

HYDROGEN TRASPORT SAFETY: CASE OF COMPRESSED GASEOUS TUBE TRAILER

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ABSTRACT

The following paper describes researches to evaluate the behavior under various accidental conditions of systems of transport compressed hydrogen. Particularly have been considered gaseous tube trailer and the packages cylinders employed for the road transport which have an internal gas pressures up to 200 barg.

Further to a verification of the actual safety conditions, this analysis intends to propose a theme that in the next future, if confirmed projects around the employment of hydrogen as possible source energetic alternative, could become quite important. The general increase of the consumptions of hydrogen and the consequently probable increase of the transports of gaseous hydrogen in pressure they will make the problem of the safety of the gaseous tube trailer particularly important.

Gaseous tube trailers will also use as components of plant. for versatility, easy availability' and inexpensiveness.

The first part of the memory is related to the analysis of the accidents happened in the last year in Italy with compressed hydrogen transports and particularly an accurate study has been made on the behavior of a gaseous tube trailer involved in fire following a motorway accident in March 2003.

In the central part of the job has been done a safety analysis of the described events trying to make to also emerge the most critical elements towards the activities developed by the teams of help intervened.

Finally in the last part you are been listed, on the base of the picked data, a series of proposals and indications of the possible structural and procedural changes that could be suggested with the purpose to guarantee more elevated safety levels.

1.0 ANALYSIS OF THREE CASES OF ACCIDENT INVOLVED HYDROGEN GASEOUS TUBE TRAILER AND STORAGE.

Three traffic accidental have been analyzed in this part of the paper. Also interventions of firebrigades rescue teams has been described. Accidents happened in Italy during the year 2003 and 2004 and involved hydrogen gaseous tube trailer.

1.1 Motorway accident of Cessalto (Ve) in the March 2003.

The motorway accident happened in march 2003 and involved a large quantity of vehicles and a gaseous tube trailer which transported gas hydrogen in pressure. The accident has happened along the A4 motorway between the tollgates of Cessalto and Noventa near service area of "Calstorta." The chronology of the accident describe better the complexity of the intervention and the difficulties and risks of rescue teams:

- 1. Times 07.07:** Alarm for road accident arrives in the operational room of the Medical Rescue Team 118 SUEM of Mestre (Ve), in A4 motorway direction from Venice to Trieste

at the Km 32 with the involvement of persons. Operational room sends on the place ambulances of the hospital of S.Donà di Piave.

2. **Times 07.12:** Operational room of medical emergency informs the operational room of the 115 Firebrigades of Mestre (Ve), that a medical rescue team of S. Donà di Piave hospital was going in A4 motorway at Km 32 for road accident (accident of various vehicle), and requires the intervention of Firebrigade to help people in the car involved in accident.
3. **Times 07.20:** Chemical firebrigade Team (HAZMAT Team) verify possible involvements of hazardous materials in accident.
4. **Times 07.25:** Medical rescue team communicates to Firebrigade operational room that many roads accidents are verified in the motorway direction from Venice to Trieste in correspondence of the area of service "Calstorta."
5. **Times 07.34:** A truck driver involved in the accident in the motorway, communicates, that he was in the sure zone, but he noticed a big fire that involved a gaseous tube trailer and also high tension line cables. Under the gaseous tube trailer there are other vehicles.
6. **Times 08.15:** Chemical firebrigade team arrives on the accident place.

To the arrival on the place of the HAZMAT team the situation was the following: gaseous tube trailer was involved in dense smoke, some motorcars were under the back part of the gaseous tube trailer and there was still fire in action, with notable development of flames.

Treviso Firebrigade (first intervened on the place of the accident) decided to cooling and turning off gaseous tube trailer with operating positioned near guard-rail in protected position. The level of risk has been rather elevated for rescue team. There was an explosion risks for cylinder involved in fire. Pressure inside cylinder was unknown and there wasn't possibility to evaluate from safety position. Also there wasn't possibility to evaluate hydrogen flames because they were invisible. Chemical firebrigade Team used a thermo camera to evaluate:

1. jet-fire of hydrogen from cylinder,
2. temperatures and possible deformations of the containers.

From this control they found that in proximity of the valves of the lowest containers there was flame, and there was an hydrogen release which was burning. From this control it was noticed in the right side, in correspondence of tractor's wheels, that one of cylinder was deformed.

In order to reduce explosion risk Chemical firebrigade Team decide to cooling deformation point with maximum priority.

Safety manager of gaseous tube trailer inform firebrigade team that hydrogen pressure inside cylinder was 15 barg.

Through other verifications effected through the employment of the thermo camera it was noticed that a container in the point of the deformation had a long longitudinal crack about 10 centimeters long.

The present jet-fire in correspondence of the valves of the container has continually been verified through use of thermo camera in order to verify the variation of the length of the dart in base to the diminution of the pressure, to the moment in which the jet-fire was reduced of potentiality and it was found next to the body of valve you/he/she is decided to proceed to the definitive turning off. The operation of turning off has been effected with the aid of two throws of water crossed and through use of thermo camera has been verify the definitive extinction of the flame.

Following the accident it has been verified that one of the cylinder had a complete breakup in correspondence of the anterior section (figure. 2).



Figure 1° Hydrogen tube trailer after the accident.



Figure 2° Hydrogen Cylinder breakup for combined effect of pressure inside and temperature.

1.2 Traffic accident near SERRAVALLE PO (Mantua) Of February 2004

Accident has involved a gaseous tube trailer that has gone out street in a zone of fields and to the arrival rescue teams it resulted abandoned on a side. Following the crash with the ground involved the back part of the tube trailer (high pressure collector) occurred the breakup of the auction of manoeuvre of a valve of close/open of one of the cylinder. The interested cylinder was positioned in the low band in central position. The breakup of the valve causes a consistent loss of hydrogen. All cylinders were loaded to a pressure of 200 bars.

Firefighters team provided to intercept the loss acting on the stem of the valve and they put in safety the transport after having verified the closing of all the other valves of the cylinders. Through infrared camera the temperature of the containers has been verified and it has been

excluded the possibility of overheatings following the accident. The body of the cylinders resulted entire without other losses.

Chemical Firebrigade Team provided to recovery gaseous tube trailer, even if still completely loaded, in fact there weren't necessary safety conditions to remove gas from damaged cylinder on site.

Chemical Firebrigade Team decided to lift the gaseous tube trailer by some belts which are fixed near of anchorage point of cylinder to trailer. There weren't any project point to lift the trailer.

The gaseous tube trailer has been therefore transported near the producer that has provided to the restoration of the valve, to the emptying and the consequent reclamation of the containers.

Following there are some photos that illustrate the accident and the phases of lifting of the tube trailer.

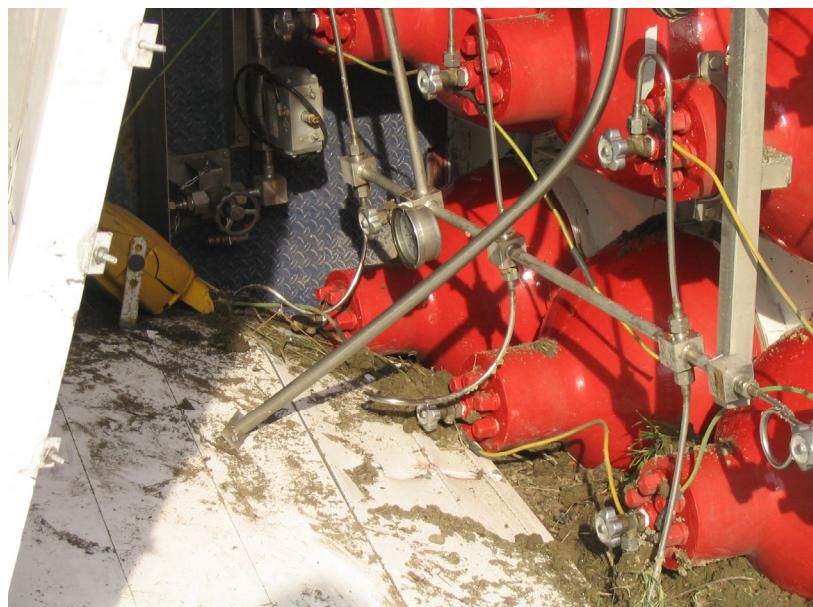


Figure 3° Breakup valves of head of the cylinders of the wagon



Fig. 4 operations of harness and lifting of the .

1.3 ACCIDENTAL TRAFIC INVOLVED PACKAGE CYLINDERS NEAR PISTOIA

This accident has happened in date 23/12/03 on the SS66 in the place Borghetto and it has involved a trailer that transported some packages cylinders containing hydrogen. Cylinder package fallen on the road center when fixing straps were broken.

Firebrigade team had verified that from truck were fallen on the road center 15 cylinders of 50 liters inside volumes.

The breakup of the collector of the package cylinders and fact that some valves on the cylinders were open or damaged by the fall produced a gas release that has given origin to an accumulation in air.

Some moments later probably for due effect to a primer caused from a spark or from other extremely warm part (component of motor) a deflagration has happened with consequent development of wave of bump that caused consistent damages to the vehicle that followed the truck and to the glass door of house in the proximities.

Rescue team intervention.

Firebrigade provided to settle in position more possible protected and contemporarily they began the operations of cooling of the cylinders with throws of nebulized water. Contemporarily firefighters team provided the evacuation of two person that were working near there. Road has been closed to the traffic.

Thermo camera has allowed to evaluate the temperature of the cylinders and therefore to drive the operations of cooling to avoid local increases of temperature.

Verified the absence of other losses and consequently the lack of other immediate dangers has been definite to still proceed to the emptying of the cylinders having care to confine the release with throws of nebulized water.



Figure 5° Packages cylinders fallen on the center road. Metallic structures of containment has collapsed.

2.0 TECHNICAL ANALYSIS OF THE ACCIDENTS

Following analysis has been conducted to evidence elements which define conditions of risk during the accident and particularly for population and of the activities in proximity of the place of the accident. Analysis also underline risks for rescue teams during intervention.

2.1 Motorway accident Of CESSALTO March 2003

Following factors represent direct or indirect source of risk which emerge from the analysis of previous accident.

1. Lack of equipments to evaluate pressure inside the cylinder gaseous tube trailer.

The problem of the evaluation pressure inside the cylinders has a fundamental importance for the evaluation of the risk and therefore for the formulation of all the necessary operations for the mass in safety of the scenery. With the actual gaseous tube trailer is not possible under accidental conditions to succeed to make an evaluation of the inside pressure and consequently of the degree of filling of the reservoirs.

Such problem is due to the fact that the manometers of measure installed on the heads of the cylinders constitute the most fragile elements of the system and therefore further to be completely invisible to a certain distance they are also the first equipments that suffer breakups. Besides such tools are installed in points that normally during the trip they are covered by the back paintings of the mean.

2. Lack of protection in the back part of the tube trailer.

In the back part of a gaseous tube trailer are present all the valves of load/unload, pipelines of link, final valves of the collector - generally 2 following valves - and a valve with pneumatic control for command to distance and all the manometers for the control of the degree of filling of the cylinders,

Gaseous tube trailer doesn't have in the back part a structure able to preserve these equipments during an accidental event (for instance road accident with other vehicles). There is only a protection in steel plate in order to prevent accesses in the zone valves whether to protect the structure from meteorological phenomenons.

Possible accidents in the back part can bring the breakup of the valves of the cylinders to spillages of product and can prevent the closing of the gas circuits. The heads of the valves to tall pressure with pivots in brass don't have enough characteristics of resistance in case of accident. The problems get worse in the case of accident with fire, infact release of the gas in pressure can bring fire that can degrade hydraulic circuits of distribution.

3. Lack of a mechanical system that allows the contemporary closing of the valves of the gaseous tube trailer..

Every cylinder is endowed with a system of manual closing through proportional valves with bolt in brass and joint elements in teflon. All the valves are reunited a collector on which two manual valves of closing are installed. According to the normative (ADR) all the valves during the transport must be in closing position.

It is not however at the present moment a mechanic control system which allows to check automatically the real closing of the valves.

4. Lack of protection among the trailer wheels in rubber and the cylinders.

In the gaseous tube trailer the part with greater fire load are constituted by the tires. Other important fire load is the tractor with tires and oil in the tanks. During the fire that is developed following road accident, heat warmed anterior parts of the cylinders of tube trailer. Thermal heater and the increase of pressure can generate cylinder collapse.

2.2 Incidental Traffic police Mantua Febbraio 2004

From the analysis of this accident the following elements of risk have emerged:

1. Lack of the side protection to the bodies valve and pipes of connection among the containers.

The back part of the mean that contains the whole hydraulic system (valves of intercept, manometers and collectors is not really provided of a system of efficient protection in degree to protect from bumps. Such situation is valid is towards back bumps that of side bumps.

2. Lack of the necessary points for the lifting of the wagon during the phases of recovery of the mean.

In case of accident with wagon hydrogen out in the road center besides the phase of mass in safety it is necessary however to perform the recovery of the mean. For this it is necessary in the majority of the cases to handle to lift through the employment of crane.

2.3 Traffic accidental Near PISTOIA Dicembre 2003

From the analysis of this accident the followings critical points have been underlined related to the transport of packages cylinders, some problem list are similar to those emerged for the gaseous tube trailer.

1. Lack of a system of signs able to visualize the pressure inside the package cylinders.

Is not present any device able to make the pressure known inside the single cylinders that constitute the package of it a system to be able to esteem its general pressure. Such situation can result extremely dangerous in case of accident in particular way for the teams of help. The inside pressure is a fundamental element that can make to vary completely the formulation and the choice of the rescue procedures.

2. System that allows to visualize the closing of all the valves set on the head of the cylinders.

Is not present any mechanical device able to allows an unique control of the situation of the valves of intercept installed on the head of the various cylinders of the package. It is possible that one or more valves result open and that the general collector results in pressure.

In case of accident with breakup of the metallic structure of the package spillage of the cylinders could occur collapse of the general collector and consequent release of hydrogen.

3. The structure of containment of the package cylinders it doesn't guarantee any structural resistance under conditions of bump following accidents.

The package cylinders following fallen by the flatcar you/he/she has suffered the complete breakup with spillage of the cylinders.

The breakup of the package can produce a situation of risk in how much the separation of the cylinders involves the collapse of the collector of distribution and possible release of gas if the valves of the cylinders are not in position of closing. Fall of separate cylinders not protected from

the metallic structure of the package can produce lesions in correspondence of the head valve with consequent risk of rupture and hydrogen release.

3.0 STRUCTURAL CHANGES PROPOSED TO INCREASE SAFETY IN HYDROGEN PRESSURE TRANSPORTS.

Analysis of accidents described above point out a list of problem related to the safety of the transport of inflammable gas in pressure. On the base of these experiences some indications are proposed for the project and the realization of such modifies which can increase safety level during accidental situation.

The most critical situations that have been examined are the followings:

1. Necessity to develop a system which permit to know the inside pressure the storage. This informations are particularly important in order to choise type of intervention to effect in critical situations. In fact the risk of release of gas and possible breakup of the cylinders for overpressure is surely determined to gas pressure inside cylinder.

The manometers set on the head of every valve don't allow to have a picture of the situation during an accidental event in fact they allow to know only the pressure when the valves are open, they are not visible in some way maintaining himself/herself/itself to a reasonable safety distance both for their position that for the real dimensions and they constitute besides a strong element of structural weakness of the circuit.

In alternative it is necessary to think to individualizing additionally system to easy distance reading as for instance a system of external paintings to those existing you possibly position in a sheltered place and possibly in degrees to withstand to bumps and fires.

Such suggestion can be wide in general all the systems of distribution gas in pressure, particularly important could result the characterization of the packages cylinders. Also in this case could be valued the possibility to position external informative panels.

2. Necessity to realize packages cylinders with suitable characteristics of structural resistance and endowed with structures for the correct anchorage on the flatcar of the means. The possibility of falls of packages cylinders from flatcars of car it is an enough frequent eventuality under accidental conditions, for such motive it is necessary to realize structures able to withstand to possible impacts with the ground with the purpose to succeed in guaranteeing at least the containment of the inside cylinders. And necessary therefore to think about appraising some programs of test and testing and therefore to plan and to certify the metallic structures of the packages according to these parameters. It owes an indication to be anticipated on the package of the happened certification.

3. Necessity to foresee a system of protection fire of the cylinders on the gaseous tube trailer.

In the accident happened near Cessalto the problem of the separation you/he/she is found between the combustible material and the impending castle of the cylinders. With the purpose to reduce the thermal impact on the reservoirs it would be necessary to guarantee the disposition of a plan of isolation fireproof. In this way you/he/she could be prevented at least the direct action of the flames on the mantle of the reservoirs and possession therefore heatings located particularly dangerous for the structural resistance.

4. Necessity to foresee a system of lifting of the gaseous tube trailer. Gives the particular structure of the wagon it would be necessary to foresee a suitable system for the lifting of the mean. Particularly such points of anchorage should be situated in the zones the more possible protected from bumps and being projected also for the lifting of the mean container internally still product. Necessity to lift the half anchor loaded is important sights the difficulties of I decant of the product and the risks that can be had in to free hydrogen in air.

5. Necessity to foresee a system of protection of the back part of the tube trailer. Back part of the tube trailer constitutes the most delicate area of the structure of the towing, I am in fact you introduce all the valves group, the collectors and the manometers. This part requires therefore a system of protection more effective than that present currently able to protect the components in case of accident as for instance crash with other vehicles, etc.....

6. Necessity to foresee a mechanical system able to guarantee the closing valves during the transport.

Such necessity is warned both for the gaseous tube trailer that for the packages cylinders. The opening or closing of the valves is completely left to the operator procedures.

In various occasions has been found that some valves have been open and the collector in pressure increasing the risks of release for the scarce abilities of structural resistance in case of accident. To reduce these risks should be anticipated a system of block of the valves that obligatorily results inserted during the transport.

5. CONCLUSIONS

The transport of great quantities of compressed gas involves risks both for the consequences of the possible accident and for the rescue teams that have the assignment to resolve emergency situations.

Problem list above are more important in the case in which the gas results to be a fuel.

Risks could increase in the future also in the case of realization of cylinders with inside pressures up to 700 bar against the 200 bar actual

This memory, whose objective is that to give a list of proposal drawn by the direct experience of firebrigade rescue teams in Italy, shows that there are many possibility to increase safety degree of transports. In some cases technical modifies request are quite easy to introduce and with low costs. Some of these solutions have already been adopted in other nations among which some European ones.

The advantages that could derive from the employment of new solutions should be to our notice rather consistent. This could give more safety to hydrogen transport and so could advantage the hydrogen economy development.