Title

Typhoon™: an innovative extinguisher for fire protection

1 Abstract

Once, equipments gathering mechanics and energetic materials named Energetic Material Actuated Devices were mainly used in the field of military and space industries, but since the development of airbags for automotive safety, these devices have been more and more used in areas of everyday life and people safety.

It is above all the very high level of safety and reliability of energetic materials placed at the heart of airbags and thus the perfect control of the release of their energy at the precise time of triggering, which has allowed their spread in all cars manufactured worldwide.

Energetic materials implemented in airbags generate a great amount of gas on demand to inflate the cushions and soften impacts of vehicles occupants on hard points of cockpits in cases of violent crashes.

The transfer of technology coming from airbags in fire protection field has given the birth to a new family of Energetic Material Actuated Devices called Typhoon™ extinguishers which embed the last generation of energetic materials with the aim to control the spray of the extinguishing agents. Skills and know-how coming from millions parts of energetic materials made for automotive safety match undoubtedly expected levels of reliability and safety of operation requested in such fire protection products.

This paper:

- Presents the design of Typhoon™ extinguishers;
- Provides an overview of performances of energetic materials intended to automotive applications and focuses on those that are potentially of interest for Typhoon™ extinguishers;
- Presents first tests results;
- Highlights features and benefits of Typhoon™ extinguishers.

2 - Reminder of existing technology

Usually a conventional fire extinguisher contains an extinguisher agent that is pushed out toward a fire by the action of a driving gas pressure which is continuously present inside the tank and discharged with the agent when it is operated by a valve opening for example. The gas driving pressure can be also generated in the extinguisher tank at the precise time of its use by piercing the lid of an auxiliary gas cartridge filled usually by nitrogen or carbon dioxide.

For the quality of the spraying (shape and speed of the sprayed jet, droplet size distribution, quantity and density of the projected agent,…) and the optimization of the structure weight, the best is to pushed out the extinguishing agent with a constant and high enough gas driving pressure from the beginning to the end of the spaying.

However, conventional fire extinguishers usually provide a decreasing driving gas pressure as soon as the free volume of the container increases and may present a large variations between the start and the end of operation.

Designers try to compensate this difficulty by:

- Implementing a strong driving gas pressure at the beginning of the release of the extinguisher agent with the consequence to oversize the structure of the container and thus, to increase the weight and the cost of fire extinguishers;
- Accepting a significant decrease of the spraying quality at the end of operation with the consequence to lower the global extinguishing efficiency.

Furthermore:

- Conventional fire extinguishers are subjected to compulsory periodic controls related to the driving gas pressure as weighing and leakage controls.
- The fact that this same driving gas pressure is sensitive to ambient temperature can damage also the efficiency of the extinction.

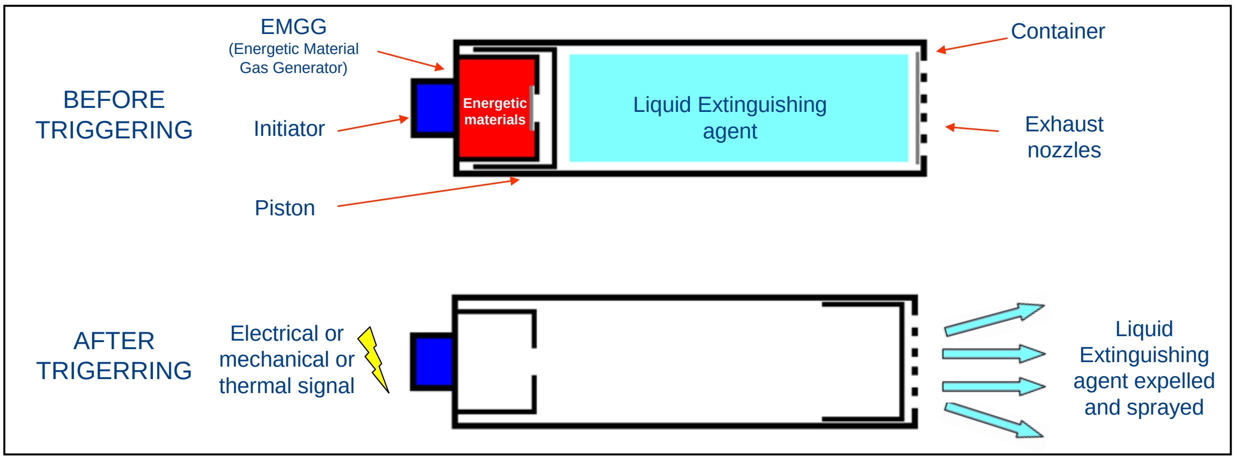
3 - Typhoon™ extinguishers presentation

3.1 - General design

The Typhoon™ extinguisher is designed to implement any type of liquid extinguishing agent as additive-water or other.

It consists of a cylindrical container comprising two chambers separated by a piston. The first chamber contains the liquid extinguishing agent and the second one named "piston thrust room" is provided with an Energetic Materials Gas Generator (EMGG) which delivers the driving gas pressure acting on the said piston and propelling the extinguishing agent out of the container .

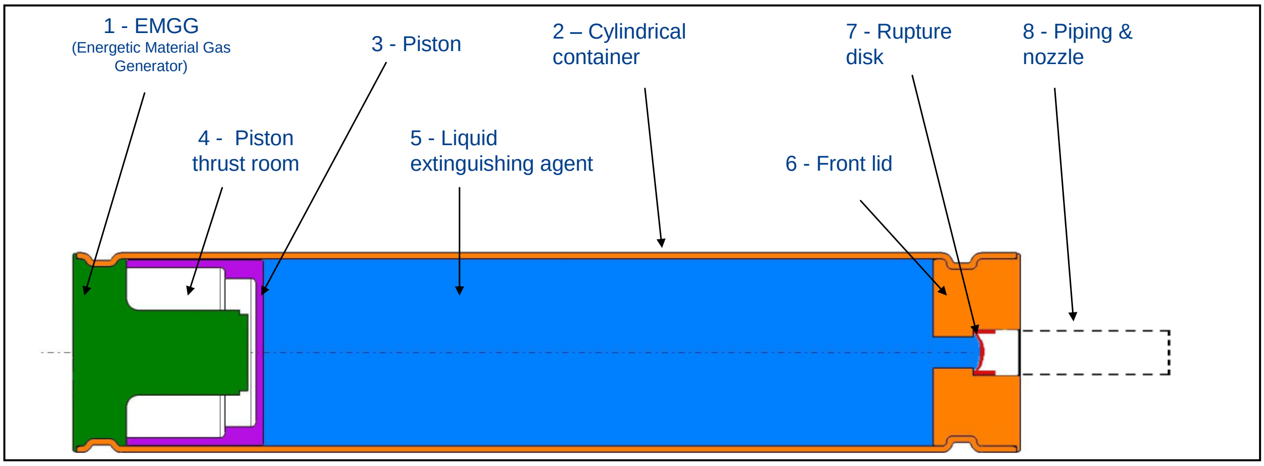
Figure 1 - Functioning principle of Typhoon™ extinguishers



3.2 - Operation

3.2.1 General description

Figure 2 - Typhoon™ extinguishers sketch



Typhoon™ components are:

1 EMGG (Energetic Materials Gas Generator);
- 1.2 Bottom lid embedding EMGG as housing;
- 1.3 Initiator (in this case it is an electric type);
- 1.4 Energetic Material as igniting load;
- 1.5 Energetic Material as gas generant load;
- 1.6 EMGG chamber;
- 1.7 EMGG nozzle;
- 1.8 EMGG closing lid;

See figure 7, § 3.4

2 Cylindrical container;
3 Piston;
4 Piston thrust room;
5 Liquid extinguishing agent;
6 Front lid;
7 Rupture disc;
8 Spray piping and nozzle.

The driving gas pressure generated by EMGG (pos.1) in the piston thrust room (pos. 4) is communicated through the piston (pos.3) to the liquid extinguishing agent (pos.5) which is discharged outside of the tank and sprayed when the rupture disc (pos.7) is broken.

3.2.2 Operation with no side effect

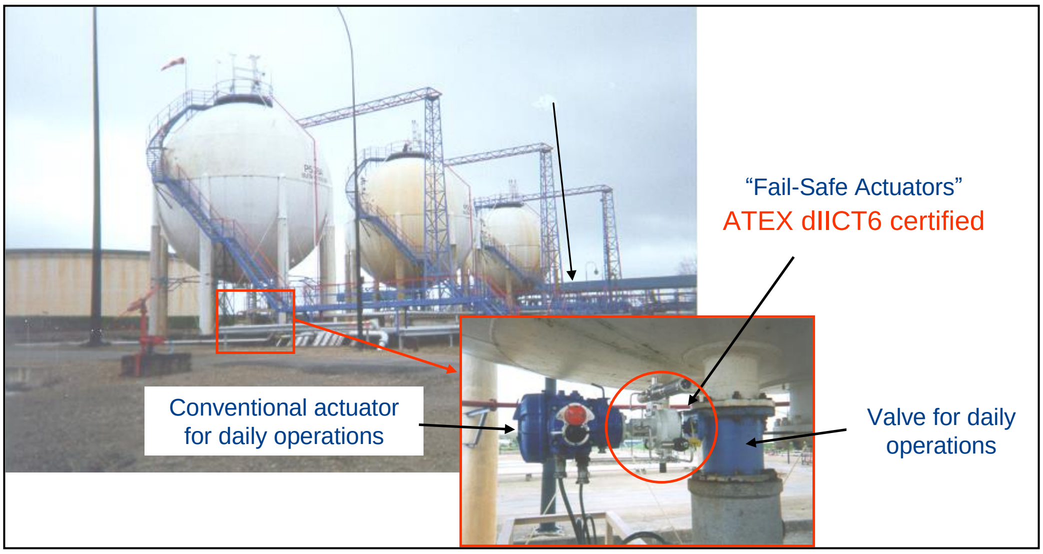
We chose to illustrate this paragraph with the product named "Fail-Safe Actuators" controlled with energetic materials as well as Typhoon™ extinguishers and other Energetic Material Actuated Devices to which they belong.

The common feature of these products is to give back upon request the energy stored up in energetic materials they embed through various mechanical actions carried out as expected under perfect control of duration and mechanical result, e.g. Pressurize; Transfer a signal; Fasten; Cut through; Separate; Pull, Push; Close; Open; Weaken.... Furthermore, some of them as "Fail-Safe Actuators" provide a safety function and are often installed in very sensitive atmospheres such as the ones met in oil, gas and chemical facilities where highly explosive gas mixed up with air remains.

As shown in figure 3, "Fail-Safe Actuators" are in that case, fitted at the bottom outcome of spherical tanks of flammable liquid gas and are located more precisely between their working valves and their conventional actuators operated for daily filling and emptying operations.

In case of surrounding fire "Fail-Safe Actuators" disconnect the conventional actuators and shut off the valves automatically and without external power supply.

Figure 3 - Flammable liquid gas tanks protected with "Fail-Safe Actuators" controlled with Energetic Materials



“Fail-Safe Actuators” have passed:

- Tests in flammable gas fire according to the British Standards n° BS6755-2, and under the control of the Lloyds Register;
- Tests in gasoline fire according to the French TOTAL (ELF) company procedure n° RGTUYTO2;
- Functioning tests in explosive atmospheres, according to ATmosphère Explosible (ATEX) regulation (ATEX dIICT6 certified).

So, if necessary, Typhoon™ extinguishers could be ATEX certified as well as “Fail-Safe Actuators”.

3.2.3 Typhoon™ extinguishers transport classification

Typhoon™ extinguishers belong to Energetic Material Actuated Devices family and by this way, are subjected to UN Recommendations of dangerous goods for transportation, which are the single referenced regulation in force in the world for transportation.

Energetic Material Actuated Devices are classified according to UN Recommendations with regard to their dangerousness level and transported under packaging and shipping conditions linked to their classification results.

For example:

- Class 1 gathers pyrotechnical items and explosives.
- Exclusion from class 1 is a possible assignment (see criteria for that exclusion mentioned in § 2.1.3.6 of UN recommendations). Products excluded from class 1 are classified in Class 9.
- Class 9 is particularly used by Automotive Safety products as airbags and pretensioners.

Classification for transport is under the responsibility of shippers which have to request the classification to a competent authority.

Insofar Typhoon™ extinguishers are currently in development, they are assessing under the control of the French regulatory authority INERIS (National Institute for Industrial Environment and Risks). INERIS is recognized worldwide as well as others bodies scattered worldwide such as:

- Germany: Ministry of Industry and BAM (Bundesanstalt für Materialforschung und-prüfung);
- Great-Britain: Ministry of Industry and HSE (Health and Safety Executive);
- Belgium & Switzerland: Office of explosives;
- United States: US-Department of Transportation (DOT) and Food and Drug Administration (FDA)…

Typhoon™ extinguishers are expected to be classified in Class 9, leading transportation under minimum constraints such as:

- No packaging to be approved
- Light transportation constraints as airbags, for road, air and sea worldwide

The first tests results of Typhoon™ extinguishers related transport classification are as follows:

- Typhoon™ extinguishers meet UN number 3072 which define packaging and shipping conditions under official definition: “Life-saving appliances not self-inflating containing dangerous goods as equipment”.
- Class 9 is now available for 1 liter capacity of extinguishing agent, before filling.

Figure 4 - Typhoon™ extinguishers transport classification

Classification target	Class 9
ONU Number	UN3072
Packaging	No packaging approved
Transportation constraints	Light as airbags (Road, air and sea worldwide)
Regulatory competent authorities	French body Ineris

3.3 Operational principles of Typhoon™ control.

Typhoon™ extinguishers:

- can be easily connected to conventional control units implemented for example in standard automatic and fix fire fighting installations;
- and/or can integrate their own triggering devices which make them fully autonomous (both for triggering and operation).

Triggering signals can be:

- initiated manually or automatically, and also remotely controlled with a low electric energy supply (figure 5);
- applied locally with a manual action (e.g. push-button or lever) or with a standalone system detecting ambient temperature and reacting by itself when a threshold is reached (e.g. energetic composition used as thermal-fuse or mechanical fusible-link as sprinkler-glass-bulb – figure 6).

Figure 5 - Typhoon™ extinguishers control with electric signal

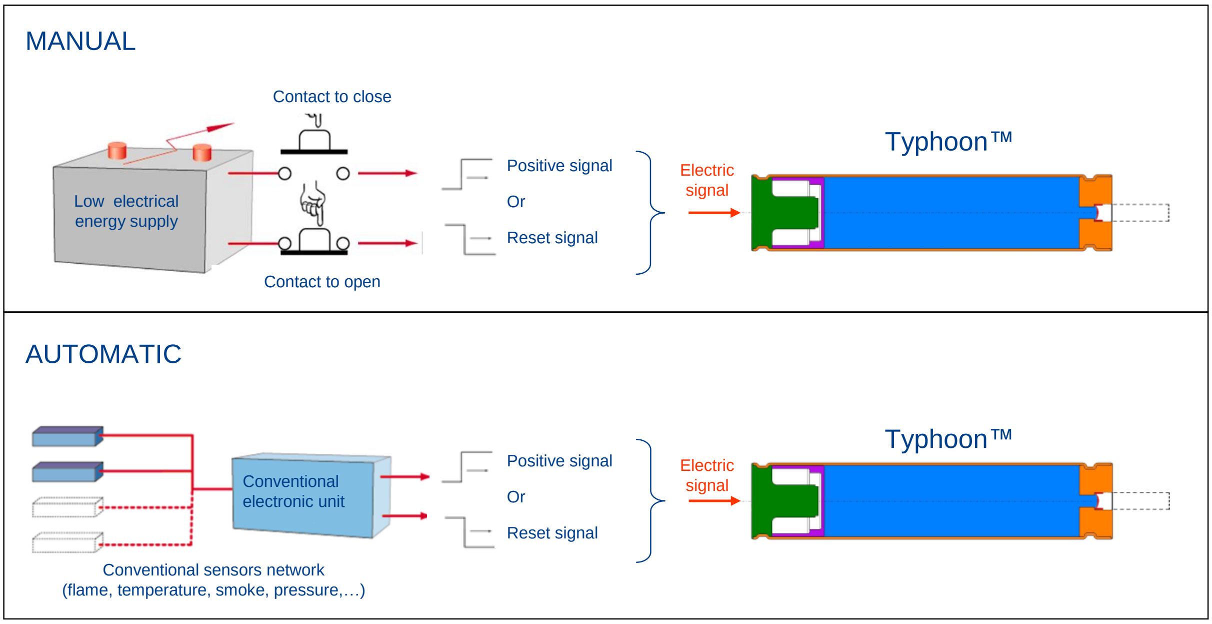
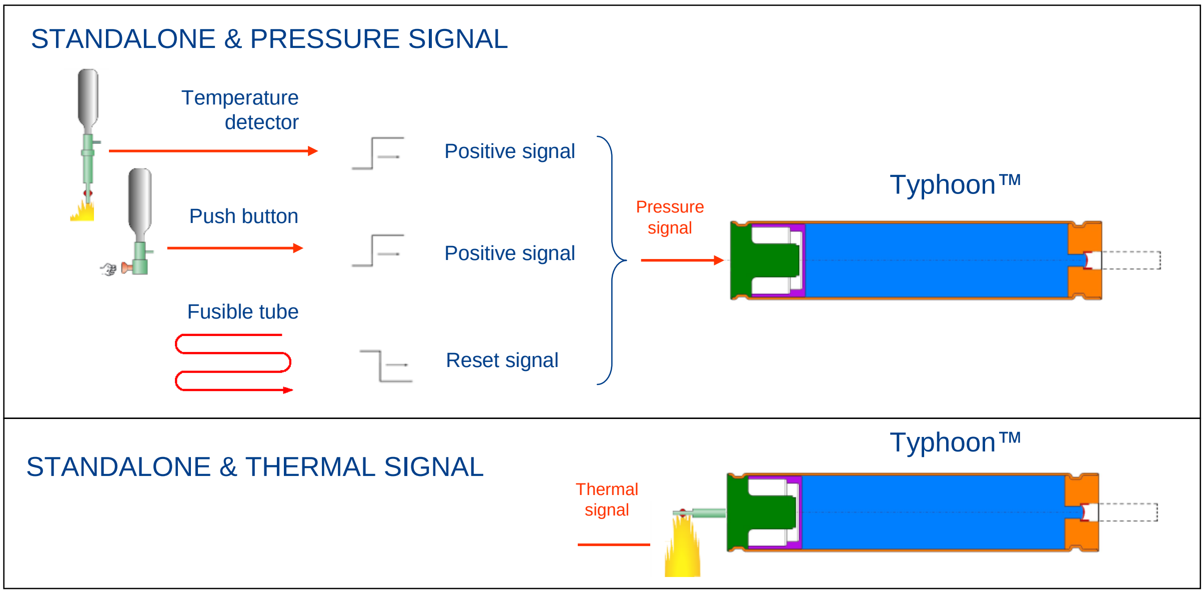


Figure 6 - Typhoon™ extinguishers control with pressure or thermal signal



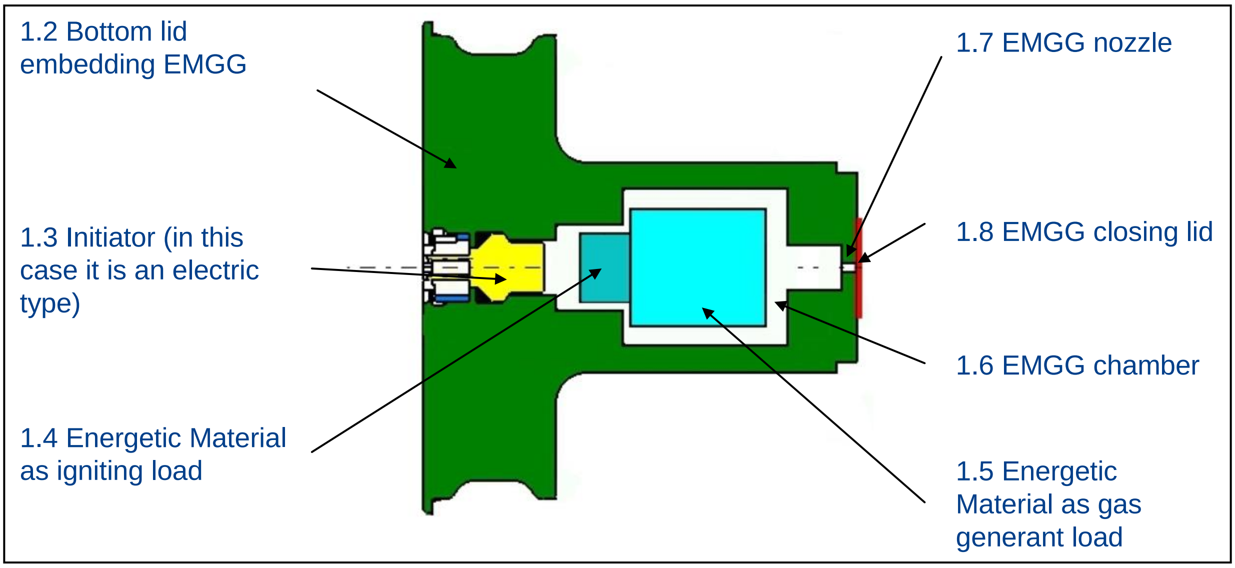
3.4 – Energetic Materials Gas Generators (EMGG)

3.4.1 - General description

They gather (see § 3.1):

1.2 Bottom lid embedding EMGG as housing;
1.3 Initiator (in this case it is an electric type);
1.4 Energetic Material as igniting load;
1.5 Energetic Material as gas generant load;
1.6 EMGG chamber;
1.7 EMGG nozzle;
1.8 EMGG closing lid.

Figure 7 – Energetic Materials Gas Generators (EMGG) sketch



When a triggering signal (Electrical and / or mechanical and / or thermal – Only few millijoules are needed) is received by the initiator (pos.1.3), the energy delivered is fast transformed (less than 1 ms for electrical initiators) into a gas pressure in the EMGG chamber (pos. 1.6).

Then, this gas pressure initiates energetic materials (pos.1.4 and 1.5) which in turn, amplifies the pressure inside the EMGG chamber (pos.1.6).

As soon as this pressure exceeds the breakage level of the EMGG closing lid (pos.1.8), the gas is released into the piston thrust room of Typhoon™ extinguishers (pos.4, figure 2) through the EMGG nozzle (pos.1.7). Then the delivered gas provides the gas driving pressure into the piston thrust room.

3.4.2 - Electrical initiator

The initiator receives the triggering signal and as a consequence ignites an energetic micro energetic load that it embeds.

The most common initiator is electrically triggered and named "Bridgewire". It consists of an electrical resistance (~2 ohms) placed between two electrical conductors (e.g. pins) surrounded by a very small quantity of an energetic composition.

This micro energetic load is activated when an appropriate electrical signal is applied between the two conductive pins. Due to the current, the temperature of the electrical resistance ("Bridgewire") of the initiator increases and reaches a level which ignites its micro energetic load.

Initiators usually used to trigger airbags have electrical characteristics that are potentially compatible with the ones delivered by standard automatic control units of fire fighting systems. Moreover, their proven robustness and reliability during lifetime added to their availability and their very low cost, make them really of interest for Typhoon™ extinguishers.

Figure 8 – Main features of initiators used to trigger airbags and potentially applicable to Typhoon™ extinguishers

➔ **Electrical resistance (T -40 °C to +105 ° C)**
- 2.0 Ω ± 0.3 Ω;

➔ **All fire currents monitored by Bruceton tests (-40 °C, 99.9999%, 95%)**
- 1.2A/2ms;
- 1.75A/0.5ms;

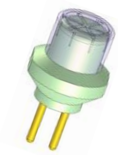
➔ **Non-fire current monitored by Bruceton tests (105 °C, 99.9999%, 95%)**
- 0.4A/10ms.

➔ **Insulation resistance**
- > 100MΩ;

➔ **Current control line current (1008 hrs / 85 °C)**
- 160mA;

➔ **Maximum current**
- 40A/2ms;

➔ **Qualifications international standards (for automotive applications)**
- AK-LV 16;
- USCAR 28.


Electrical initiator

3.4.3 - Energetic Materials

3.4.3.1 - Overview

For reasons of performance, reliability, availability and cost, the best solution for Typhoon™ extinguishers is to implement the last generation of energetic materials developed for airbags.

Energetic materials used in Typhoon™ consist of two complementary compositions named igniting load (pos.1.4, figure 7) and gas generant load (pos.1.5, figure 7).

- The igniting load is characterized by a medium burning rate and a medium level of energy for initiation. Its function is to produce hot gases which will ignite the gas generant load.

- The gas generant load is a slow burning energetic material and generates the driving gas pressure insuring the spraying of the extinguishing agent out of the Typhoon™ reservoir.

3.4.3.2 - Theoretical representation of the functioning

Three main parameters enable to tune gas flow and duration of EMGG:
- Geometries of the gas generant loads, and particularly the burning areas and the thicknesses;
- Chemical compositions and mass;
- EMGG nozzle area.

Normally, a set of equations is used to describe the relationships between the functioning parameters of EMGG, but only two equations describe the main that are the mass flow (m) and the combustion rate (r) which are linked together as follows:

$dm_1/dt = \rho\ A\ BR$ and $BR = aP^n$;

Where:
- dm_1/dt : the mass flow of the energetic material as gas generant load;
- A is the combustion area of the energetic material;
- ρ is the energetic material density;
- BR is the burning rate which follows the "Vieille's law" on a given pressure range;
- a is a coefficient;
- P is the EMGG chamber pressure;
- n is the pressure exponent.

There is also an equation linking the mass flow which leaves the EMGG chamber with the EMGG chamber pressure (P) and the cross section area of the nozzle (An):

$dm_2/dt = Cd\ P\ An$

Where :

- dm_2/dt : the mass flow which leaves the EMGG chamber through the nozzle;
- Cd : is the rate or flow coefficient as is related to thermodynamical results of the gas generant;
- An : Nozzle cross section area.

In steady state condition, $\rho\ A\ BR = Cd\ P\ An$

The ratio A / An between the gas generant burning area A and the EMGG nozzle area An is called “klemmung”. This ratio is one of the driving parameters of the internal pressure. The setting of this ratio allows to adapt the pressure in the EMGG chamber and therefore the gas flow toward the thrust room of the piston.

3.4.3.3 – Energetic materials used in airbags

Figure 9 - Gas generant loads used in airbags

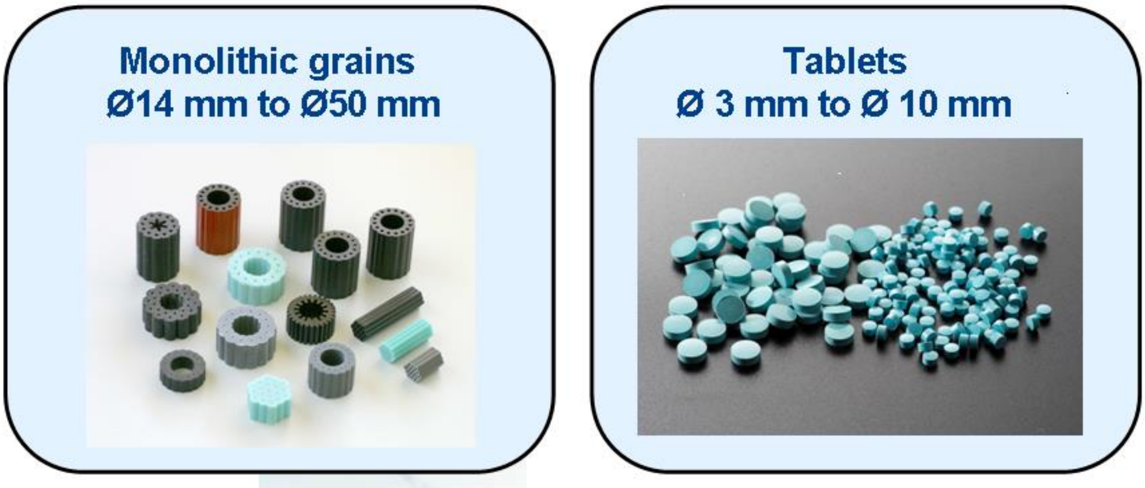
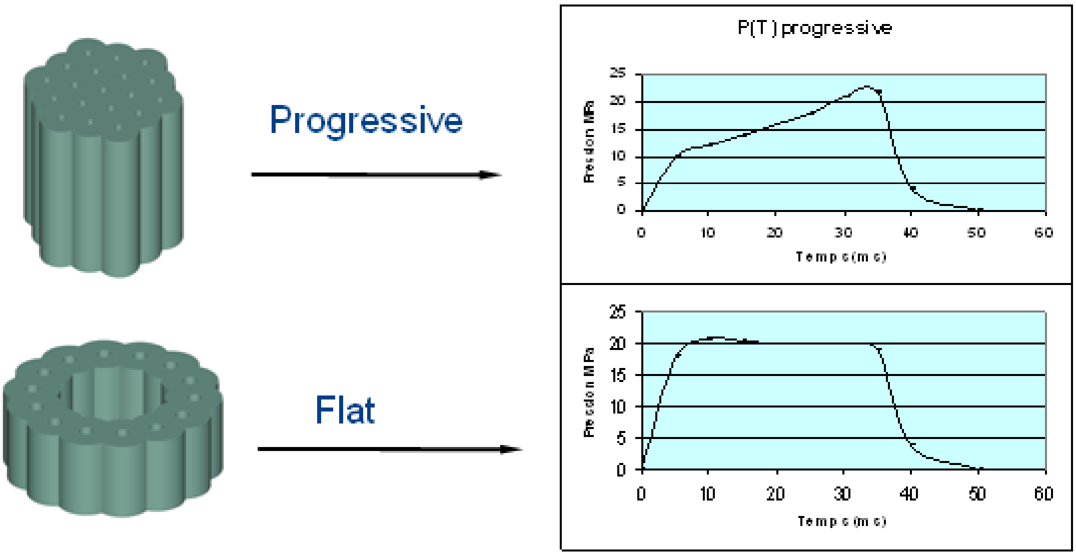


Figure 10 - Influence of the shape of gas generant loads used in airbags



3.4.3.4 – Energetic materials suitable to Typhoon™ extinguishers

Typhoon™ extinguishers needs energetic materials achieving as much as possible a constant pressure in the piston trust chamber despite an increasing of the volume, and also during a period of time ranging up to few ten seconds.

The latest compositions and geometries designed for airbags and potentially applicable to Typhoon™ extinguishers are described below.

These compositions are of two different kinds :

- Some of them exhibit behaviours that are usual “Energetic reaction”, namely transformations of solid materials in gas by combustions reactions. “Energetic reaction” compositions are used primarily for periods of gas generation of few seconds.

- Others display behaviours that are thermal-decompositions, namely transformations of solid materials in gas by “Self-pyrolysis”. “Self-pyrolysis” compositions are used for durations up to several tens of seconds.

a) “Energetic reaction” compositions

The first compositions (“Energetic reaction” compositions) preferably include:

- Guanidinium nitrate as a reducer;
- Basic copper nitrate as the oxidizing agent;
- Some additives can be added as:
    a. endothermic agents to lower temperature such as a metal hydroxide, a metal oxalate, or a metal carbonate;
    b. Metal oxides as burning rate modifier or slagging agent;
    c. Processing aids.

The purpose of these compositions is to produce the following performances:

- Combustion temperature: 1400 < burning temperature <2000 K;
- gas yield : > 28 moles / kg;
- Burning rate stable at low pressure (~40 to 80 bars)
- High density: > 1.5 g/cm³.

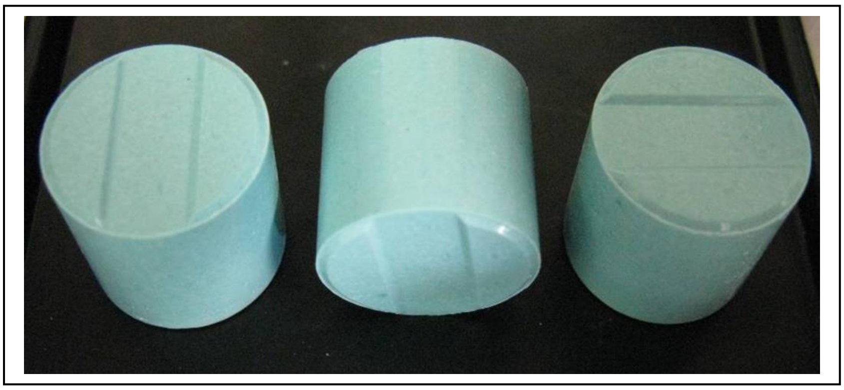
Moreover the compositions have to be easily achievable in large size of monolithic generant load namely dimensions of few centimeters.

Examples of generant loads are presented below as an indicative way.

These grains may also include (see § 3.4.3.3 and figure 10 above):

- complex shapes of radial faces to ease the gas flow in the inflator;
- holes to tune the burning area versus thickness during combustion.

Figure 11 - Blocks of 22 mm in diameter as examples (18 mm to 22 mm high)



b) - Compositions operating by “Self-pyrolysis”

“Gas generant with “Self-pyrolysis” compositions are constituted with:

- A family of high nitrogen content reducing agents as triazoles or tetrazoles. These reducing agents are usually 5AT or BTA salts;
- Associated reducing agents exhibiting an exothermic decomposition as for example AZDC or DCDA;
- Various additives ingredients under the ratio of 10%, for stabilizing the combustion rate; as slagging agent and processing aids.

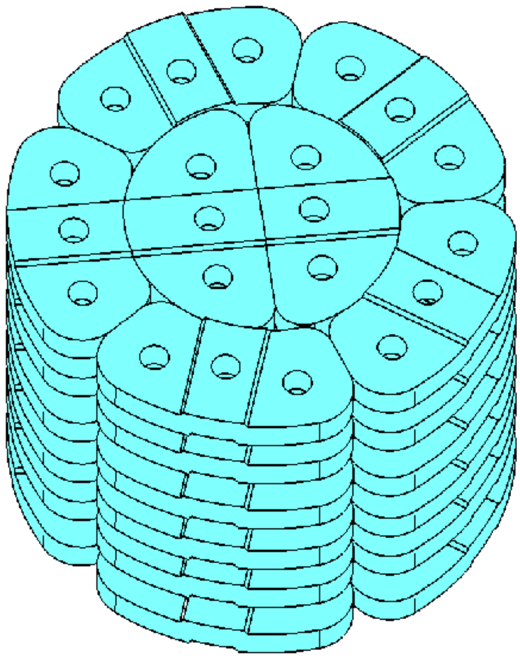
Theses compositions give the following performances:

- Combustion temperature: <1200 K;
- Effective gas output: > 20 mol / kg;
- Slow pyrolysis rate at moderated pressure: (~ 40 bar): 0.1 ~ 1 mm/s;
- Slow pyrolysis rate at atmospheric pressure: ~ 0.02 mm/s to ~ 0.2 mm/s;
- High density: > 1.5 g/cm^3.

These products decomposing themselves by “Self-pyrolysis”, are used because of their particular low burning rate. They are manufactured under the shape of pellets or wafers with relatively low thickness (e.g. from 2 to 6 mm) and enable nevertheless a gas flow during a long duration. Indeed a wafer of 4 mm thick is able to sustain gas flow during 20s with a self-pyrolysis rate around 0.1 mm/s.

These pellets can be arranged and stacked up (see example below).

Figure 12 - Arranged and stacked “Self-pyrolysis” compositions



4 - Spraying tests

Typhoon™ extinguishers have been tested in various configurations. Examples below present their potential uses.

The tested models are currently split on two ranges characterized with reservoir diameters and agent capacities.

- Ø80 mm for small volumes of liquid (1 liter);
- Ø160 mm for largest volumes of liquid (8 liters).

Figure 13a - Spraying test of Typhoon™ Ø80 mm - 1 l capacity with liquid agent

Figure 13b - Spraying test of Typhoon™ Ø80 mm - 1 l capacity with liquid agent

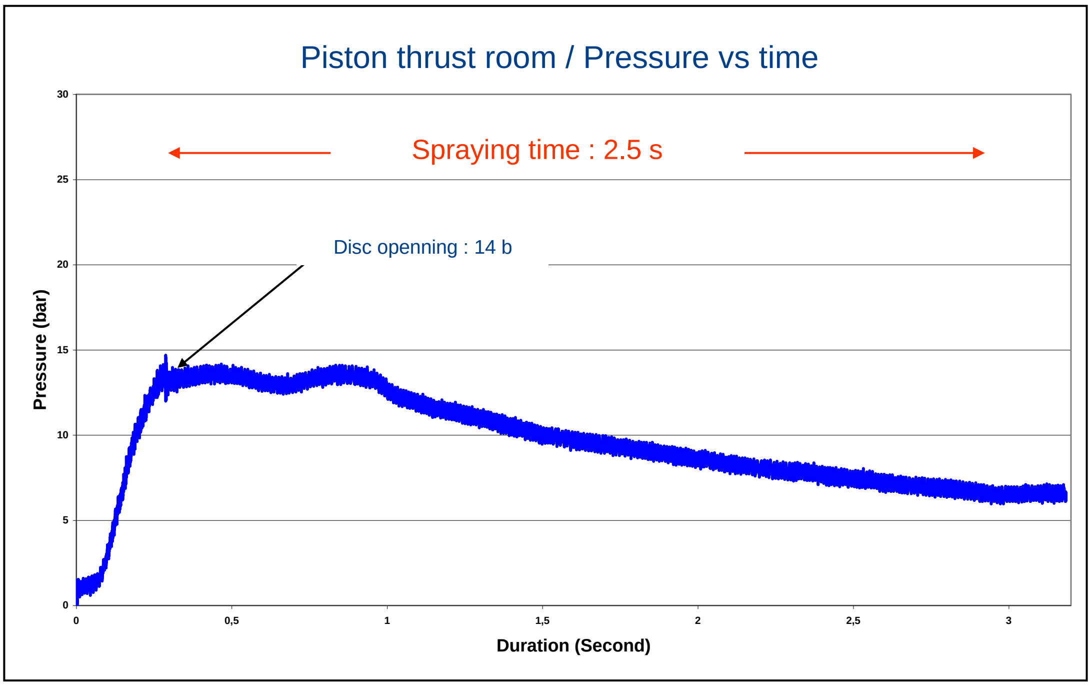


Figure 14 - Spraying test of Typhoon™ Ø160 mm - 8 l capacity with water

5 - Benefits and areas of use of Typhoon™ extinguishers

5.1. Benefits

Unlike conventional systems, Typhoon™ extinguishers are submitted to the driving gas pressure, just when they are activated and therefore do not need permanent pressure or additional gas cartridge that requires regular inspections during lifetime.

Typhoon ™ extinguishers provide the same benefits as traditional systems commonly noticed as:

- Respect for environment;
- Safety for people;
- Powerful cooling effect and reducing radiant heat;
- Very low water consumption;
- Lack of warning time before activation.

The key of the effectiveness of Typhoon™ extinguishers comes from their EMGG (Energetic Materials Gas Generators) which provide original features such as:

- Standalone energy for operation;
- High level of reliability with no regular inspections throughout lifetime;
- Easy adaptation of the driving gas pressure vs time through a large corridor (e.g. from few bars to few tens bars) depending on :
    - volumes and viscosities of extinguishing agents;
    - designs and shapes of outcome piping, geometries of nozzles....
- Easy adaptation of various and existing triggering devices:
    - electrical or mechanical and remote controlled;
    - locally connected and enabling a manual action or an autonomous detection of ambient temperature.

Typhoon ™ extinguishers will so pave the way of a new generation of extinguishers which is expected to enlarge the family of existing systems because of their original features carried out by their original design as follows:

- Permanent availability;
- No maintenance;
- Operational dependability;
- Response time suitable for targeted applications (from few second to few tens seconds);
- Adaptive triggering mode;
- Standalone energy;
- Confined space;
- No side effect.

5.2 : Areas of uses

Typhoon ™ extinguishers are designed to fight against fires in many applications.

They can be used alone with their own triggering systems and without any connection with external supplies or linked with existing fire fighting systems fix or mobile.

Their uses are so potentially very numerous:

- Buildings and business premises;
- Industrial processes;
- Trains carrying passengers or goods;
- Commercial vessels carrying passengers or goods, or pleasure boats;
- Cars, trucks, buses, boats, trams;
- Machinery for public works, forester vehicles, bus;
- Industrial and household fryers and chimneys;
- Clean rooms, TV and other similar spaces….