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Automotive Fuel Fed Fire-a Preventative Approach

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APPLICATION OF THE RESULTS of this work towards FMVSS 301 problem solving are not clear at this time, since those test procedures assume a combustible fuel.

CHARACTERIZATION OF LIQUID FUELED FIRES

The most obvious characteristic of fires in motor vehicles is that fire originates or is fed by liquid hydrocarbons (class B fire) that are highly evaporative. In other words:

a) The ease of priming with limited heat sources, such as sparks.

b) Immediate flame propagation to all combustibles in contact with air.

c) The possibility, with high probability (during an accident), of fuel spreading over large areas; subsequently igniting any combustibles contacted.

d) The fuel that burns is a light liquid of low specific weight (0.75 g/cc) having the flame on its upper surface.

Flames can be put out with an extinguishant characterized as suitable for the various types of combustible materials. The light weight of motor fuel prevents extinguishing with water, since the water is not miscible nor will it float on the fuel.

There are few liquids light enough to float on the fuel at the flame/fuel interface. We have no knowledge of any such liquid that can also function as an extinguishant.

For these reasons there have always been problems in extinguishing large quantities of motor fuel.

USE OF HALOGENATED HYDROCARBONS AS AN EXTINGUISHANT

A step forward has been made with the advent of "halogenated hydrocarbons". These products are defined as "chemical extinguishants", as opposed to previous types of extinguishants that put out fires by physical means, i.e. H_2O via "cooling" mechanism, CO_2 via "suffocation", and foams by "mechanical separation".

The chemical action is explained through the subtraction of the radicals required for the propagation of combustion (OH-H-CH_3) where these radicals are captured by the halogens present in the extinguishant. It is for this reason that such products sometimes are described as "anticatalytic". Several products of this type are being marketed and others under study throughout the world. The main products are:

ABSTRACT

The Autodelta group of Alfa Romeo has examined the contribution of fuel tanks to the risks of fuel fed automotive fires. Preliminary work has been done with Formula 1 and Prototype racing machines to determine the basic practicalities, weight penalties, effectiveness and cost/benefit. The motorsports area was chosen for first application, since there are statistics available indicating a need for investigation.

Accurate data on passenger vehicle crash induced fuel fed fires is scarce and of questionable value as to the cause/effect relations, since there is no standardized method of reporting that yields significant information either in Europe or the U.S.A.

B.T.M. = Freon 13B1
D.D.M. = Freon 12B2, etc.

These products have all been rated as to their abilities to extinguish fire, the most efficient being Freon 13B1 or B.T.M. (1)* However, these ratings have been determined by comparing the extinguishant's performance during standard tests, which may not reflect specific real world in-use requirements. As an example, Freon 13B1 is a gas and as a result difficult to direct precisely at the flame. With liquids this job is much easier, especially if the fuel and extinguishant can mix (as with Freon 114B2). We can see that the choice of extinguishing media is important and must reflect all aspects that could influence the results. In any event, the most effective and commonly used product is presently Freon 114B2 (D.T.E.).

THE DIFFICULTY OF PROMPT INTERVENTION

Some very effective automatic extinguishing systems using Freon 114B2 have been produced. These transport the 114B2 via plastic tubing and special ejector nozzles into pre selected critical areas of a vehicle. The action can be either manually valved or automatic by the melting of the plastic tubing. However, past years of experience have shown that these devices are not completely effective, as:

a) The system must frequently be checked since very small leaks can result in depressurization of the reservoir.

b) The driver must sense the fire and react immediately to actuate the system. In many cases he already has his hands full or may be in the ridedown phase of a crash.

c) For the device to actuate, there must already be a fire (whether it is sensed by melting tubes, infra-red detector, heat sensor or other means). At this point, the volume of extinguishing agent carried on board is usually insufficient to control the fire.

d) The nozzles of the system are located in predetermined zones where experience has shown that fires are most likely to begin in that vehicle. However, their value is limited when one considers that most fires result during accidents or from postcrash secondary damage.

e) Often the extinguishing system reservoir is small, very heavy and can become an injury producing projectile during a collision, or can be ejected from the vehicle during impact - rendering the system inoperative; and fire ensues.

To these points above, one must consider that in race cars with 200 l fuel tanks these systems will not extinguish such a large volume of fuel, as an adequate amount of extinguishing agent is impractical to be carried onboard the vehicle. While emergency fire equipment may be spaced every 100 meters trackside, the problem is still one of time required to reach the vehicle before the vehicle's fuel tank is ignited. This usually requires action within the first 20 seconds of the fires onset.

METHODS OF PREVENTING FIRE

The most effective method is to prevent ignition or, at least, extinguish the fire as it begins. The problem is basically that the fuel in the tank is combustible. Therefore, one must consider how to protect the fuel, or better, to render it incombustible. As its name implies, "fire fighting" methods treat the effect. Our efforts have been to treat the cause, through prevention of fire. The alternatives are, therefore, fuel protection or inerting. Both alternatives can be achieved using the chemicals described above.

The approach has been to develop a method of inerting by mixing the extinguishant with the fuel, in order to render it incombustible at the time of collision impact; preferably using a passive system design.

An example of this philosophy can be used with methanol (methyl alcohol). If to the fuel methanol was added an equal volume of water - at the time of impact - the mixture would be incombustible.

With gasoline as fuel, Freon 114B2 ("Fluobrene") becomes the inerting agent which mixes with the fuel. For each type of extinguishing agent, there is a mixture ratio beyond which ignition is no longer possible.

Following are some of our experiences with such a system:

(a) PREVENTATIVE INHIBITION (Inerting) - This is the most radical approach and provides for the containment of the fuel and extinguishant within the vehicle's fuel tank in an incombustible state. To do so, it requires that both fluids be physically separated during normal vehicle operation. This problem presents some difficulties, since the fuel is a mixture of hydrocarbons having different boiling points. Therefore, we are required to find an extinguishing agent having a boiling point outside the BP range of the fuel. Agents with a BP just below this range are available, but in such cases we must build tanks capable of withstanding high pressures. This leads to difficulties in refilling, excess on board vehicle weight, special

* Numbers in parentheses designate References at end of paper.

chassis construction and uneconomical maintenance costs.

Another method is to immobilize the fuel by gelling or solidification, at least enough to contain the size of the fire. Here, though, the problems are many to solve; since the fuel basically remains flammable. The problem of reaction time also remains to be solved.

(b) TANK STRUCTURE - This system is closer to feasibility and offers the best cost/benefit ratio at this time. It is presently used in race cars around the world, as well as aircraft; since it offers a reasonably light weight solution as compared to surrounding the tank with heavy protective vehicle structure.

1) F.I.A. Type Tank - The U.S. regulations for aircraft prescribe an elastomer bag contained within the fuel tank. This bag is then filled with a plastic foam of the open mesh type. The F.I.A. has derived its standards from this regulation, and the system is mandatory in most forms of auto racing (NASCAR, SCCA, as examples).

In studying this system, its limitations become evident. Among them are the disadvantages that the elastomer bags can (and do) become punctured or torn during crashes. The inner sponge avoids explosion due to its void filling capabilities, but it does not prevent fire. There are also needs for periodic inspection and pressure testing.

Other solutions looked at by the U.S. military, F.A.A. and racing safety engineers include the well known principle of nitrogen inerting, where N_2 is injected at low pressure into the fuel tank above the fuel level. While preventing internal explosion through the lack of a suitable air/fuel vapor mixture, the system is not suitable for race machines and highly impractical for application to production passenger vehicles.

Normally the proper air/fuel vapor mixture does not exist in automotive fuel tanks, instead the mixture is overich and above the ignition ratio. In cases (few) where the fuel is aerated, an explosive mixture could be achieved. However, in the case of tank leakage, the N_2 inerting system could be useful if it did not force fuel to leak out. In the case of ruptured lines or broken fittings (as could be possible in a FMVSS 301 test procedure), the nitrogen would only serve to increase the size of the fire. Since N2 inerting systems are normally manually actuated, the problem of driver's response must again be considered; as well as the fact that if used in production passenger vehicles the 301 test procedure assumes a passive design.

2) Cellular Tanks - In order to arrive at an optimized solution, we have studied, built and tested tank systems based upon the mixing of Freon fluids with the fuel during the impact phase (3).

To avoid mechanical sensing problems in mixing the fuel and Freon fluids we have studied a system of cellular tanks which are completely passive. This approach allows for automatic mixing of the fluids without any reliance on accessory devices.

The work also included the protection of the fuel system's hoses and pipes, if necessary. The cellular configuration was optimized through two generations of systems (Photo 1). One of the early difficulties encountered was to develop tests which represented real-world conditions.

3) Test Method Requirements:

a) Reproduce real-world conditions as determined from actual accidents.

b) Attempt to promote ignition in order to determine flame onset characteristics.

c) Determine which conditions were required to explode or ignite fuel in normal fuel tanks.

d) Develop a prototype tank that could be built quickly in large numbers, so that extensive dynamic tests could be performed. This tank evolved in a 10 liters capacity (Photos 5 and 6). The use of the 301 test procedure was determined too costly for the number of tests required, as well as not providing the basic information needed in characterizing flame onset.

The following test methods were used and have been recorded on film:

(i) Drop test, 20m onto rocky and concrete surfaces.
(ii) Puncture test, using weapon firing incendiary (tracer) projectiles.
(iii) Puncture test, lance heated bright red (1100°C).
(iv) Puncture test, using metallic ram connected to arc welder to create sparking.
(v) Explosion test, ignition via squib and 20g dynamite; results in photos 2,3, and 4.
(vi) Pendulum test, for crushing into spikes with and without arc welder.(*)
(vii) Impact test, via acceleration sled into varying surfaces. (*)

TEST RESULTS

Type	Tank	Results
i ii	Normal	Ignition % very low
	Autodelta	No ignition
iii	Normal	Ignition 100%
	Autodelta	No ignition

(*) Not in this paper, but included in the test film.

iv		Normal	Ignition 100%
		Autodelta	No ignition
v		Normal	Ignition 100%
		Autodelta	No ignition
vi	vii	Normal	100% leakage and/or ignition
		Autodelta	No leakage or ignition

More than 100 tests have been made using both normal and Autodelta tanks, and in all cases the Autodelta system has shown positive test results. Tests also included standard production tanks and tanks of the Alfa Romeo "GTAm" Group II and "333" prototype class racecars.

Freons used were Fluobrene^R and Fluobrene B30^R (DTE) in 90% of the tests. The remaining tests were done with other fluids included in ongoing study programs.

First indications from the test program:
- The cellular tank construction of dual wall configuration has proven to be mechanically stronger upon impact than the conventional F.I.A. tank having twice normal bag thickness. It appears that the plastic foam used in the second generation tanks when filled with Fluobrene^R absorbs some energy of the impact on the external wall and redistributes it hydraulically to the internal wall.
These two walls (1.0 mm thick) are separated by 8 mm of Fluobrene^R, and their impact equivalence is about that of 3.8 mm mild steel.
- Mechanical security is afforded by the dual wall construction which acts as a shield between a penetrating object and the fuel.
- Independent from these effects which may increase the protection level, the basic principle (inerting by mixing) is a valid concept. The chemical response in mixing is demonstrated clearly in test films where some small flames were seen to extinguish immediately during the lance-arc spark tests on metal tanks.

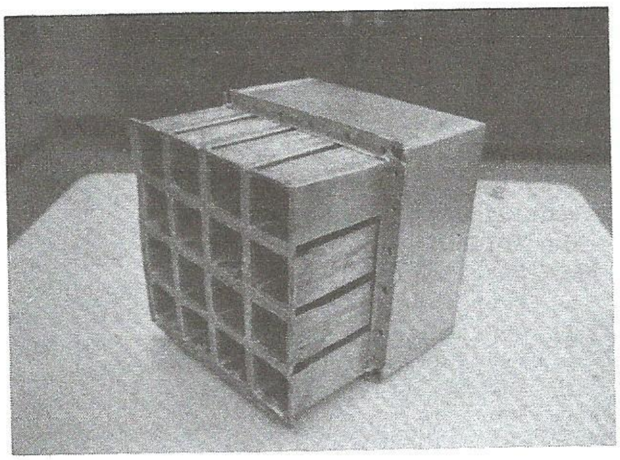

Fig. 1 - First generation test tank construction

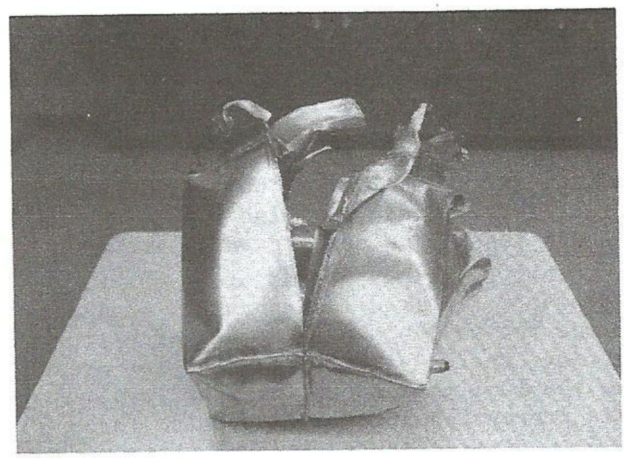

Fig. 2 - First generation test tank following detonation by electric squib and 20 g dynamite

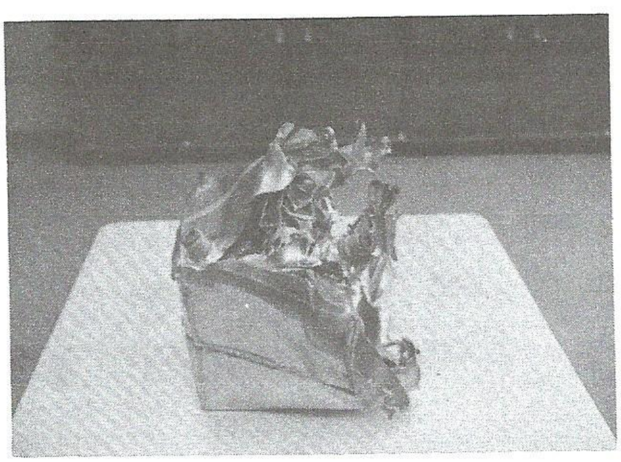

Fig. 3 - First generation test tank, post explosion, no combustion

Fig. 4 - First generation, post explosion, no combustion

- During experimentation, studies were made to determine the volume of extinguishing or inerting agent required for a given fuel cell configuration, since many cell shapes were investigated. Fluobrene B30 has been determined to be most effective in the ratio of 1:3 fuel. However, this ratio is influenced by some factors:

(a) The parameters of pressure and ambient temperature alter the evaporative fractions in the fuel (and in the Freon if allowed to evaporate). This can create a slight disparity in the ratio.

(b) The characteristics of the container where the bench tests are performed, as regards the free surface area of the liquid and the container wall heights.

In field tests with the Autodelta tank we found that the volume of Fluobrene 30R required was actually less than the volume needed in lab tests where the basic ratio was determined. We feel that this difference was due to these reasons:

1) If we place two fluids in a container, adjacent to each other, separated by a wall - upon removing the wall we instantly have two volumes equal or a volumetric ratio of 50/50, which is more than sufficient to prevent ignition. This is true in the case also when the cell wall between the agent and the fuel is broken - during the instant before the fluids mix.

2) Resulting from the construction design, damage to an inner fuel cell remains temporarily localized and is mixed with the extinguishant in an extremely high ratio, well above the minimum ratio required in lab tests on the bench.

Fig. 5 - Second generation test tank, side view

3) To reach the ratio necessary to prevent ignition when the tank is ruptured, an excess of Freon (compared to the minimum needed for ignition in lab) is required at that point, since a completely homogeneous mixture requires several seconds.

4) The Freon 114B2 has a tendency to evaporate more rapidly than the fuel when in the presence of heat, such as during explosive tests. Also, since it is heavier, it tends to stay on the ground below any spilled fuel. This is unfavorable to its normal function. However, following an accident where there is fuel spillage, the mixing will continue on the ground before evaporation has occurred. In higher ambient tempratures it is possible that the Freon evaporates leaving only combustible fuel. But the risk here is minor, since the ratio is seldom reduced to the ignition point in less than one minute. This is more than sufficient to permit a crash crew to be on the scene.

One should consider also that following impact vehicles usually come to stop some distance from the point of impact. If the tank was ruptured, the fuel would then have been spread over a longer distance giving a lower surface/volume ratio, and the vehicle's tank most probably empty (a fact not considered in the 301 procedure). However, experience has not shown this to be any problem other than theoretical, since this fuel spillage can buy more margin as the flame onset is more difficult and requires more time, with any resulting flame being more readily extinguished. Since the majority of fires occur as a result of impact, the multicellular concept in itself affords a higher level of protection, and at the same time avoids the use of mixing subsystems and inertial sensors.

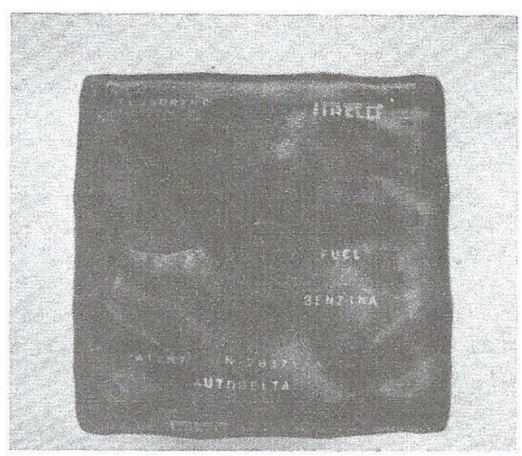

Fig. 6 - Second generation test tank, top view

SUMMARY

1. Over 50 tests with the cellular Autodelta tank have all been successful.

2. The tank's design allows for construction in varying media: steel, aluminum, dual bag of various materials, metal/plastic combination, laminates. While preliminary work was done with aluminum for ease in fabricating prototypes, the second generation tanks through recent technology with synthetics are made in dual bag versions (Photo 7).

3. Fuel spillage on the ground presents, under worst conditions (evaporation of Freon), less violent and more readily controlled fire.

4. First generation system weight was unacceptable. The system required a 66 kg increase for every 100 liters of fuel when using Freon 114B2 or B30 (2). However, this disadvantage is minimized in the second generation system utilizing a more recent Fluobrene[R] of 1.2 sp.gr. Combined with a flexible synthetic tank construction, this allows for a projection of weight disadavantage of only 24 kg when comparing with the present F.I.A. (FT3) 60 liters tanks in use.

5. Field tests give high confidence with the ratio of 25 kg to 100 liters of fuel.

6. The application of such a system by limited production manufactuers needs consideration by government officials as an acceptable alternative to those present compliance demonstrations involving costly crash tests.

7. Future costs could be lower as a result of experience gained during future testing, new construction technologies, and eventual higher quality production demands.

REFERENCES

1. Dr. Rainaldi, "Advance Report on Halon", Montedison S.p.A., presented at the 1969 N.F.P.A. Annual Meeting.

2. "Technical Information Report 1550", Industrial Products Division, Montedison S.p.A.

3. Patent 28374-A/70 (Italy)

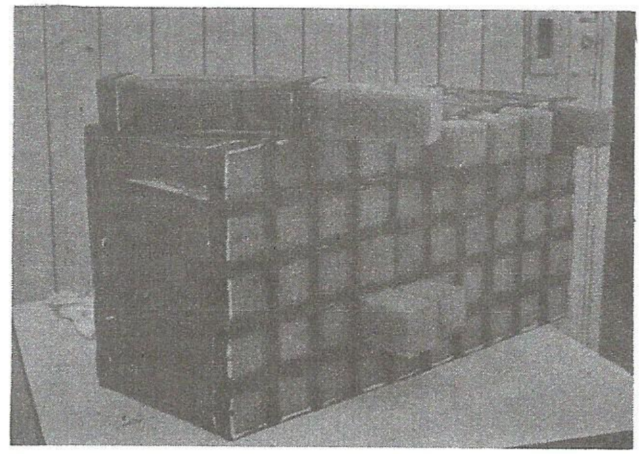

Fig. 7 - Second generation race car tank showing cellular matrix build up and antislosh foam

APPENDIX 1 - Continuing Development of the Second Generation Autodelta Safety Tank of High Strength Rubber F.T.3.

Specifications:

- External carcass made of special rubber complying with F.T.3. (F.I.A.) specifications.
- Internally filled with foam.

Comparison between a "normal" fuel cell that also meets the F.I.A. (F.T.3) specifications		
	"Normal" Fuel Cell	Autodelta Safety Tank According to F.T.3 Specs (Safety Type 1)
Fuel capacity, liters	60	60
Extinguishing agent capacity	--	21
Tank weight	11 kg	15 kg
Fuel weight	45 kg	45 kg
Fluobrene[R] weight	--	20 kg
Total weight	56 kg	80 kg

It is necessary to take note that as fuel is consumed the volume of extinguishing fluid remains constant, providing higher protection levels.

Technical Details:

- Extinghishant/Fuel Ratio Using "New Fluobrene" - DIBROMETHETETRA-FLUORETHANE Extinguishant (C2Br2 F4) (Halon 2402) (114B2) (D.T.E.):

  Minimum new Fluobrene/gasoline ratio extablished by the Montedison laboratory in order to prevent ignition follows:

  - in volume 26/100
  - in weight 41/100 — new Fluobrene (**) = 1.2 gr/cc; Gasoline = 0.75 gr/cc

  These values could be increased as a cushion in practice about 30% when considering the possible errors in mixing (depending upon the dimension of the cells and the incident modalities) and on the level of protection desired as described below.

- Protection Requirements - Three modes of anti-fire protection must be provided. The increase of protection in conforming with these three requirements has been attained by progressively increasing the quantity of extinguishant Fluobrene.

(**) Previous sp.gr. of Fluobrene was 2.1 (2)

Specifically:

Mode 1	- Protection during impact of the tank. Ratios even lower than those theoretically stated on the previous page will suffice: New Fluobrene[R] in volume 25/100 in weight 40/100
Mode 2	- Protection during the period of leakage of the Fluobrene into the gasoline cells. Ratios of Fluobrene sufficient, approximately: New Fluobrene[R] in volume 35/100 in weight 56/100
Mode 3	- Protection during the time the Fluobrene/gasoline mixture is spilled on the ground as a result of the two events above, with the possible danger of eventual ignition. Here the ratio of Fluobrene increases, for instance to: New Fluobrene[R] in volume 55/100 in weight 88/100

APPENDIX 2 - Procedures Used in Back to Back Tests of Autodelta U.S. Conventional Tanks and FIA Type F.T.3 "Fuel Cells":

Field Tests (Autodelta):

- Tanks full of gasoline, ignition via blasting cap.
- Tanks half full of gasoline, ignition via cap.
- Daytime.
- Night.

Impact:

- Pendulum.
- Pendulum arc welder spark generator.
- Dropped wedge.
- Tank launched against spiked pole.

Puncture:

- Lance, cold.
- Lance, red hot.
- Lance + arc welder spark generator.

Open Flame:

- Tanks impacted by dropped wedge while surrounded by open propane flame burners.

Lab Tests (Montedison):

- Fluobrene[R] and gasoline ratio optimization.
- Toxicity.
- Materials compatability.
- Dielectric performance.
- Storage methods.
- Handling procedures.
- Deterioration and stability.
- Extinction methods.
- Pyrolisis product's analysis.

Track Tests:

- 8 vehicles were used in 6 tests at the Monza race track. The vehicles were 4 open wheel "Formula Monza" race cars, 3 "Formula 3" race cars and 1 passenger car. These tests were to determine effectiveness of Fluobrene[R] rather than tank design.