TECHNICAL PRESENTATION:

"A Fuel Tank Which Prevents Fire and Explosion in Vehicles"

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Within the scope of automotive safety research, the Autodelta group of Alfa Romeo has examined the risk of fire as related to fuel tanks. Below are some of the results found:

Characteristics of liquid fueled fires.

The most obvious characteristic of vehicular fires, especially race cars, is that fire originates or is fed by liquid hydrocarbons (class B fire) which are very evaporative.

In other words:

A) The ease of priming with low heat sources such as sparks.

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

C) The possibility, with high probability (such as during an accident) of fuel spreading over large areas and igniting combustibles in contact.

D) The fuel that burns is a light liquid of low specific weight (0.75 g/cm^3) having the flame on its upper surface.

Flames can be put out with an extinguisher characterized as suitable for the type of combustible material. The light weight of the fuel prevents extinguishing with water, since the water is not miscible and will not float on the fuel.

There are a few liquids light enough to float on the top of 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 fuel.

<u>Use of halogenated hydrocarbons as an extinguishant.</u>

A large forward step has been made with the advent of "hydrocarbon halogens." These products are defined as "chemical extinguishants" as opposed to previous types of extinguishants which 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) which are captured by the halogens present in the extinguishant. It is for this, that such products are described as "anticatalytic." Several products of this type have been sold and others are under study throughout the world. The main products are:

B.T.M. = Freon 13B1

D.D.M. = Freon 12B2

D.T.E. = Freon 114B2

= Fluobrene

= Fluobrene B30

These products have all been rated as to their extinguishing ability. The most efficient being Freon 13B1 or B.T.M. However, their ratings have been determined by comparing the extinguishant's performance during standard tests, which may not reflect real world in-use requirements; i.e., 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 must reflect all aspects that may influence the results. In any event, the most effective and commonly used product is presently Freon 114B2 (D.T.E.).

<u>The difficulty of prompt intervention</u>.

U.R.E.P. of Varese has built some very effective automatic extinguishing systems using Freon 114B2. These transport the 114B2 via plastic tubing and special ejector nozzles into critical areas of a vehicle. The action can be either manual or automatic through melting of the plastic tubing. However, past years of experience have shown that these devices are not fully effective, the reason being:

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

B) The driver must sense the fire (difficult in race cars) and react immediately to activate 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 activate, there must already be a fire (whether it is sensed by melting tubes, infra-red detector, heat sensor, etc.). At this point, the volume of extinguishing agent carried on board is 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. However, their value is limited when one considers that most fires result from or during accidents.

E) The extinguishing system, which is small and very heavy, often becomes an injury-producing projectile during a collision, or merely becomes ejected from the vehicle during impact -- rendering the system inoperative and fire ensues.

To these points above, one must consider that in Formula 1 cars with 200 L. fuel tanks that such systems can never extinguish this large volume of fuel since the amount of extinguishing agent necessary is not possible to be carried on board the vehicle. Emergency fire equipment may be spaced 100 meters trackside, however close. The problem is one of time required to reach the vehicle before the vehicle's fuel tank is ignited. This usually requires action in the first 20 seconds of the fire's onset.

Methods of preventing fire.

The most effective method is to prevent fire or at least extinguish it when 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. Traditional methods of fire fighting treat the effect. Our efforts have been to treat the cause through prevention of fire. The alternatives are therefore fuel protection or fuel inerting. Both alternatives can be realized with the chemicals described above.

Our 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.

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 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 b.p. range of the fuel. Agents with b.p. 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 chassis construction, etc.

Another approach into immobilization of the fuel is by jelling 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 the time. It is presently used in race cars around the world as well as aircraft.

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 fact 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.

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 explosion through the lack of a suitable air/fuel vapor mixture, the system is not suitable for race vehicles.

Normally the proper air/fuel vapor mixture does not exist in automotive fuel tanks, instead the mixture is over-rich 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 where the fuel did not leak out. In the case of spillage or tank rupture on impact, the fuel is still combustible. Since N_2 inerting systems are normally manually actuated, the problem of driver response must again be considered.

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.

To avoid mechanical and sensing problems in mixing the fuel's 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.

Our ideas also lent themselves to the protection of the fuel system hoses and pipes -- if ever needed. Following several years of research we have optimized the cellular configuration through two generations of systems. One of the difficulties encountered during the early research was to develop tests which represented real world conditions.

3) Test Methods

Requirements were:

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

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

c) Develop a tank which could be built quickly in large numbers so that extensive tests could be performed. This tank evolved in a 10 L. capacity.

The following test methods were used:

i) Drop test, 20 m. onto rocky and cement surfaces.

ii) Puncture test, using weapon firing incendiary (tracer) projectiles.

iii) Puncture test, using lance heated bright red (1000 - 1100^{o} C.)

iv) Puncture test, using metallic ram connected to arc welder to create sparking.

v) Explosion test, ignition via squib and 20 gm. dynamite.

vi) Pendulum test, for crushing into spikes with and without arc welder (*).

vii) Impact test, via acceleration slide into varying surfaces (*).

* Not in this paper, but included in test films.

Test Results:

Type	Tank	Results
i , ii	Normal	Ignition % very low
	Autodelta	No ignition
iii	Normal	Ignition 100%
	Autodelta	No ignition
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. In all cases, the Autodelta system has shown positive test results. Tests also included standard (normal) tanks and tanks of race car types "GTAm" and "333."

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

First indication from the test program:

The cellular tank construction of dual well 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 filled with Fluobrene absorbs the energy of the impact on the external wall and redistributes it hydraulically to the internal wall. The two walls (1.0 mm thick) are separated by 8 mm of foam filled with Fluobrene and their impact equivalence is 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 welder spark tests.

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 25% to 75% fuel. However, this ratio is influenced by these 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 30 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 effects:

* 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 where the cell wall between the agent and the fuel is broken, during the instant before the fluids mix.

* Resulting from the construction design, damage to an inner fuel cell remains temporarily isolated and the fuel is mixed

with the agent in an extremely high ratio, well above the minimum ratio required in laboratory tests.

* To achieve 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 homogenous mixture requires several seconds.

* 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. Therefore, following an accident where the fuel leaks onto the ground, before mixing has occurred completely, the mixing will continue on the ground. In higher ambient temperatures it is possible that the Freon evaporates, leaving only combustible fuel. The risk here is minor since the ratio is very seldom reduced to the ignition point in less than one minute. This is more than sufficient time to permit a crash-crew to be on the scene. One should consider also that vehicles when impacted, usually come to rest some distance from the point of impact. If the tank were ruptured, the fuel would have been spread over a longer distance giving a lower surface/volume ratio, and the vehicle tank probably empty. However, experience has not shown this to be any problem other than theoretical, since this fuel spillage can buy more time for the rescue crew to reach the driver with some assurance of safety heretofore unavailable.

Since the majority of fires occur as a result of impact, the multi-cellular concept in itself affords a higher level of protection.

SUMMARY

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

2. The Tank design allows for construction in varying media: steel, aluminum, dual bag of various materials, metal/plastic combinations, etc. While preliminary work was done with aluminum for ease in fabricating prototypes, the second generation tanks through recent technology, are made in dual bag versions.

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

4. System weight is too heavy. The system requires a 66 kg. increase for every 100 L. of fuel when using Freon 114B2 or B30. (sp.gr. 2.0). However, this disadvantage is hoped to be minimized in the near future when studies utilize a more recent Fluobrene of 1.2 sp.gr. combined with synthetic tank construction. This allows for a projection of a weight disadvantage of only 24 kg. when comparing with the present FIA (F.T. 3) 60 L. tanks in use.

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

6. Future costs can be lower as a result of experience gained during testing, new construction technologies, and eventual higher quantity production demands.