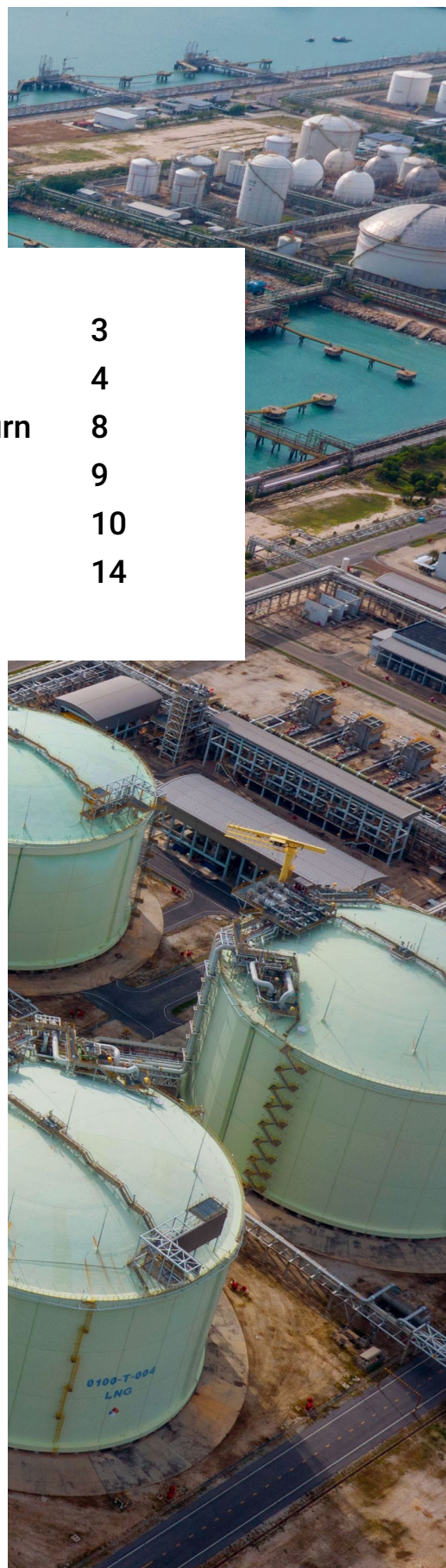
ABSTRACT

In February 2025, Owens Corning conducted a series of tests to evaluate the effectiveness of the FOAMGLAS® Pool Fire Suppression™ (PFS) Gen 2 system on reducing the burn rate, flame length, and thermal heat flux of a medium-sized LNG pool fire. Testing took place during the week of February 17, 2025, at the Texas A&M Engineering Extension Service's (TEEX) Brayton Fire Training Field. Texas A&M's Engineering Experiment Station (TEES) was enlisted to support instrumentation and data collection, while Blue Engineering and Consulting assisted with test design and data analysis.

The experiment found that the FOAMGLAS® PFS system reduced the LNG burn rate by 86% and average flame length by 87% when compared to an unmitigated LNG pool fire. Radiant heat flux was also found to be reduced between 49% and 69% across three locations that were compared between the two LNG burns.

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INTRODUCTION

Liquefied natural gas (LNG) must be processed, transported, and stored at cryogenic temperatures to maintain its liquid state. For facilities that handle large amounts of LNG, impoundment basins are a commonly used safety measure to limit the potential distance that liquid material can travel in the event of an unexpected release. These impoundment basins may vary in size and function by capturing and containing LNG during a spill and may be constructed in various sizes. When LNG enters an impoundment basin in this manner, it will begin to vaporize as heat from the ambient surroundings transfers into the cryogenic material, forming an invisible cloud of flammable natural gas. If these vapors were to encounter a nearby ignition source, a fire could occur within the basin. The resulting radiant heat from such an LNG pool fire may pose significant risks to both nearby personnel as well as other critical facility equipment, potentially leading to cascading events within the facility.

The FOAMGLAS® PFS Gen 2 system is a passive system designed to mitigate the risk of cascading events within LNG facilities by limiting thermal radiation and flame height associated with a potential LNG pool fire. The system is composed of individual modules that are secured together to form a continuous structure at the bottom of an impoundment basin. Each module consists of an inner core of cellular glass insulation with an outer jacketing of stainless-steel, as shown in Figure 1. In the event of a spill, the system will float atop the cryogenic liquid, where it functions as an insulating cap. In the event of a fire, the system reduces radiant heat transfer from the fire into the cryogenic liquid pool. This limits the rate of vaporization of the LNG, which in turn yields a smaller fire that produces less radiant heat.

Cellular glass insulation is used as the base material of the PFS system due to several important characteristics that make it compatible with direct LNG exposure:

- It is inorganic and noncombustible.
- It has a completely closed-cell structure and is impermeable and nonabsorbent to natural gas in both liquid and vapor forms.
- Its density is 117 kg/m^3 (7.28 lb/ft^3) ($\pm 12\%$), which is less than one-third the density of LNG, making it naturally buoyant in the presence of LNG.
- It has a high compressive strength of 620 kPa (90 lb/in^2).

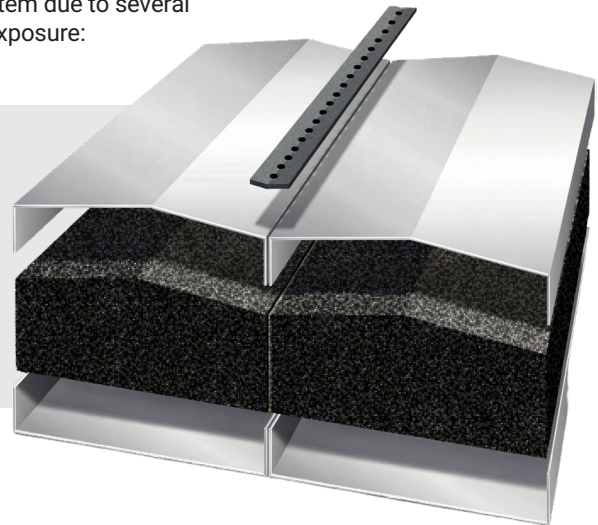


Figure 1. FOAMGLAS® PFS Gen 2 blocks.

This project provides a unique insight into LNG pool fires and can serve to inform future mitigation efforts for LNG operations. The following sections provide a detailed description of the experimental setup, data collected, observations made, and conclusions drawn from the testing.

TEST SITE AND INSTRUMENTATION

Testing was conducted at the Texas A&M University Brayton Fire Training Field located in College Station, Texas. One of the main functions of the Brayton Fire Training Field is to train and educate firefighters on the behaviors of LNG. This dedicated LNG training facility contains three LNG concrete impoundment basins and one L-trench, as shown in Figure 2. The facility is equipped with a series of water curtains around the training area as well as four additional locations for water supply.

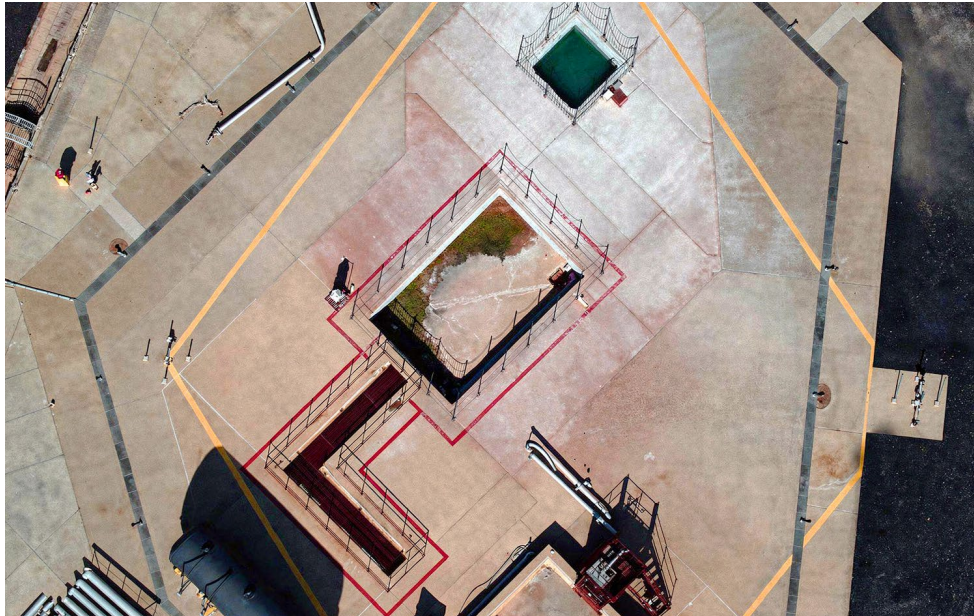


Figure 2. View of the TEEX LNG training area, with the large impoundment in the center.

For this testing, the largest impoundment basin by surface area was selected, as shown in Figure 3. The interior dimensions of the basin were 9.91 m (32 ft 6 in.) long by 6.53 m (21 ft 5 in.) wide by 1.22 m (4 ft) deep. The basin was constructed from concrete and reinforcing rebar and included a metal safety fence around the perimeter. The basin contained a further recessed area in the eastmost corner of the pit, with a pipe located inside that can be opened for drainage. During testing, a steel plate with drainage holes was placed over this recessed location to provide a continuous floor for the PFS system to be installed over.



Figure 3. The LNG impoundment.

A thermocouple tree was used during testing for the purpose of submerging thermocouples within the LNG at known depths to analyze the burn rate of LNG. The thermocouple tree was constructed using various components of 316 stainless-steel that were MIG welded into a single structure. The components included a 3 in. x 3 in. x 24 in. stainless-steel angle, a 12 in. x 12 in. x 0.25 in. base plate, and 1 in. long sections of 3/8 in. diameter tubing. The pieces of tubing were welded at horizontal orientations along the back of the angle in two vertical columns. The pieces of tubing within each column were spaced at 1 in. intervals, and the left and right columns were staggered 0.5 in. from one another. In total, 32 pieces of horizontal tubing were fixed at 0.5 in. vertical intervals along the back of the structure, as shown in Figure 4. During testing, the thermocouple tree was placed inside the impoundment basin at the northmost corner location so that it would be submerged within the LNG throughout the duration of each burn. Levels were used, and stainless-steel shims were placed underneath the four corners of the baseplate to ensure the structure was properly oriented. With the shims present, the baseplate of the thermocouple tree stood approximately 1.5 in. off the floor of the basin, as shown in Figure 5.

20 stretches of type K thermocouple wires were used to gauge the depth of LNG in real time during testing. Each stretch of wiring was constructed by welding standard-grade type K thermocouple wire to a shorter stretch of high-grade type K thermocouple wire with ceramic fiber insulation designed to withstand direct exposure to the fire. Further ceramic fiber insulation was placed on top of the welded sections of wire on the ground near the basin opening to protect the connections from heat during each burn.



Figure 4. Thermocouple tree: before installation



Figure 5. Thermocouple tree: as installed in the impoundment.

The 20 sections of high-grade thermocouple wiring were placed through the stainless-steel tubing along the back of the thermocouple tree. The thermocouples were placed at tubing levels 5 through 24 from the bottom of the thermocouple tree, which allowed for data collection between 2.5 in. and 12 in. from the baseplate at $\frac{1}{2}$ in. intervals. An air set high-temperature cement was applied to the wiring to adhere the thermocouples in place for the duration of testing. The location of each thermocouple was measured and photographed to get an accurate location for use in later analysis.

Data was collected from thermocouples using a NI-DAQ with four National Instruments NI-9213 thermocouple modules (64 channels). Sampling was performed at approximately 1 Hz per channel. A custom LabVIEW application handled channel configuration, real-time visualization, and data logging. Temperature data was written to CSV files with metadata (channel map, sensor IDs, calibration factors, and test identifiers). The DAQ-interface laptop was insulated with ceramic fiber insulation for added protection during each test.



Figure 6. Heat flux sensor prior to the test.

Five heat flux sensors were used during testing to measure the heat flux generated from each LNG burn. Four heat flux sensors used were TG9000-F (120° field of view), manufactured by Vatel Corporation. The fifth heat flux sensor was a GG01-250-SW-05 (180° field of view), manufactured by Hukseflux. All sensors included a sapphire crystal window that allowed radiation to be measured while blocking any convective heat flux from wind. The sensors also featured inlet and outlet connections for active water cooling. Each sensor was mounted to a steel stand which held the device at a height of 1.2 m (4 ft) off the ground at a fixed horizontal angle of 0°, as shown in Figure 6. Omega OM-CP-OCTPRO data loggers were used with each sensor and thermally protected with aluminum shielding and ceramic fiber insulation during testing. Long stretches of rubber tubing were used to provide each sensor with active water cooling from one of the four water sources available. Ceramic fiber insulation and aluminum foil were then wrapped around the rubber tubing and sensor wire to provide additional thermal insulation during the test.

REFERENCE TEST – UNMITIGATED BURN

A reference burn was conducted first to gather data from an unmitigated LNG fire scenario. The test began with the discharge of LNG into the impoundment basin. The LNG flow was turned off when a volume of 20.8 m³ (5500 gallons) was achieved, which correlated to a depth of approximately 0.30 m (12 in.). The LNG was ignited and allowed to burn while data was collected. The resulting flame was observed to reach an average length of approximately 23.6 m (77.3 ft) from the opening of the impoundment basin; Figure 8 shows a snapshot of the flame.



Figure 8. Flame during the unmitigated pool fire.

Approximately four minutes into the burn, concrete spalling was observed on the downwind side of the fire along the concrete floor near the basin opening as well as the top of the basin walls. This concrete spalling increased in frequency and severity as the burn continued. After six minutes, the decision was made to extinguish the fire before the original goal of 10 minutes in an effort to preserve the integrity of the basin.

Dry chemical was deployed six minutes after initial ignition to extinguish the fire. While initially successful, reignition occurred as escaping LNG vapors encountered the hot concrete and metal surfaces outside of the basin. Repeated attempts to permanently extinguish the flames were made without success until the decision was made to cease fire extinguishing efforts and allow the LNG to fully burn until the basin was empty. As a result, heat flux sensor #2 and its corresponding data logger were damaged beyond repair while stationed downwind. A timeline of events during this unmitigated burn can be seen in Table 1.

Time	Action
0:00	LNG is ignited
4:00	Significant concrete spalling is observed on downwind side of basin.
6:28	Initial attempts are made to extinguish fire using dry chemical.
12:30	Fire extinguishing efforts are halted due to repeated reignition. Decision is made to allow remaining quantity of LNG to burn freely until fully consumed.
31:00	Fire self-extinguishes as LNG is fully depleted.

Table 1. Timeline of events during the unmitigated pool fire.

EXPERIMENTAL TEST – PFS BURN

The second burn conducted involved the use of the FOAMGLAS® Pool Fire Suppression™ (PFS) Gen 2 system. The system was assembled into a continuous structure within the impoundment basin using the provided PFS modules, connector bridges, and screws, as shown in Figure 8. The module located near the thermocouple tree had a section measuring 4 in. x 4 in. removed from its corner to ensure the PFS system would not contact the thermocouple tree as it floated on the LNG during testing. A new Vatell TG9000-F heat flux sensor was installed to replace sensor #2 which was lost during the unmitigated burn.



Figure 9. Gen 2 PFS blocks installed in the LNG impoundment.

The test began with the same discharge of 20.8 m³ (5500 gallons) of LNG into the impoundment basin. Note that, due to the displacement of LNG by the PFS system, this volume resulted in a liquid depth of approximately 0.36 m (14 in.). The LNG was ignited and allowed to burn while data was collected. The resulting flame was observed to be much smaller than the unmitigated burn, reaching a length of approximately 2.9 m (9.6 ft) from the basin opening, as shown in Figure 10. The radiant heat escaping the fire was also noted to be significantly less than that of the unmitigated burn. The concrete spalling that was observed near the basin opening during the unmitigated test was not observed during this burn.

The burn continued with the goal of achieving 30 minutes of data collection. However, approximately 15 minutes into the burn, a loose section of the concrete basin wall, which had been damaged during the unmitigated burn, broke loose and fell into the basin, compromising the data acquisition. Because of this, the decision was made shortly thereafter to extinguish the fire and conclude testing.

Dry chemical was deployed to extinguish the fire after approximately 20 minutes of burn time. It took firefighting personnel less than a minute to permanently extinguish the fire. The remaining volume of LNG was allowed to slowly boil off from the pit before recording devices could be retrieved. A timeline of events during this PFS-mitigated burn can be seen in Table 2.



Figure 10. Flame during the PFS-mitigated test.

Time	Action	Table 2. Timeline of events during the PFS-mitigated pool fire.
0:00	LNG is ignited	
15:07	Section of loose concrete damaged from unmitigated burn falls into basin	
19:53	Firefighting efforts are initiated	
20:47	Firefighting efforts are concluded as the fire remains extinguished	

DATA ANALYSIS AND COMPARISON

Before termination of the reference (unmitigated) test, temperature readings of the thermocouples suggested that eight different thermocouples transitioned from being submerged within LNG to exposed to the fire. These temperature readings were analyzed to determine the point in time that the LNG level fell below each thermocouple. The specific height of each thermocouple relative to the thermocouple base was documented previously during instrumentation setup. By plotting the thermocouple heights against the times in which they emerged from the LNG, a trendline showing the average LNG regression rate could be established as shown in Figure 11. The LNG regression rate for the unmitigated burn was found to be 0.3728 mm/s.

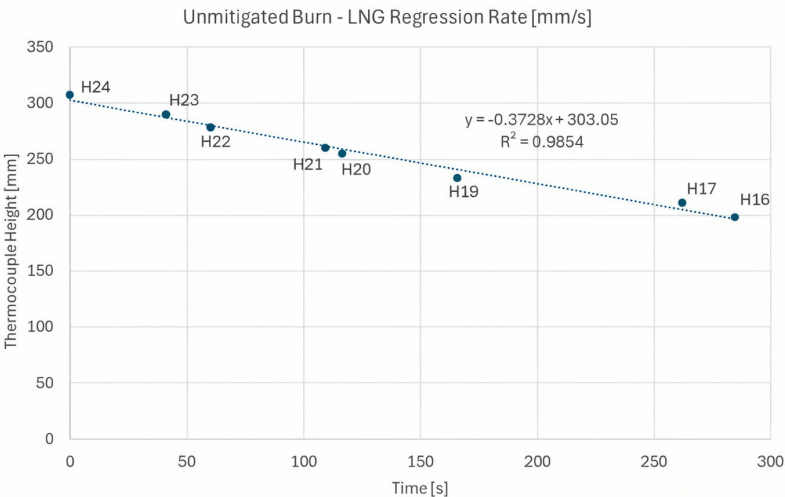


Figure 11. LNG regression rate plot for the unmitigated burn.

During similar analysis of the experimental (PFS) test, it was discovered that in the approximately 15 minutes of burn before loose concrete entered the basin, only one thermocouple had gone from submerged within LNG to exposed to the fire. This was believed to be a result of both the early test termination as well as the expected slower burn rate due to the PFS system. To obtain an estimate of the LNG burn rate during the PFS-mitigated test, it was assumed that a second thermocouple on the tree was just about to become exposed to the fire at the precise moment concrete fell into the basin. This assumption should yield a conservative estimate for LNG regression rate, as if data had been collected beyond the point of termination, any additional time for this thermocouple to become exposed would result in an even lower LNG regression rate.

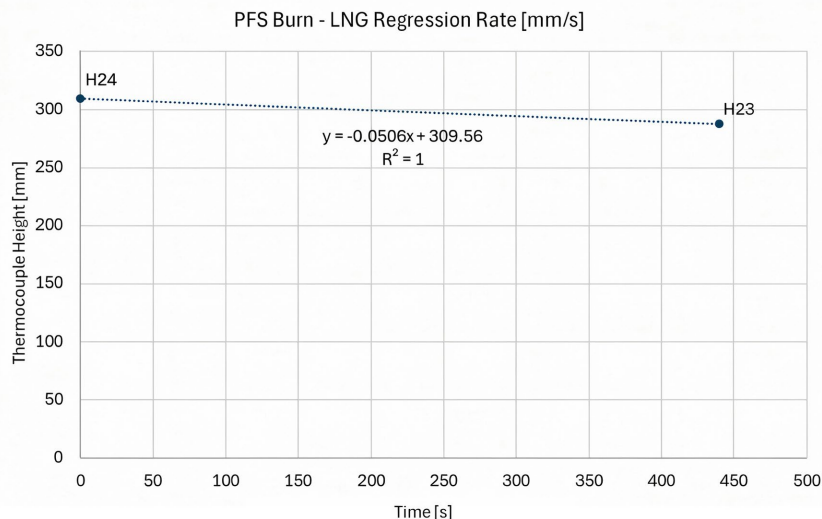


Figure 12. LNG regression rate plot for the PFS-mitigated burn.

These two thermocouple data points were analyzed in a similar manner to what was done for the unmitigated test. The known height of each thermocouple was plotted against the time at which they became (or were assumed to become) exposed to the LNG fire. A trendline between the two points was added and used to establish the LNG regression rate for the PFS test, as shown in Figure 12. The LNG regression rate for the PFS burn was found to be 0.0506 mm/s.

The density of LNG for both tests was assumed to be 440 kg/m³ (27.5 lb/ft³). Using this density, the regression rates for each burn were converted into an average LNG mass burn rate for the duration of each test. The results indicate that the LNG burn rate of the test with the PFS system was approximately 86% lower than the LNG burn rate of the reference test. Table 3 summarizes the LNG regression rates and burn rates for the two tests; a visual comparison is also shown in Figure 13.

Table 3. LNG regression rates and burn rates from the two tests.

	Reference Test (Unmitigated Burn)	Experimental Test (PFS Burn)	Reduction
LNG Regression Rate [mm/s]	0.3728	0.0506	86%
LNG Burn Rate [kg/m ² -s]	0.1636	0.0222	86%

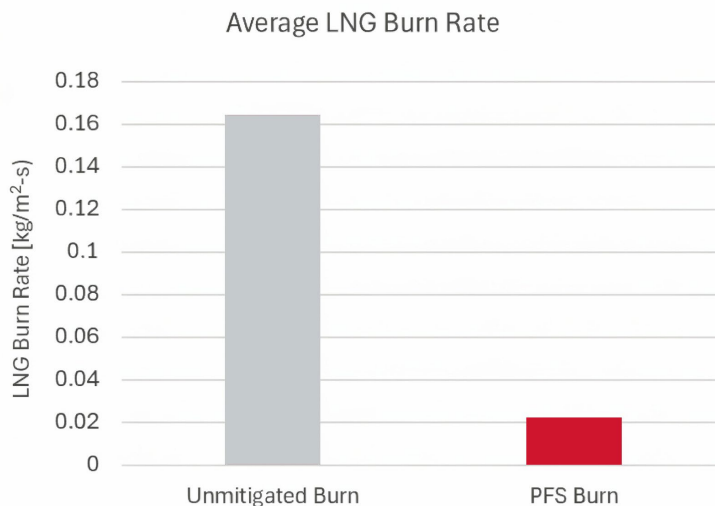


Figure 13. LNG burn rates comparison.

Table 4. Average wind conditions for the two tests.

	Reference Test (Unmitigated Burn)	Experimental Test (PFS Burn)
Wind Speed [m/s]	1.8	2.7
Wind Direction [degrees w.r.t. north]	115	45

The data from the portable weather station was analyzed for the duration of each test. The average wind speed and direction (with respect to north) for each test were determined and are listed in Table 4.

The video footage from the cameras stationed around the basin was digitized to determine the flame shape and size at each moment of the two tests. Approximately 11,000 video frames were analyzed for each test, using custom-developed software to determine the time-averaged flame length and tilt for each burn (as shown in Figure 14 – note that the apparent stretching and rotation of the images is due to the need to correct for the fish-eye effect of the lens). The results (in Table 5) indicate that the average flame length of the experimental test was approximately 87% lower than the average flame length of the reference test, which is consistent with initial observations made during the day of testing.

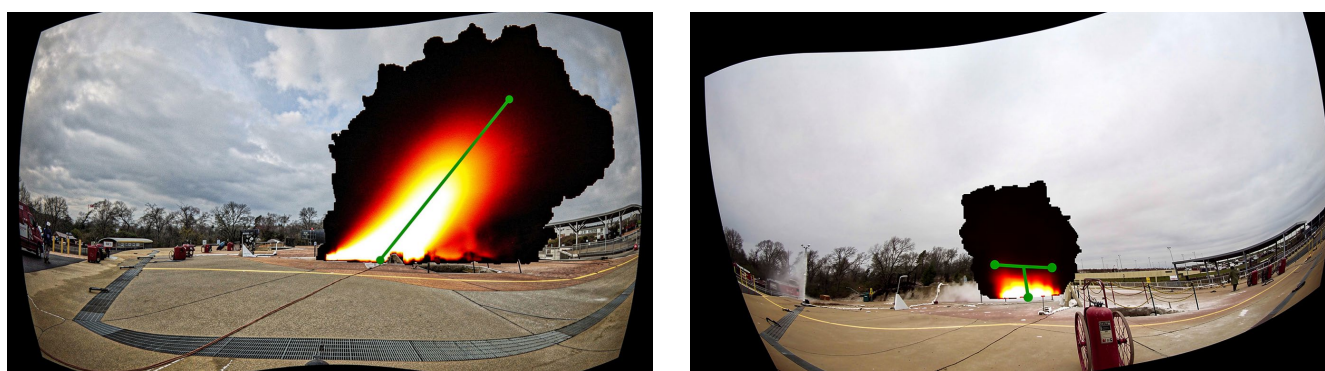


Figure 14. Cumulative density contours for the flame in the two tests: (left) unmitigated; (right) PFS-mitigated.

Table 5. Average flame length and tilt for the two tests.

	Reference Test (Unmitigated Burn)	Experimental Test (PFS Burn)	Reduction
Flame Length [ft]	77.3	9.6	87%
Flame Tilt [deg]	38	1	--

The heat flux data from the five radiometers was analyzed to understand the difference in radiant heat generated during each burn. Recall that sensor #2 was lost during the unmitigated test; as such, no data is available for this location during the reference test, though a replacement sensor was supplied in time for the PFS-mitigated test that took place later in the week. It should also be noted that while the radiometer placement stayed consistent between both burns, the average wind direction changed by about 70 degrees. Because of this, a direct comparison between the same radiometer locations would not be reasonable; instead, the comparison used radiometers that were in a similar position relative to the wind direction in the two tests, to better correlate between expected upwind and downwind locations. Table 6 lists the average heat flux measured during each test as well as the corresponding radiometer labeled for clarity; the same comparison is provided in graphical form in Figure 15.

Four of the five location reference points were assigned average heat flux values for both the reference and experimental tests. Of these four locations, three exhibited a reduction of radiant heat between 49% and 69%. The fifth radiometer, which was placed at a fixed location further from the basin, showed the greatest reduction at 81%. A possible explanation for this is the fact that this location was not moved in response to the changing wind direction between test days. While radiometer 5 was slightly downwind of the fire during the reference test, it was nearly directly upwind of the fire during the experimental test, potentially explaining the significant reduction in heat flux measured.

Table 6. Average heat flux for each radiometer location for the two tests.

		Reference Test (Unmitigated Burn)	Experimental Test (PFS Burn)	Reduction
Average Heat Flux [kW/m ²]	Downwind Location	- (Rad. 2)	28.5 (Rad. 3)	-
	Crosswind Location #1	41.6 (Rad. 3)	21.2 (Rad. 4)	49%
	Upwind Location	36.2 (Rad. 4)	14.0 (Rad. 1)	61%
	Crosswind Location #2	57.8 (Rad. 1)	17.9 (Rad. 2)	69%
	Fixed Location (Rad.5)	13.4 (Rad. 5)	2.6 (Rad. 5)	81%

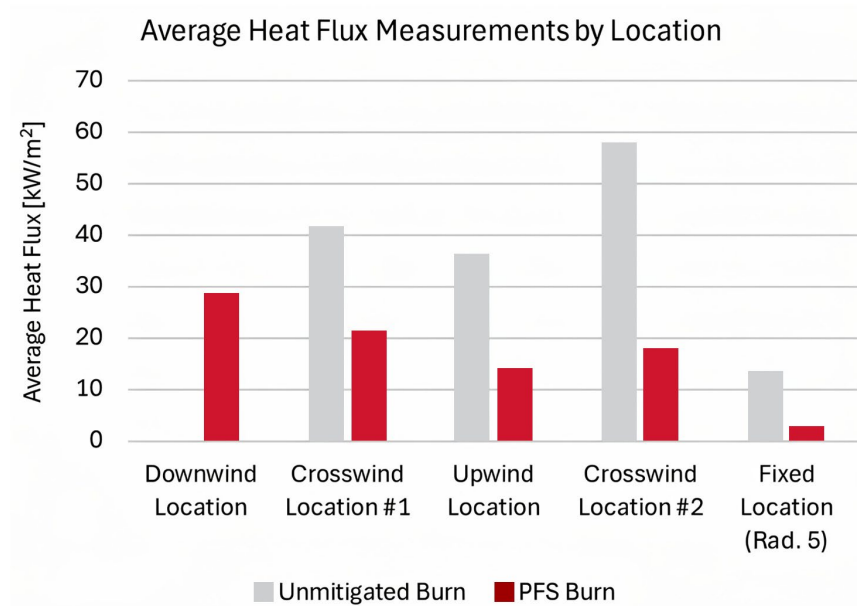


Figure 15. Average heat flux for each radiometer location, for the two tests.

CONCLUSIONS

This experiment explored the effectiveness of the FOAMGLAS® Pool Fire Suppression™ Gen 2 system on the reduction of burn rate, flame length, and radiant heat generated from a medium-sized LNG pool fire. In addition to the data collected, observations made during testing provided insights into the potential complications of unmitigated LNG pool fires.

The presence of the PFS system was shown to reduce the burn rate in an LNG pool fire by approximately 86% when compared to an unmitigated LNG burn. This could be considered a conservative value, as damaged concrete within the impoundment basin from the unmitigated test led to termination of the PFS test before the LNG level could fully recede below a second thermocouple. This damage was the result of significant concrete spalling that occurred during the unmitigated LNG burn, which took place prior to the PFS-mitigated burn.

A series of radiometers positioned around the impoundment basin recorded the PFS system to reduce the average radiant heat flux between 49% and 69% for the upwind and two crosswind locations of two LNG pool fires. No radiant heat flux comparison could be made at the downwind location, as the radiometer and data logger at this location were compromised during the unmitigated burn when firefighting efforts proved unsuccessful. A fifth radiometer at a farther location showed the greatest average radiant heat reduction of 81%, though this could be in part due to changing wind conditions relative to the fixed location of this sensor.

Cameras positioned around the impoundment basin observed the PFS-mitigated burn to generate an 87% reduced flame length (measured from the basin opening) when compared to the unmitigated burn.

This experiment demonstrated a significant reduction in burn rate, flame length, and radiant heat of an LNG pool fire mitigated with the FOAMGLAS® PFS Gen 2 system. The data from this experiment may help specifiers and modelers make more informed decisions when designing fire safety programs for LNG facilities.



Alec Cusick^a (alec.cusick@owenscorning.com)

Bryant Hendrickson^b (bhendrickson@blueeandc.com)

Filippo Gavelli^b (fgavelli@blueeandc.com)

Mitchell Huffman^c (mhuffman@tamu.edu)

Qingsheng Wang^c (qwang@tamu.edu)

a: Owens Corning

b: Blue Engineering and Consulting

c: Texas A&M Engineering Experiment Station

