Status of Fast Cook-off Testing using Propane Burners

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Abstract

Most ordnance items are required to be subjected to a fuel fire fast heating test. The liquid fuel fire test, commonly known as the fast cook-off (FCO) test, is used to simulate exposure in a fire, and is one of a suite of tests used to determine if the munition meets Insensitive Munition (IM) requirements. Increasing environmental concerns with respect to air quality, as well as soil and groundwater contamination, have led to changes in the international test standards to allow more environmentally friendly FCO setups to be used. As an added benefit, these new FCO test setups have been demonstrated to be less expensive and more convenient compared to the liquid-fuel fire that was traditionally used to perform FCO testing. The US Navy and Bofors Test Center have been two of the leading organizations working to develop the standards which allow propane burners to be used for FCO testing. They also developed the procedures used to validate that the burners developed meet and follow these standards. Both organizations have now developed, and are currently operating, propane burners to perform FCO testing. This paper discusses recent advances in the propane burner design along with representative results of continued FCO testing performed with these propane burners. Using propane burners continues to be an environmentally friendlier, less expensive and more convenient way to perform FCO testing.

Introduction

US DoD ordnance items, except those exempt i.e. pyrotechnics and small caliber ammunition, are required to be tested in a liquid-fuel fire fast heating test and have the results reported and approved by higher authorities. The liquid-fuel fire test, commonly known as the fast cook-off (FCO) test, is used to simulate exposure in a fire, and is one of a suite of tests used to determine if the munition meets Insensitive Munition (IM) requirements. The test subjects full-scale ordnance to a liquid-fuel fire and assesses the violence of reaction and susceptibility of the item to fire. During the life cycle of an ordnance item, exposure to fire may result from an accident related to transportation, storage and/or mishap on the deck of a ship. The liquid-fuel fire test required for Insensitive Munitions (IM) is currently performed in accordance with STANAG AOP-4240 [1]. In this test, the ordnance item is suspended or positioned 1 meter above the fuel. The fuel is ignited, producing a flame that completely engulfs the item under test. The quantity of fuel used is sufficient to produce a fire duration which is 50%

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longer than the anticipated item reaction time. After the ordnance item reacts, its response is scored based on the pressure output of the event and relative violence of reaction based on the overall video along with the number, size, and distance of any fragments thrown.

Past work demonstrated and validated the use of propane as a viable alternative to kerosene-based fuels for the liquid-fuel fast heating munition test [2-5]. With this supporting information, the STANAG AOP-4240 was changed in 2018 to allow for alternative fuels and test configurations with proper calibration and characterization. The Annex C of the STANAG AOP-4240 gives the guidance for using the fuel burner fire method. The AOP states "This test method has been introduced to allow other hydrocarbon fuels to be used by test centers when undertaking a Fast Heating Test. Research has shown that gaseous fuels (e.g. propane) can produce comparable absolute temperatures and heat fluxes to those of a pool of burning liquid hydrocarbon fuel, producing equivalent heating conditions to the test item. Testing and modeling has shown that the radiative and convective components of both gaseous propane and liquid hydrocarbon fuels are not always equivalent, but the total heating of the test item is equivalent when the correct test setup is used."

The initial driver to allow for fuel burner fast heating testing was to reduce the environmental impact of FCO testing. Using the propane burner allows for a more controlled and reproducible test compared to the liquid-fuel pool fire. In addition, soil and ground water contamination is no longer an issue as propane is a gas at ambient temperature and atmospheric pressure. Propane also offers greater combustion efficiency compared to larger hydrocarbons and produces significantly fewer atmospheric emissions. To demonstrate this improvement, a suite of emissions' measurement hardware was flown above a 3.7 m square propane burner fire and a JP-5 pool fire to determine the difference in emissions between the two FCO test fires. The particulate matter emissions were reduced by 99.96%. The CO2 emissions were reduced by 94%. The CO emissions were reduced by 99.3%. The polycyclic aromatic hydrocarbon (PAH) emissions were reduced by 99.6%. The volatile organic compounds were reduced by 99.1%. The elemental carbon (EC) emissions were reduced by 99.99%. The organic carbon (OC) emissions were reduced by 99.6%. The total carbon (TC) emissions were reduced by 99.97% [6,7]

Some additional benefits were discovered as the test methodology was developed. The propane burners can be modular in design. Different test sites will test different sized ordnance items and having flexibility in the size of the burner will make it applicable to any site adopting the technology. Four burners were built and tested. They were the 2.4 m by 2.4 m burner, the 3.7 m by 3.7 m burner, the 3.0 m by 6.1 m burner, and the 4.6 m by 6.1 m burner. All four burners performed as designed and met the STANAG AOP-4240 requirements.

Additionally, a study demonstrated that the operation and annual maintenance costs were reduced [8]. Also, the liquid propane burner can be turned off after the ordnance item reacts, saving thousands of dollars per test. The test setup is inexpensive and easy to manufacture making rebuilding of the burner easy after a violent reaction. Having a reduction in cost will make this technology more appealing to customers requesting the FCO testing.

Currently, the liquid fuel must be pumped into the pool container with the test item set up. This process takes time and there is the possibility that the wind will suddenly increase and prevent further testing. If this were to happen, then an energetic item would be suspended above a pool of jet fuel for an unknown amount of time or a test would be required to be performed during non-ideal wind conditions. With liquid propane, the fuel is immediately ready for use and no pumping before the test is required. This, and the fact that the fuel can be shut off after the item reacts, reduces the total test time and improves the test turnaround time. Also, if the winds were to increase to prevent the test, there is no fuel in the vicinity of the test item and the test will not be forced to occur during non-ideal weather conditions. Workers setting up and taking down the test dislike working around jet fuel as it has a strong smell and can lead to headaches. They prefer the propane burner where the fuel is only fed to the test fixture after they have left and the fact that it leaves behind no strong smell.

This paper discusses recent advances in the propane burner design along with representative results of continued FCO testing performed with these propane burners. Using propane burners continues to be a more environmentally friendly, less expensive, and more convenient way to perform FCO testing.

Supporting Time and Cost Savings

At Bofors Test Center in Sweden, development of a propane burner to be used as an alternative to the, at that time, standardized kerosene fuel fires begun as an internal study in 2005. The first design of a torch burner was in use in 2006 and was presented to a wider community at the 2009 IMEMTS in Tucson [9], in Munich 2010 [10] and at the first Fuel Fire Experts Custodial Working Group meeting in Meppen in 2010 [11].

Since the meeting in Meppen, several different burner designs were developed and tested at Bofors Test Center. These included the torch burner described earlier, the Sand Bed Burner, presented at the IMEMTS in San Diego 2013 [12] and the Bofors Hellflute, presented at the IMEMTS in Rome 2015 [13]. All these burners had benefits but also some drawbacks. During this same period, a burner was developed, built and thoroughly tested by the US Navy at the NSWC Dahlgren site. There are currently four such burners in use; one at NSWC Dahlgren, one at NSWC China Lake, one at the Nevada National Security Site, and one at Bofors Test Center. Some design parameters are not exactly the same in these burners but the working principles are all the same.

The burner at Bofors Test Center was ready for use in 2018 and has since then been used in several testing campaigns. One of these campaigns will now be discussed as an example of the time and cost saving benefits of using propane instead of kerosene fuel. Since the results of the tests in this campaign are confidential there will be no discussion regarding the test items or the results of the tests.

This particular test campaign consisted of four tests. Each test was performed on one bare live round. The type of round was similar in all tests but they did not have exactly the same configurations (e.g. fuzes etc.). If this test campaign would have been performed at Bofors Test Center using kerosene fuel, the total range time needed would have been six days. One day for preparations, four days for testing and assessment of the results (fragment mapping etc.) and finally one day for cleaning work at the test site. For safety and practicality reasons it has normally not been possible to perform more than one FCO test per day. The hearth needs to cool down between the tests and the time required for refueling of the hearth is relatively long.

The total man hours of all personnel involved from when the preparations starts to when the test site is clean and ready for another test campaign is roughly 380 man hours. In Sweden the cost for kerosene fuel is, including all taxes, calculated to be roughly 2 USD per liter. In each test a total of 5,040 liters is used which gives a total of 20,160 liters per test campaign. This translates to a total fuel cost of 40,320 USD per test campaign. Since it is not possible to extinguish the fire after all reactions in the test item are completed in order to save some fuel, all fuel filled in the hearth at the start of the test will be consumed. In summary, the efforts needed to perform four FCO tests using kerosene fuel can be estimated to be 380 man hours and with a fuel cost of 40,320 USD.

When these tests were performed with Bofors Test Center's propane burner, half a day was used for preparations. A full day was used for performing all four tests including the assessment work on the test site including fragment mapping. Another half a day was used for cleaning of the test site. In total, approximately 125 man hours were used. To provide context on the efficiency of the testing, Test No. 1 started at 4.47 am, Test No. 2 started at 6.13 am, Test No. 3 started at 7.21 am and finally Test No. 4 started at 8.29 am. Including the assessment time for Test No. 4 the whole campaign was completed in about 4.5 hours.

Furthermore, since it is possible to turn the flow of propane off after all reactions in the test item are completed using a propane burner, and the time to all reactions were completed were relatively short, the average fuel consumption was 600 kg propane per test. In total 2,400 kg of propane were used for performing the four tests. The cost of propane is in Sweden about 2.1 USD per kg which gives a total fuel cost for all four tests of 5,040 USD. In summary, the efforts needed to perform four FCO tests using propane can be estimated to 125 man hours and with a fuel cost of 5,040 USD.

All details of time and costs related to four tests using kerosene fuel and propane are summarized in Table 1.

Table 1. Time and Cost Savings Using Propane instead of Kerosene Fuel

Range Time (days)			Man hours required			Fuel costs (USD)		
Kerosene fuel	Propane	Time saved	Kerosene fuel	Propane	Time saved	Kerosene fuel	Propane	Money saved
6	2	67%	380	125	67%	40,320	5,040	88%

Continued Ordnance Testing

FCO testing with both a liquid-fuel pool fire and a propane burner were conducted on identical test items. The setup is shown below in Figure 1. Both tests had flames that encompassed the test item as shown in Figure 2. The average temperature measured by the STANAG thermocouples for the FCO with the liquid-fuel pool fire was 840°C and for the FCO with the propane burner was 1100°C. These values are within the bounds of normal liquid pool fuel fires. The asset in the liquid-fuel pool fire FCO test had a reaction at 3:40 into the test and vented until about 10:30. The asset in the propane burner FCO test had an initial reaction at 1:47 and then the major reaction at 3:14. In the FCO test with propane, some of the energetic material was ejected from the asset and the venting was not as pronounced. The posttests for both tests are shown in Figure 3. The item fell off the A-frame for both tests and landed in a similar position. Also, the item opened in the same location on the test item for both. In the propane burner FCO test, the asset fell on the pipes and severely warped them and broke open one of the pipes. Even with the compromised pipes, the burner continued to function to provide the time of burner operation to 50% greater than the last reaction time. The liquid-fuel pool fire used 13,400 liters of fuel and the propane burner used 4,870 liters of fuel.

Figure 1. FCO setups for test items. Item on left tested with liquid-fuel pool fire. Item on right tested with propane burner.

Figure 2. Fully developed flames before reaction, left photo of liquid-fuel pool fire and right photo of propane fire.

Figure 3. FCO posttest for identical test items. Item on left tested with liquid-fuel pool fire. Item on right tested with propane burner.

Two identical rocket motors were subjected to the FCO test. One of the motors was tested above a pool of F-24 liquid-fuel and the other motor was tested above the 4.6 m by 6.1 m propane burner located at China Lake, CA. The motors were approximately 13 cm in diameter and 2.1 m in length. The motors had approximately 25 kg of reduced smoke propellant for a total approximate weight of 68 kg. Both motors also had an inert simulated warhead. The test setups for both tests are shown below in Figure 4 and the thermocouple setup for both tests is shown in Figure 5.

Figure 4. FCO setups for identical rocket motors. Motor on left tested with liquid-fuel pool fire. Motor on right tested with propane burner.

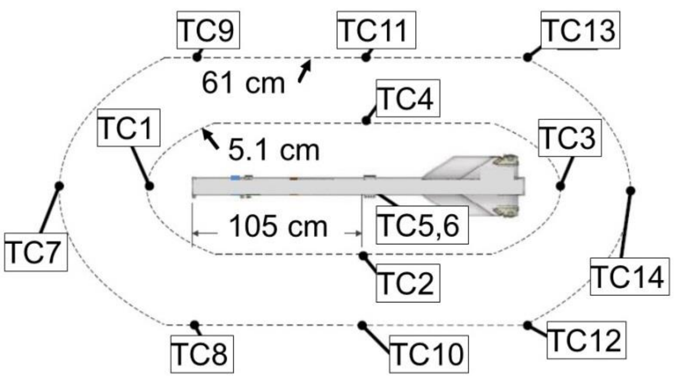

Figure 5. Flame temperature thermocouples and standard thermocouples, top view.

The liquid-fuel pool fire test used 7,500 liters of F-24 and the propane burner test used 740 liters of propane. In both tests, the temperatures reached 550°C within the 30 seconds specified in the STANAG AOP-4240 [1] and had average temperatures of the six standard thermocouples above 800°C. Figure 6 and Figure 7 compare the 6 standard thermocouple temperatures located 5.1 cm from asset and an additional 8 surrounding thermocouples to measure flame temperature 61 cm from asset of the liquid-fuel pool fire with the propane burner fire. The two fires have very consistent flames. The vigorous reaction occurred about 50 s into the test for both tests. Before that time for both tests, the thermocouple temperatures are all around 1000°C. Except for the effect of the asset reactions, the propane flame has more steady temperature readings.

Figure 8 shows the fully developed flames of the liquid-fuel pool fire and the propane fire. In both cases the flames are continuous and completely envelope the test asset. During the FCO with the liquid-fuel pool fire, there were sounds of reaction at 21 s, 25 s, and 28 s. A loud whistle started at 45 s into the test while the main reaction occurred at 49 s. There was a final reaction at 2:21 into the test with a reaction and an ejection of what appears to be ignited energetic material. During the FCO with the propane burner, there were sounds at 20 s and 22 s. The main reaction occurred at 47s. The posttest photos are shown in Figure 9. In both tests, the front end was split open with the simulated warhead on the ground below. The case separated at its center in the liquid-fuel pool fire while the case did not in the propane fire. Both cases stayed attached to the A-frame. Figure 10 shows the remains of the rocket motor that were collected after the test. In both tests, the remains of the rocket motor were similar, with most of the case present along with the inert warhead, and pieces of the aft wings in molten form.

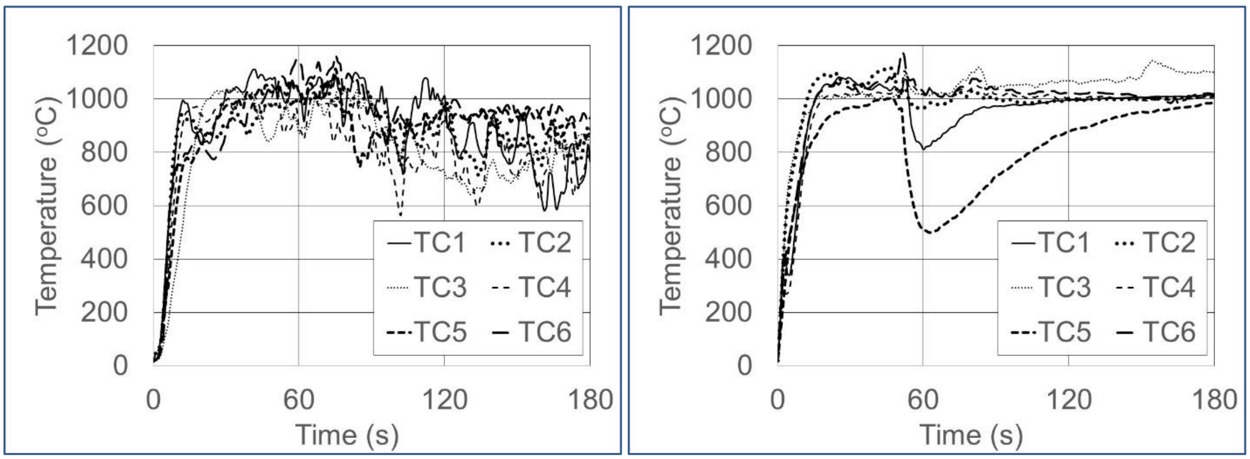

Figure 6. Thermocouple temperatures, left plot of liquid-fuel pool fire and right plot of propane fire.

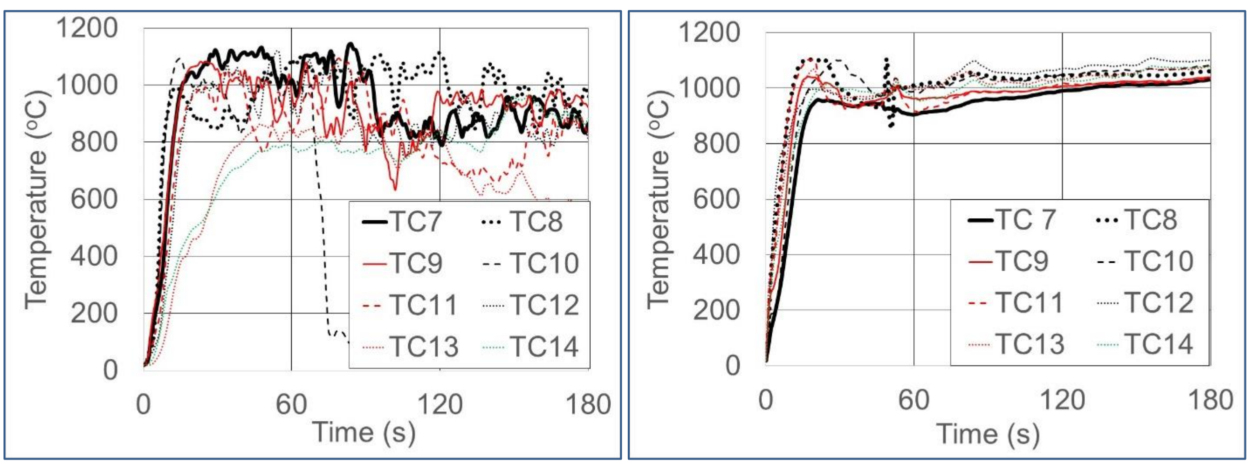

Figure 7. Surrounding flame thermocouple temperatures, left plot of liquid-fuel pool fire and right plot of propane fire.

Figure 8. Fully developed flames before reaction, left photo of liquid-fuel pool fire and right photo of propane fire.

Figure 9. FCO posttest for identical rocket motors. Motor on left tested with liquid-fuel pool fire. Motor on right tested with propane burner.

Figure 10. FCO posttest rocket motors remains. Motor on left tested with liquid-fuel pool fire. Motor on right tested with propane burner.

The times to reaction and violence of reactions of the test with the liquid-pool fire and the propane burner were extremely close for these two tests. These results are closer than what would be expected in multiple test with the same item in the same type of fire. Much of this discrepancy likely comes from the normal variation in the fire. As shown in Figure 6 and Figure 7, these two tests had very similar flame temperatures. This demonstrates the comparability of the liquid-fuel pool fire and this propane burner fire once again.

Burner Improvements

The current propane burner designs of the US Navy and Bofors Test Center are robust and have demonstrated the capability to meet STANAG AOP-4240 requirements. Further improvement to the burner is still possible and this section documents a current proposed improvement to the burner.

During vigorous ordnance reactions during FCO tests, propane burners can suffer from warping of their steel pipes. The combination of elevated temperatures and gradients and the lowered yield strength of steel at elevated temperatures causes pipes to warp. Since the pipes deliver fuel, warped pipes can lead to unwanted changes to the fire such as unintended fuel/air mixing and local oversupply or undersupply of fuel if the pipe spacing changes. In addition, warped pipes can interfere with test item placement and make breakdown/buildup of the burner more time consuming and difficult. Normally, bent pipes are replaced before the next test. The result is that warped pipes cost time and money.

In order to mitigate pipe warping, the US Navy at China Lake, CA is testing the use of a steel substructure, on which the burner will rest. The steel substructure consists of partially buried I-beams. In addition to being structurally rugged and designed to prevent warping, the I-beams can provide a level surface for the pipes to rest on, which is expected to somewhat reduce the warping caused by unevenness of the underlying ground.

The I-beams work in the following ways. First, the beams are massive (~15 cm x 15 cm x 0.6 cm). Although they are made of steel and their strength should diminish at high temperatures, they will remain strong in part due to their size (see Figure 11). Second, the beams are partially buried so that most of the structural steel will remain at temperatures low enough to prevent significant loss of strength. Much of the beam, especially the bottom portion will remain relatively cool and therefore maintain its strength (Figure 11). Spacers are welded onto a large I-beam that is buried approximately 10 cm deep. Spacers prevent the pipes from warping in the horizontal direction and a steel bar above the pipes prevents them from bending in the vertical direction. In the China Lake demonstration, a 6.4 m x 6.1 m burner will have three I-beams, one approximately every 3 m.

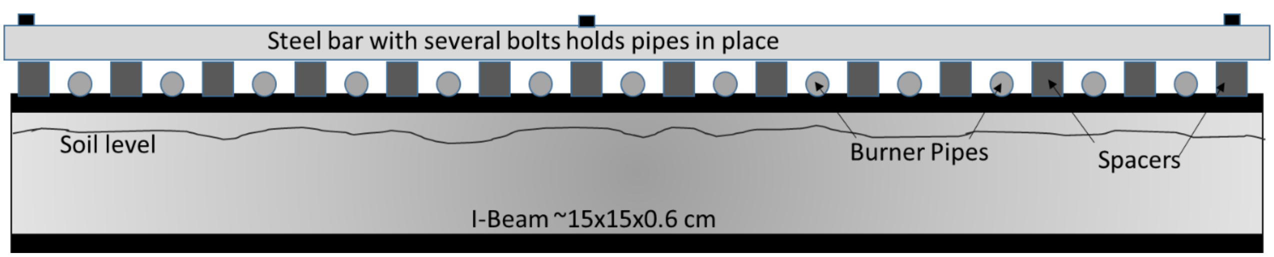

Figure 11. Depiction of I-beam support used to mitigate steel pipe bending viewed along the direction of the burner pipes.

A similar design is already implemented in the propane burner at Bofors Test Center (see Figure 12) due to problems with pipe warping in the startup face of the system. Since it was taken in use this design has faced no problems with pipe warping at all.

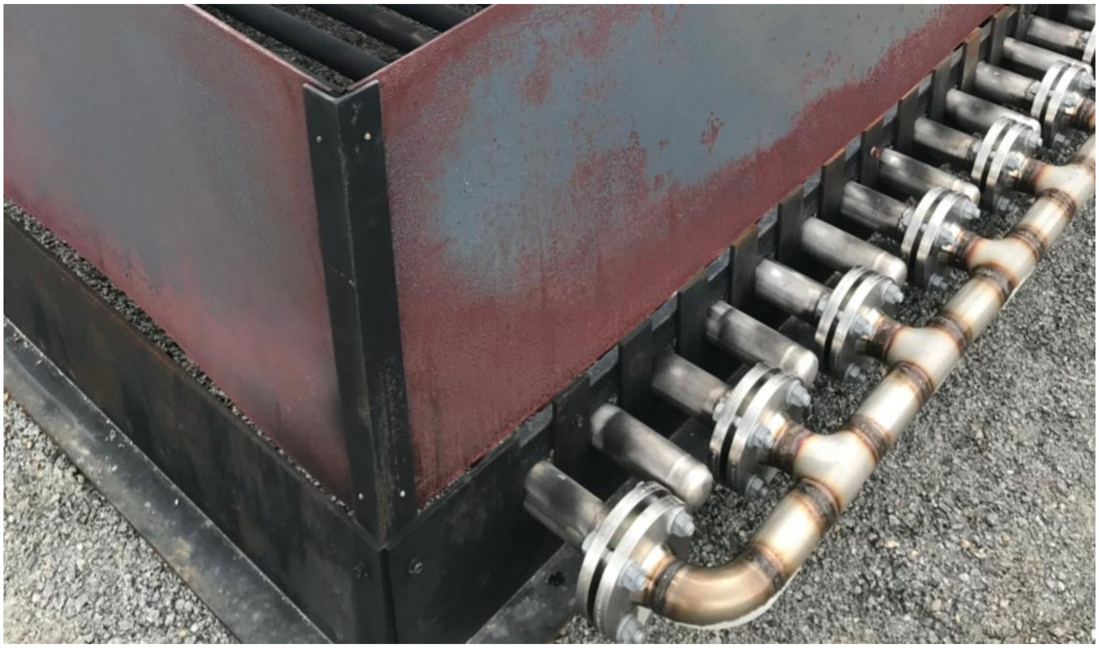

Figure 12. The design used at Bofors Test Center in order to prevent pipe warping.

As another example of the use of a propane burner in an ordnance testing applications, additional work has been done to harmonize STANAG AOP-4240 FCO test with the UN-6(c) bonfire test using propane burners. Information can be found in reference [14].

Conclusions

Further FCO testing of ordnance items has been completed. Recent testing was completed with significant savings in time and money. Other testing completed with the same type of ordnance item in both a liquid-fuel pool fire FCO test and a propane burner FCO test gave similar results in time to reaction and violence of reaction. Using propane burners continues to be an environmentally friendly, less expensive, and more convenient way to perform FCO testing.

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