FAST COOK-OFF USING LIQUIFIED PROPANE GAS
– The development of an alternative test method

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Summary– It is well known that Fast Cook-Off testing using liquid hydrocarbon fuel has a lot of disadvantages. The fact that this way of testing is prohibited in several countries due to negative environmental impact has created an increasing demand for an alternative test method. This alternative is now introduced in the third edition of AOP-39, Guidance on the Assessment and Development of Insensitive Munitions (MURAT). Therefore Bofors Test Center has designed a small scale test equipment using Liquified Propane Gas (LPG) as fuel. The tests carried out at Bofors Test Center show that Fast Cook-Off tests performed with a test equipment using LPG as fuel give the same test results as when similar test objects were tested using liquid hydrocarbon fuel. The tests also showed that it is possible to meet the temperature requirements stated in STANAG 4240, Liquid Fuel / External Fire, Munition Test Procedures. Besides the fact that the LPG system is more environment friendly it is also more cost efficient, gives shorter lead times in the development phase of a new munition system, provides a better working environment for the test personnel and gives increased possibilities for measurements and test evaluation.

INTRODUCTION

In recent years Bofors Test Center has noticed increased demands from industry as well as from authorities, e.g. the Swedish Defence Materiel Administration (FMV), to perform more cost-efficient and more environment friendly Insensitive Munitions (IM) testing. The test in focus from our point of view has been the Fast Cook-Off Test.

According to STANAG 4240, Liquid Fuel / External Fire, Munition Test Procedures [1], Fast Cook-Off Tests shall be performed using liquid hydrocarbon fuel. This way of testing has some well known disadvantages. It gives a negative impact on the environment and is therefore prohibited in several countries. It is also quite expensive to perform such a test due to high fuel costs as well as long set-up times and run times. The quality of the fuel is another issue. At Bofors Test Center we experience that different batches of fuel give unacceptable variations in average flame temperatures. Moreover it is also not possible to measure blast pressures at a distance of 5 m from the test object since the gauges will be destroyed by the fire and it is impossible to see what happens to the test object during the test since it is concealed by the flames. The test method is also very dependent on weather conditions i.e. only very low wind speeds are allowed. At Bofors Test Center, Fast Cook-Off Tests with liquid hydrocarbon fuel are not performed at wind speeds exceeding 1 m/s even though a wind speed of 10 km/h (approximately 2.8 m/s) is accepted in [1]. The working environment for the test personnel working with liquid hydrocarbon fuel in Fast Cook-Off Tests is another important issue. All of these problems have been pinpointed by several nations and have been discussed in many forums e.g. at the Fuel Fire Experts Meeting at WTD 91-Meppen, Germany, in February 2010.

In March 2010, the third edition of AOP-39, Guidance on the Assessment and Development of Insensitive Munitions (MURAT) [2] was published. In that document it is now stated that "Where environmental concerns dictate, alternate fuel such as propane or natural gas may be used if testing verifies that the overall heat load to the test item matches what would be achieved from a liquid fuel fire at the established ramp and average temperature. For those items with exposed reactive surfaces (energetic materials, intumescent paints; not including packaging) the radiative conditions should match that of a liquid fuel fire.".

As a solution of the problems described, Bofors Test Center has designed a small scale test equipment which is able to meet the temperature requirements given in [1]. In this equipment, Liquefied Propane Gas (LPG) is used as fuel.

INITIAL TESTS

In [1] it is stated "An average flame temperature of at least 800°C, as measured by all valid thermocouples (sample rate > 0.2 Hz) at the test-item without contribution of the burning munition, will be considered a valid test. This temperature is determined by averaging the temperature from the time the flame reaches 550°C until all munition reactions are completed. Any deviation from this shall be recorded with appropriate time versus temperature data. The flame temperature shall reach 550°C in the order of 30 seconds after ignition as measured by any two of four flame thermocouples. The time (over a 30-second period) until flame temperature, as measured by the two thermocouples, reaches 550°C shall be subtracted from the time of reaction.". The purpose of the initial tests was to study if it is possible to fulfil the temperature requirements stated in [1] using standard LPG components which could be bought in more or less any hardware store. The main reasons of using standard LPG components are that spare parts are easy to get and that the price is relatively low. It is important to keep that in mind since a violent reaction from a test object most probably will destroy parts of the LPG system and therefore the LPG system must be easy to repair in a short time and to a low cost.

Temperature measurements using a standard LPG burner

The tests were carried out with a standard LPG burner and temperature as a function of time was measured with one thermocouple type K at different distances from the orifice of the LPG burner. These measurements were made in order to study at which distance from the orifice of the LPG burner the temperature requirements stated in [1] could be met in best way. The test setup is shown in Fig. 1.

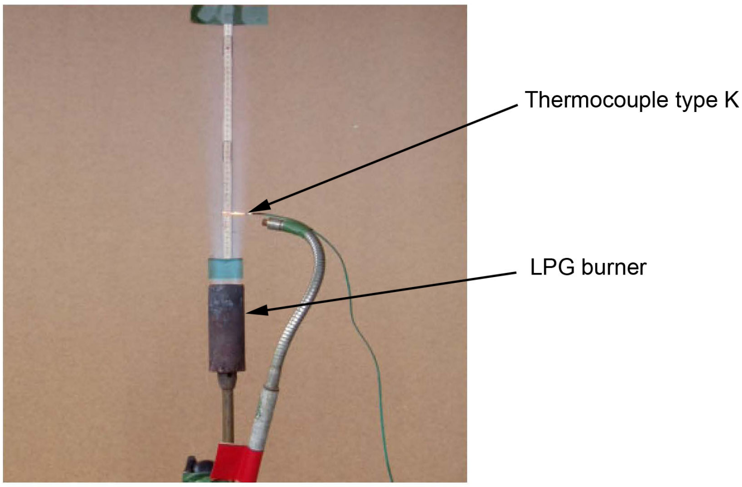

Fig. 1. Test setup for initial tests.

The results of these tests are shown in Table 1.

Table 1. Results of the initial tests

Test No.	*Distance from the thermocouple to the orifice of the LPG burner* (mm)	*Temperature after 30 seconds* (°C)	*Average temperature over a period of 8 minutes* (°C)
1	10	513	554
2	50	664	675
3	100	970	1031
4	200	1272	1277
5	250	1263	1249

As shown in Table 1, a position from the orifice of the LPG burner to the test object could be at least between 100-250 mm to meet the requirements stated in [1].

The results of these tests were promising and design and construction of a small scale test equipment started.

THE BOFORS TEST CENTER LPG SYSTEM

Since many IM-tests at Bofors Test Center are performed in the development phase of a munition system they are often performed on subsystems or naked rounds and warheads. The dimensions of typical test objects are usually relatively small, e.g. medium calibre gun ammunition, shoulder launched anti-tank weapons or subsystems from large munition systems. The LPG system is therefore designed to meet these dimensional requirements. If test objects with larger dimensions shall be tested, Bofors Test Center has both the equipment and permissions needed to perform Fast Cook-Off Tests according to [1] using liquid hydrocarbon fuel. In such cases Bofors Test Center consider it more cost-efficient to use liquid hydrocarbon fuel than to build a large scale LPG system which might be totally destroyed during the test due to a violent reaction from the test object. Test objects with such dimensions are also often so expensive that only one or very few tests are performed which means that costs for fuel and set-up times are relatively low in an overall perspective.

The design of the LPG system

The LPG system is designed to meet the following main requirements compared to testing with liquid hydrocarbon fuel:

- More environment friendly
- Lower fuel costs
- Shorter set-up times
- Shorter run times, up to four tests per day shall be possible to perform
- Possibility to measure blast pressures at a distance of 5 m from the test object
- Improved working environment for the test personnel

Other benefits with the LPG system are that it allows you to visually see what happen to the test object during the test, it is also possible to use High Speed Video, and it is possible to perform tests at higher wind speeds than when using liquid hydrocarbon fuel. The LPG system is also portable and could easily be transported between different test sites.

The LPG system, which is shown in Fig. 2, consist of one steel table with following dimensions (width x length x height): 1350 x 1400 x 1070 mm. On the steel table a removable steel grid, on which the test objects are placed during a test, is mounted. The steel grid is made removable in order to make it easy to replace with another steel grid in case of a violent reaction during a test. Another benefit with a removable steel grid is that it makes the run times shorter due to the fact that no time for cooling the grid between tests is needed. The only thing needed to be done is to remove the hot grid and replace it with a grid with ambient temperature.

Beneath the steel grid two steel bars are placed. On each of these steel bars a total amount of up to ten LPG burners are placed. LPG to each LPG burner is delivered from one commercial LPG cylinder of size P10. The LPG cylinders are kept in a container in which also the control equipment for the LPG cylinders is mounted.

Fig. 2. The LPG system.

The steel bars are adjustable in height and the LPG burners are adjustable in angle as shown in Fig. 3. This design makes it possible to adapt the LPG system depending on the dimensions of the test object.

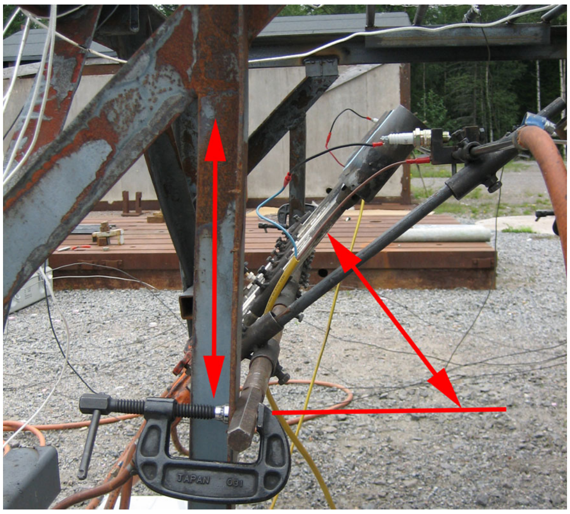

Fig. 3. The possibilities to adjust the LPG burners.

The igniting and extinguishing processes of the LPG system are remotely controlled and it is possible to stop and restart the heating process during a test if required. The LPG is ignited by four spark plugs as shown in Fig. 4.

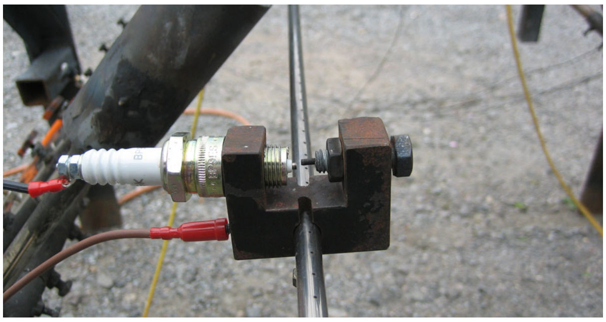

Fig. 4. Spark plugs are used in order to ignite the LPG system.

COMPARATIVE TESTS

During the development phase of the LPG system comparative tests using the LPG system were performed. The purpose of the comparative tests was to study if there were any differences in type of reaction on three different products which had already been tested using liquid hydrocarbon fuel. The test objects chosen for these tests were:

- One naked 40 mm L70 LK cartridge case assembly
  (two similar tests were performed)
- One naked Launch Rocket (LR) from the Next Generation Light Anti-tank Weapon (NLAW) system
  (one test was performed)
- One NLAW Flight Motor (FM) mounted in a NLAW Combat Weapon (CW)
  (one test was performed)

The test objects are shown in Fig. 5-7.

Fig. 5. One naked 40 mm L70 LK cartridge case assembly.

Fig. 6. One naked LR from the NLAW system.

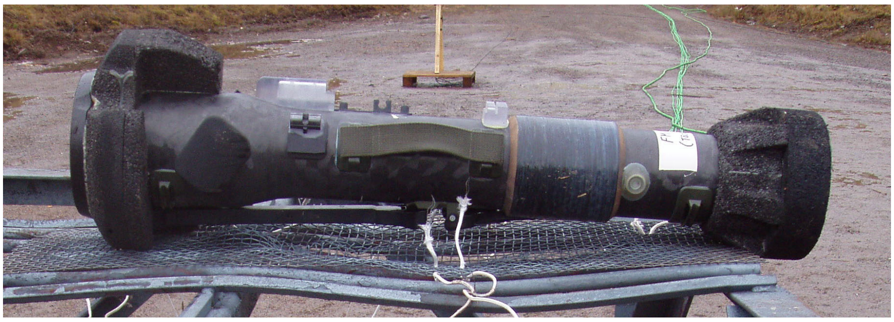

Fig. 7. One NLAW FM mounted in a NLAW CW.

The results of the tests, regarding the performance of the LPG system, are summarized in Table 2.

Table 2. The results of the tests, regarding the performance of the LPG system

Test No.	*Test object*	*Time to 550°C (s)*	*Average flame temperature from 550°C to reaction (°C)*
1	40 mm L70 LK	5	982
2	40 mm L70 LK	3	981
3	NLAW LR	3	948
4	NLAW FM	5	900

The types of reaction of the test objects in the LPG tests were similar to the types of reaction of the test objects in the liquid hydrocarbon fuel tests. The blast pressures levels, time to reaction from 550°C, appearance of the witness plates and how parts from the test objects were scattered were similar. The type of reaction in each test is shown in Table 3.

Table 3. The type of reaction of the test objects when tested using liquid hydrocarbon fuel and LPG

Test object	*Type of fuel*	*Type of reaction*
40 mm L70 LK	liquid hydrocarbon fuel	V
40 mm L70 LK	LPG	V
NLAW LR	liquid hydrocarbon fuel	*
NLAW LR	LPG	*
NLAW FM	liquid hydrocarbon fuel	V
NLAW FM	LPG	V

* The type of reaction in each test was judged but the reaction types are not comparable due to the fact that the NLAW LR was mounted in a NLAW CW when it was tested using liquid hydrocarbon fuel, not naked as when it was tested using LPG. Therefore these judgements are not shown in Table 3.

The scattered parts from the tests using liquid hydrocarbon fuel and from the tests using LPG are shown in Fig. 8-13.

Fig. 8. Scattered parts from one 40 mm L70 LK cartridge case assembly when tested using liquid hydrocarbon fuel.

Fig. 9. Scattered parts from one 40 mm L70 LK cartridge case assembly when tested using LPG.

Fig. 10. Scattered parts from one NLAW LR when tested using liquid hydrocarbon fuel.

Fig. 11. Scattered parts from one NLAW LR when tested using LPG.

Fig. 12. Scattered parts from one NLAW FM when tested using liquid hydrocarbon fuel.

Fig. 13. Scattered parts from one NLAW FM when tested using LPG.

COMPLEMENTARY TEMPERATURE MEASUREMENT TEST

One complementary temperature measurement test has also been performed. The purpose of this test was to measure temperatures on more places around a test object (in order to give a deeper knowledge about the temperature distribution around a test object) than usually are performed when testing according to [1], in which following requirements are stated: "…a minimum of 4 thermocouple elements are required. These thermocouples shall be mounted 40-60 mm from the surface of the test item at positions fore, aft, starboard and port along a horizontal plane through the centreline of the test-item.". In this test a total amount of 14 LPG burners were used (the maximum amount is 20 LPG burners). The test object chosen for this test was an inert 40 mm round. Ten thermocouples were placed 40 mm from the surface of the test object, the placement of the thermocouples is shown in Fig. 14. The temperature as a function of time is shown in Fig. 15 and the result of the test is also presented in Table 4. The test was terminated 3 minutes and 2 seconds after the first two thermocouples measured a temperature of ≥ 550°C.

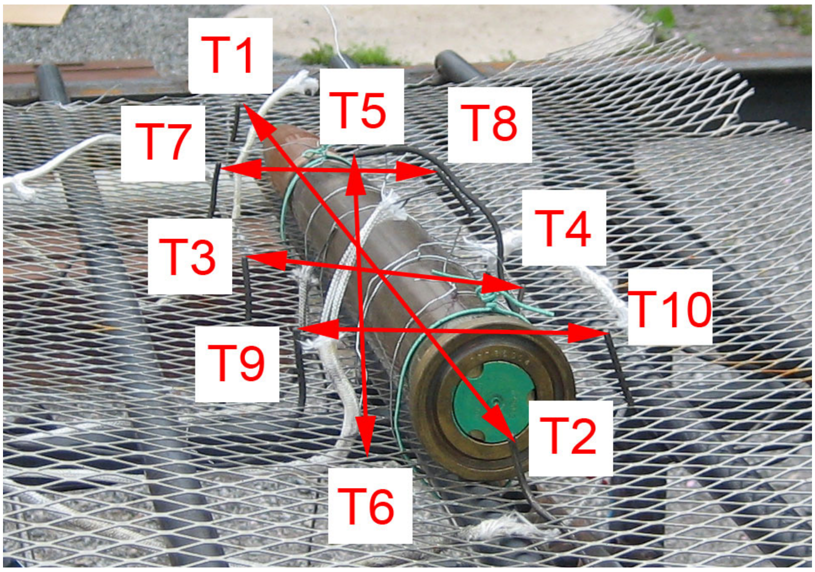

Fig. 14. The placement of the thermocouples.

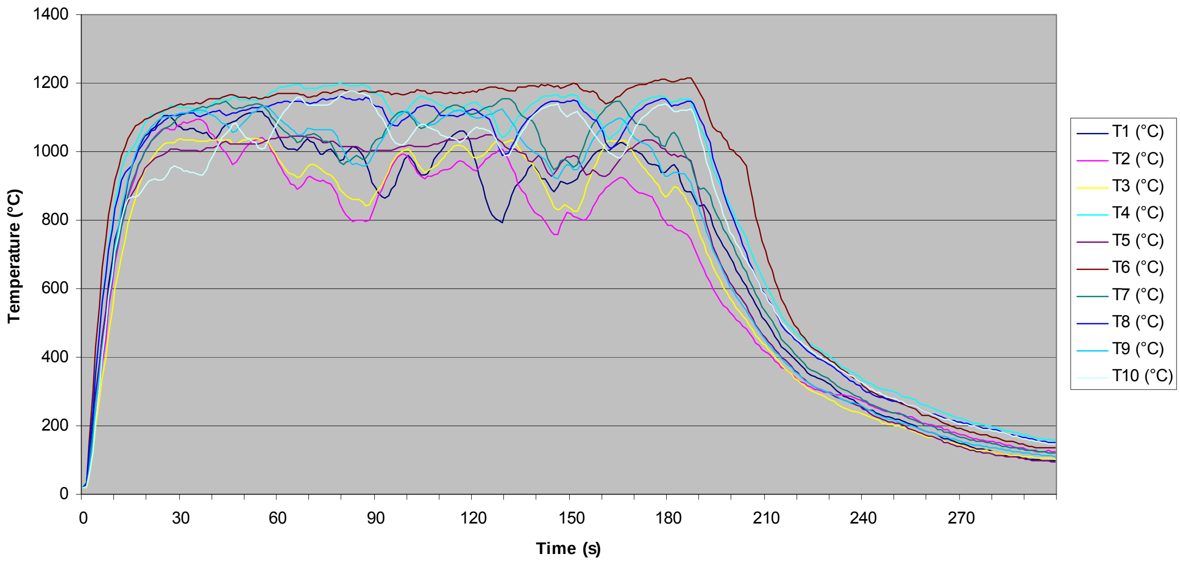

Fig. 15. Temperature as a function of time.

Table 4. The results of the test regarding the performance of the LPG system

Thermocouple No.	*Distance from the surface of the test object (mm)*	*Placement related to the test object*	*Time to 550°C (s)*	*Average flame temperature from 550°C to when the test was terminated (3 minutes, 2 seconds) (°C)*
1	40	Front	8	974
2	40	Rear	9	909
3	40	Side	10	941
4	40	Side	6	1123
5	40	Over	8	989
6	40	Beneath	6	1155
7	40	Side	8	1051
8	40	Side	6	1095
9	40	Side	8	1034
10	40	Side	8	1040

The conclusion of this test is that the LPG system provides temperatures in accordance with the requirements stated in [1] at a distance of 40 mm from the surface of the test object on all sides.

CONCLUSIONS

It is well known that Fast Cook-Off testing using liquid hydrocarbon fuel has a lot of disadvantages. The fact that this way of testing is prohibited in several countries due to negative environmental impact has created an increasing demand for an alternative test method. This alternative is now introduced in [2]. The tests carried out at Bofors Test Center show that Fast Cook-Off tests performed with a small scale test equipment using LPG as fuel give the same test results as when similar test objects were tested using liquid hydrocarbon fuel. The tests also showed that it is possible to meet the temperature requirements stated in [1]. Besides the fact that the LPG system is more environment friendly it is also more cost efficient, gives shorter lead times in the development phase of a new munition system, provides a better working environment for the test personnel and gives increased possibilities for measurements and test evaluation.

REFERENCES

1. Liquid Fuel / External Fire, Munition Test Procedures, *STANAG 4240*(2), (2003)
2. Guidance on the Assessment and Development of Insensitive Munitions (MURAT), *AOP-39*(3), (2010)