BOFORS TEST CENTER

DEFEATING THE IMPOSSIBLE SINCE 1886

PIMP MY FLAMES – HOW TO CREATE A HOT ENVIRONMENT

JON TOREHEIM[*], ADAM JANSSON[**] and KENT CONNEDAHL[***]

[*]Marketing and Sales Manager, Bofors Test Center, Karlskoga, Sweden
[**]B.Sc., Karlstad University, Karlstad, Sweden
[***]Test Technician (Rt), Bofors Test Center, Karlskoga, Sweden

Summary: For several years Bofors Test Center has been involved in an international work to change STANAG 4240 for Fast Heating in order to allow alternative fuels as substitutes to liquid hydrocarbon fuel. There are many reasons for that; reasons like negative environmental impact, high fuel costs, long set-up times and unpleasant working environment when liquid hydrocarbon fuel is used. Since the thermal exposure delivered to the test item from the heat source is a key issue regarding the test results, such as time to reaction and reaction level, the alternative test systems need to replicate the thermal exposure delivered from a liquid hydrocarbon fuel fire as close as possible. Our first built alternative, the Liquefied Propane Gas System which was presented at IMEMTS in Tucson 2009 and in Munich 2010 has been questioned, by ourselves and others, whether it can deliver a similar uniform thermal exposure to the test item as a liquid hydrocarbon fuel fire or not. With these doubts in mind we decided to think in other terms and work in other directions. At IMEMTS in San Diego 2013 Bofors Test Center's latest invention, the Sand Bed Burner, was introduced. In cooperation with Luleå University of Technology, Bofors Test Center designed and tested a Sand Bed Burner demonstrator based on propane gas which diffuses through a sand bed. This makes the combustion result in flames with a higher radiation than premixed flames from standard torches and creates a very uniform thermal exposure to the test item. There was however some technical issues with this demonstrator that still remained to be solved. All these issues have now been solved and we are now able to introduce the new Bofors Hellflute. A burner that meets all proposed future requirements for alternative-fuel test equipment in a very flexible and cost-efficient way.

INTRODUCTION

The negative environmental impact, high fuel costs, long set-up times and unpleasant working environment etc. associated with the use of liquid hydrocarbon fuel for Fast Cook-Off (FCO) tests in accordance with STANAG 4240 is well-known and an alternative-fuel fire test is proposed in the draft update of STANAG 4240; the AOP-4240.

Several criteria for how to guarantee that test equipment for this alternative-fuel fire test can produce similar heating conditions as a liquid hydrocarbon fuel fire are currently under discussion. Basically a limited volume called “hearth” within the flames produced by the test equipment shall be defined and calibrated. This “hearth” will then be the approved volume in which a test item can be placed at a live test. The calibration requirements of the “hearth” can briefly be summarized as follows:

- The flame temperature shall meet the requirements for a liquid hydrocarbon fire stated in STANAG 4240.
- The heating must be uniform. The standard deviation of the temperatures should not be greater than 10% of the average temperature.
- The heat flux, as measured by a device of specified dimensions, must be greater than 80 kW/m^2 when averaged over a 20 second period after a minimum temperature of 800°C is achieved.

At Bofors Test Center there are two different systems for FCO testing with alternative-fuel. The BTC Liquefied Propane Gas System, shown in Fig. 1, was presented in 2009 and is a torch burner. Several similar burners have been manufactured by other organisations since, but there has always been a concern whether it can deliver a similar uniform thermal exposure to the test item as a liquid hydrocarbon fuel fire or not. Therefore Bofors Test Center in 2013 in cooperation with Luleå University of Technology designed, built and tested a Sand Bed Burner, shown in Figure 2, based on ideas from Professor Ulf Wickström at Luleå University of Technology. In the Sand Bed Burner propane gas diffuses through a sand bed. This makes the combustion result in flames with a higher radiation than premixed flames from standard torches and creates a very uniform thermal exposure to the test item.

Fig. 1. The BTC Liquefied Propane Gas System.

Fig. 2. The Sand Bed Burner.

When the SBB first was tested two technical problems came up:

- The propane gas flow and heat release rate was decreased considerably during the tests and this had a direct impact on the heating of the test object. This was a consequence of freezing in the propane bottles due to the high gas flow rate, see Fig. 3.
- An area with no combustion occurred in the middle of the SBB as shown in Fig. 4.

Fig. 3. Frozen propane bottles.

Fig. 4. In the area covered with soot no combustion occurred.

THE SOLUTION OF THE GAS FLOW PROBLEM

To take care of these issues Bofors Test Center started to cooperate with Karlstad University. The problem with the gas flow was solved by changing the relatively small, some with steel casing and some with composite casing, bottles of size P11 to bottles with size P45 – all of them with steel casing. Each bottle was also equipped with a gas regulator so the pressure could be controlled. The bottles, ten in total, was also placed in two water tanks (five bottles in each tank) where water was circulated and heated to a temperature of approximately 30-35°C. These technical improvements, shown in Fig. 5-6, have solved the problem with the decreasing gas flow and heat release rate during testing. Since they were introduced no such problems have been observed. The issue with the area where no combustion occurred was however still a problem to overcome.

Fig. 5. Large steel propane bottles with regulators placed in water tanks.

Fig. 6. The system for heating and circulation of the water in the tanks.

FURTHER TESTING

In a study performed by Bofors Test Center together with Dr. David Hubble and Dr. Jon Yagla from NSWCDD, USA, in 2014 it was shown that the torch burner as well as the Sand Bed Burner did not meet the proposed requirements for an alternative-fuel test fire. The torch burner met the temperature and heat flux requirements but the main problem was the lack of uniformity – just as foreseen. Thus there is a risk of producing hot spots with a torch burner system. The Sand Bed Burner had problems in reaching the temperature requirements and also the heat flux requirements. The uniformity on the other hand was even better than the uniformity reached in the Jet A-1 tests which were performed as reference tests. The Jet A-1 pool (1.2 x 1.2 m) had a similar size as the Sand Bed Burner (1.0 x 1.15 m). In summary a system producing flames as the Sand Bed Burner seemed more promising than a torch burner system.

A NEW DESIGN – THE BOFORS HELLFLUTE

During the tests Dr. Hubble and Dr. Yagla were showing their latest propane burner from NSWCDD shown in Fig. 7. This system is, just as the Bofors Test Center torch burner and the Sand Bed Burner, designed and built with the philosophy of using inexpensive parts to make it affordable to repair or replace. It is also designed to be easy to rapidly repair if it should be damaged during testing – which happens from time to time – and scalable or modular for testing of larger items. The NSWCDD propane burner is an approximately 3.7 x 3.7 m arrangement with 26 burner tubes with totally 676 holes which works as gas jet nozzles. The 2 inches steel pipes allows for the flow of liquid propane which is vaporized when heated and ejected from the holes as gaseous propane. The performance of this burner is very good and it successfully fulfils all temperature and heat flux requirements discussed.

Fig. 7. The NSWCDD propane burner (picture from Ref. 1).

At Bofors Test Center most FCO tests are performed on relatively small items like e.g. bare naval gun ammunition and anti-tank rounds etc. Therefore a propane burner with the size of the NSWCDD burner is most of the time overkill. The size will also make it quite difficult to move from one test site to another and at Bofors Test Center we strive for mobility since we currently have no test site dedicated for FCO tests only. The use of liquid propane also makes things more complicated since such an installation will require permission for the Swedish authorities. Then the idea came up to combine the technology in the NSWCDD propane burner using steel pipes with drilled holes with Bofors Test Center's propane bottle gas fuel system. A system like that will look and work more or less like a BBQ grill used for cooking in the garden.

The Bofors Hellflute is shown in Fig. 8. It is built with the same dimensions as the Sand Bed Burner (1.0 x 1.15 m). Ten 1.15 m long, 15 mm outer diameter, steel pipes (one for each propane bottle) with a wall thickness of 1.5 mm with totally 570, 2.8 mm diameter, holes is used in the burner as shown in Fig. 9. The burner is built in modules which are very quick to repair and replace if needed.

Fig. 8. The Bofors Hellflute.

Fig. 9. The pipes in the burner.

EVEN MORE TESTING

A verification of the Bofors Hellflute has also been performed. It has been made by several tests of which two will be further discussed. First of all the limited volume called "hearth" within the flames, i.e. the approved volume in which a test item can be placed at a live test, had to be defined. In order to define the temperatures a steel grid, in which 8 thermocouples (with an outside diameter of 0.040 inches) were placed on several positions, was placed in the fire as shown in Fig. 10-11. The result of one of these tests (Test No. 19) is shown in Fig. 12 and in Table 1.

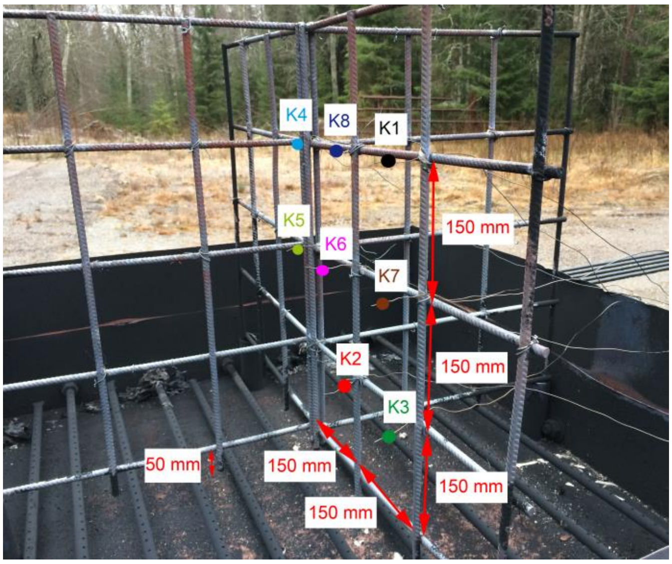

Fig. 10. The position of the thermocouples in Test No. 19.

Fig. 11. The steel grid engulfed in flames.

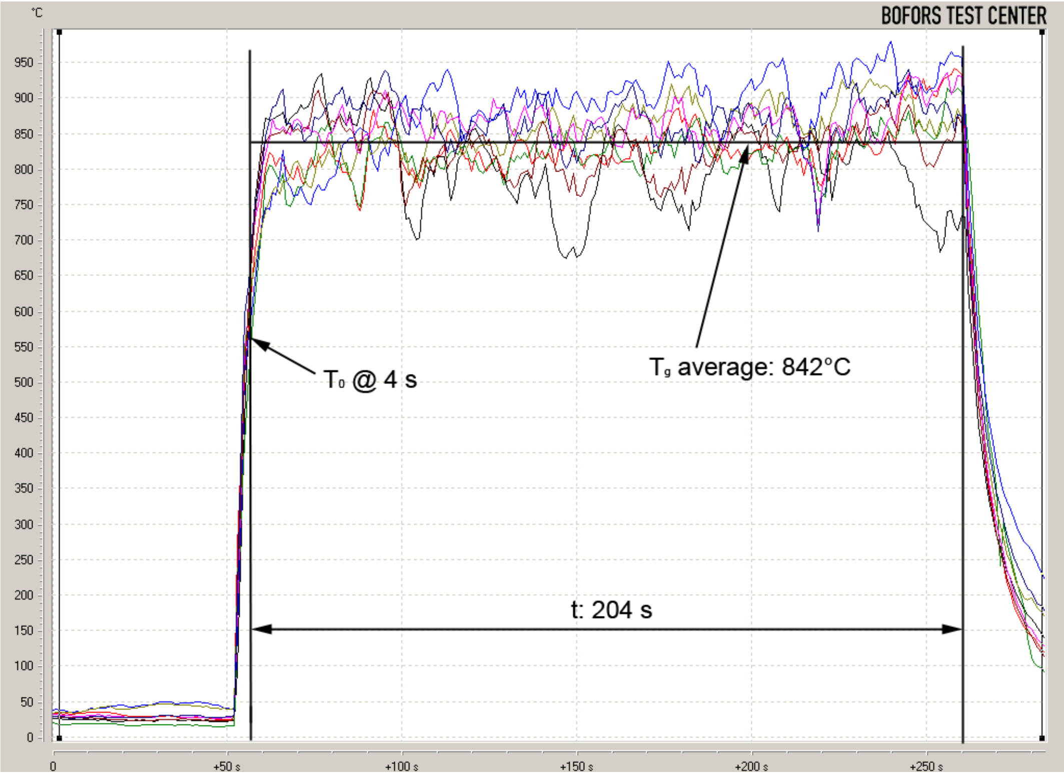

Fig. 12. Temperature as a function of time in Test No. 19.

Table 1. Temperature data from Test No. 19.

Thermocouple	Temperature average (T_0 - End of Test) [ºC]	Standard deviation [ºC]	Standard deviation/ Temperature average [%]	Approved position [yes/no]
K1	804	62	8	yes
K2	826	44	5	yes
K3	819	45	5	yes
K4	881	65	7	yes
K5	851	49	6	yes
K6	861	38	4	yes
K7	829	41	5	yes
K8	865	40	5	yes

This test, together with other test performed and not presented in this paper, shows that an approved volume is a box with a height of 300 mm and a length and width of 600 mm. The box is placed in the centre of the pan, 200 mm above the bottom. This box, shown in Fig. 13, can from a temperature point of view be defined as the “hearth”. This “hearth” is large enough for test items such as 40 mm naval gun ammunition, 81 mm mortar rounds and 84 mm Carl-Gustaf rounds. For bigger items like e.g. 155 mm shells a larger burner is however required.

Fig. 13. The “hearth”.

In the defined “hearth”, heat flux measurement tests have also been conducted. The gauge used was an Adiabatic Surface Temperature Probe (ASTP). The ASTP is shown in Fig. 14 and is discussed in detail in Ref. 4-5. The test setup from one of the tests (Test No. 15) is shown in Fig. 15 and the result of this test is given in Fig. 16 and in Table 2. The heat flux was calculated and averaged for a time period of 60 seconds, 322 seconds after T_0.

Fig. 14. The ASTP.

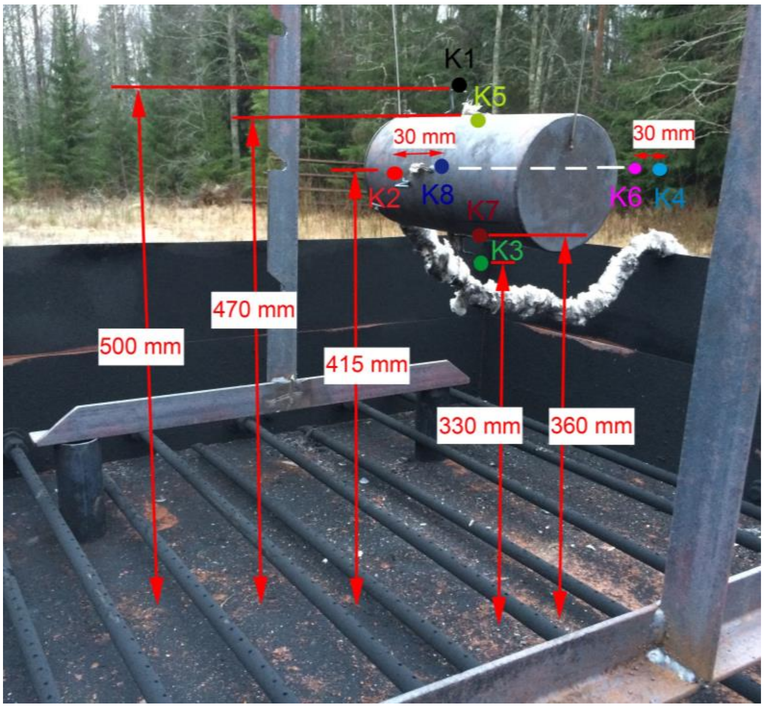

Fig. 15. The test setup in Test No. 15.

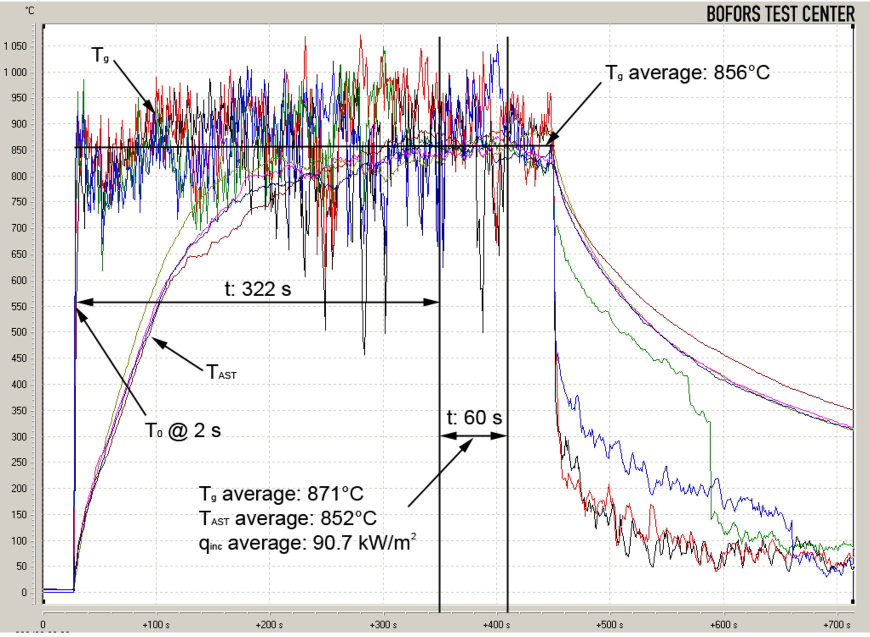

Fig. 16. Temperature as a function of time in Test No. 15.

Table 2. Temperature and heat flux data from Test No. 15.

Thermocouple(s)	Gas temperature (T_g) average (T_0 - End of Test) [ºC]	Gas temperature (T_g) average (322 s - 382 s) [ºC]	Adiabatic Surface Temperature (T_{AST}) average (322 s - 382 s) [ºC]	Calculated average heat flux (322 s - 382 s) [kW/m²]
K1 (T_g top)	839	828	*NA*	*NA*
K2 (T_g side)	884	893	*NA*	*NA*
K3 (T_g bottom)	849	854	*NA*	*NA*
K4 (T_g side)	852	909	*NA*	*NA*
K5 (T_{AST} top)	*NA*	*NA*	846	*NA*
K6 (T_{AST} side)	*NA*	*NA*	847	*NA*
K7 (T_{AST} bottom)	*NA*	*NA*	870	*NA*
K8 (T_{AST} side)	*NA*	*NA*	845	*NA*
K1/K5 (top)	*NA*	*NA*	*NA*	89
K2/ K8 (side)	*NA*	*NA*	*NA*	88
K3/ K7 (bottom)	*NA*	*NA*	*NA*	97
K4/ K6 (side)	*NA*	*NA*	*NA*	88

The heat flux was calculated using the equation shown in Fig. 17. In this equation ε is the surface emissivity which controls the amount of energy emitted from the object (here assumed to be 0.9). The convective heat transfer coefficient h_c affects the convection heat transfer to the object. A description of how to calculate h_c is given in Ref. 5. σ is the Stefan-Boltzmann constant (5.67 x 10^{-8} W/m^{2}K^4). T_g is the measured gas temperature and T_{AST} is the measured adiabatic surface temperature in Kelvin.

$$\dot{q}''_{inc} = \sigma T^4_{AST} - \frac{h_c}{\varepsilon}\left(T_g - T_{AST}\right)$$

Fig. 17. The equation used for calculating the incident heat flux.

CONCLUSIONS

The new burner design presented, the Bofors Hellflute, has shown to be compliant with all requirements which are currently discussed for an alternative-fuel test equipment. The burner fulfils the temperature requirements as well as the requirements for temperature uniformity and heat flux.

It has been demonstrated that with a small scale system like the Bofors Hellflute it is possible to perform FCO tests on items such as bare mortar rounds and medium calibre ammunition. If there is a need for testing of larger test items the burner can easily be scaled up. This system represents a new area of burners which are mobile, reliable and cost-efficient – both when it comes to the manufacturing costs of the equipment as well as the fuel costs.

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CONTACT INFORMATION

Presenter:	Jon Toreheim
Address:	Bofors Test Center, P.O. Box 418, 691 27 Karlskoga, SWEDEN
Phone:	+46 586 840 95
Mobile:	+46 73 446 40 95
Email:	jon.toreheim@testcenter.se

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