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Failure Mode and Effect Analysis DME vehicle storage tank systems

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1. Introduction

As a part of the international project "DME as an automotive fuel", sponsored by IEA/AMF and NOVEM (NL), a safety assessment has been carried out under the responsibility of TNO. For a number of possible storage tank systems, a Failure Mode and Effect Analysis (FMEA) was performed, the outcomes of which are reported in this document.

A Failure Mode and Effect Analysis is a well-known and often applied hazard assessment technique, which provides a quick insight into the hazards of an installation and in the relative contribution of the individual hazards to the overall risk. It may be carried out by a single analyst or by a group of experts in one or more interactive sessions. The FMEA of DME vehicle storage tanks was carried out by a team consisting of representatives of TNO Road Transport Institute (automotive knowledge), TNO Industrial Safety (risk assessment expertise, session leader), Renault (DME vehicle developer) and AKZO Nobel Chemicals (DME producer).

The FMEA addresses a well-defined installation or part of it, which is formalised in the so called system definition. For every system component, the following information is collected:

a. name, identification, function;
b. possible modes of failure (malfunctioning) and failure causes;
c. effects and consequences of failure;
d. compensating provisions.

Failure modes are best identified at one installation level at a time. Failure effects will include connected installation parts. Often, failure effects of one level may be regarded as failure modes of the next level up. In the current study, the DME storage tank and connected appendages and piping are regarded as one level; the motor parts up to the injector system are considered as the next level up.

2. System definition

2.1 Introduction

In this particular case, the system to be assessed was basically the storage tank with appendages and the pipework immediately connected to the tank. Failure modes were only determined for this part of the system. The effect assessment included the connected motor parts up to the injectors.

The following systems were assessed in the FMEA:
1. membrane tank;
2. in-tank pump system;
3. multiple tank system *(p.m.)*;

See figure 1 for a schematic overview of systems 1 and 2.

The systems analysed are at the moment not on the market. The design is based on LPG-systems and prototypes of DME systems. Differences between LPG and DME systems can be found in operating pressure, test pressure, burst pressure and maximum filling. More information on these parameters can be found in another TNO-report i.e.: "Proposal for safety provisions for DME fuelling systems and their installation in vehicles", report ref. 98.OR.VM.051.1/JV by J.Verweij and J. Berendsen.

2.2 Membrane tank

The membrane tank system consists of a tank which is connected to the Fuel Injection System (FIS) by pipelines and a high pressure pump. The FIS includes the common rail, solenoid valves, resilient checks and injector nozzles (see figure 1 in the annex with FMEA worksheets).

The membrane tank consists of two parts which are separated from each other by a synthetic membrane. The two tank parts are connected by a bolt-and-seal connection. Prior to delivery of the system, one part of the tank is filled with propane; although the system contains a propane filler unit, it is envisaged that the tank is only filled once in a lifetime. The propane part is provided with a pressure relief valve.

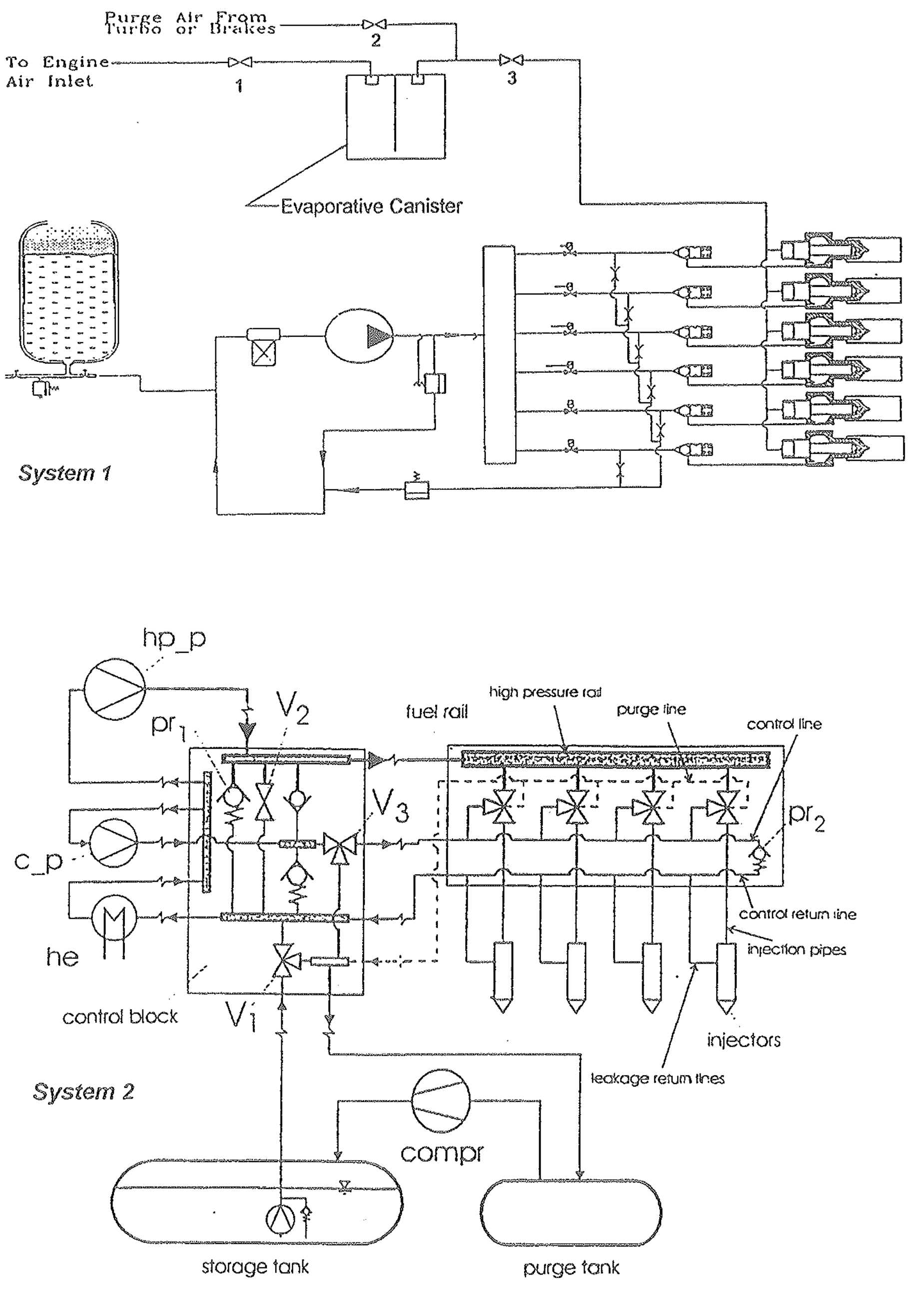

Figure 1 Schematic overview of system 1 and 2.

The other part of the tank, the actual DME container, is connected to the FIS by pipelines provided with a filler unit, a pressure relief valve and an electrical - magnetic shut-off valve.

> *Probably the tank will also contain a level gauge, an 80% fill-stop, one or two excess flow valves and a valve + line to the vehicle heating system (the line to the heating system to be used in specific appli-*

cations for example in buses). However, during the FMEA session, no specific information on these items was available. Therefore, they were preliminary excluded from the FMEA.

All appendages are placed inside a gas-tight housing which is connected to ambient by a pipeline, most often ending underneath the vehicle.

Furthermore, the injection system is connected to a carbon canister which is vented with purge air from either the turbo or from the brake system. Since DME injection leaks are fed to the canister, it was decided to include these items in the FMEA. Failure modes considered were erroneous positions of the valves numbered 1, 2 and 3 in figure 1. This is systematically explored in table 2.1.

Table 2.1 Positions of valves 1, 2 and 3 in system 1 (see figure 1).

Valve position (Open or Closed)			Failure mode code
1	2	3	
Open	Open	Open	b.3
Closed	Open	Open	a.2, a.3
Open	Closed	Open	a.1, c.3
Open	Open	Closed	c.2
Closed	Closed	Open	normal
Closed	Open	Closed	b.1
Open	Closed	Closed	b.2
Closed	Closed	Closed	a.4, c.1

Engine operation mode:

a. Engine not running; valves 1 and 2 closed, valve 3 open.
b. Engine running, purge mode; valves 1 and 2 open, valve 3 closed.
c. Engine running, no-purge mode; valve 1 open, valves 2 and 3 closed.

2.3 In-tank pump system

The second storage philosophy assessed was the in-tank pump system, consisting of a storage tank connected to the injection system.

Inside the tank itself, one or more pumps are placed which are provided with a discharge valve. Furthermore, the tank is provided with:

- an excess flow valve and electrical magnetic shut-off valve, connected to FIS by a pipeline;
- a non-return valve connected to FIS by a pipeline;
- a level-gauge (on the tank) and level detector (in the tank);
- a pressure relief valve;

- an electrical magnetic shut-off valve connected to an optional line to the vehicle heating system;
- a filler unit (at the outside of the vehicle) with a pipeline and non-return valve, connected to an 80% fill-stop and a level detector;
- a man-hole, allowing for access to the tank and pump mounting.

In order to comply with the regulations, also this system has to be provided with a gas-tight housing with a connection to ambient which contains all the appendages mentioned (except the filler unit at the outside of the vehicle).

The in-tank pump system is presented as figure 2 schematically in the annex with FMEA worksheets.

2.4 Multiple tank system

During the FMEA-session of June '98 no information on this system was available.

3. Physical and chemical properties of DME

Dimethyl ether is a chemical which largely resembles the well-known fuel LPG (Liquefied Petroleum Gas). Actually, LPG is a mixture of propane and butane whose composition may vary between certain limits. Table 3.1 contains the most important physical and chemical properties of DME and of LPG and its constituents.

Table 3.1 Selected physical and chemical properties of DME and related chemicals.

Property	Units	DME [1]	LPG [1]	Propane [2]	Butane [3]
Chemical formula	-	C_2H_6O	-	C_3H_8	C_4H_{10}
Molar mass	kg/kmol	46	approx. 50	44	56
Boiling point	°C	-25	approx. -20	-42	-0.6
Melting point	°C	-141	approx. -160		
Flash point	°C	far below zero; flammable gas at ambient temperature			
Auto ignition temp.	°C	235	approx. 400	470	-
Flammability limits in air	vol %	2.7 - 18.6 3.4 - 27 [2]	1.5 - 10	2.4 - 9.5	-
Specific liquid gravity	kg/dm³	0.7 [1] 0.67 [2]	approx. 0.6	0.51	0.58
Relative vapour density (air = 1)	-	1.6 [1] 1.59 [2]	1.8	1.52	-
Specific volume (= absolute vapour density, 20 °C)	*kg/m³*	*1.92*	*2.16*	*1.82*	-
Vapour pressure (20 °C)	bar	5.3 [1] 5.12 [2]	4 - 8	8.35 (20°) [2] 9.4 (25°) [3]	2.4 (25 °C)

[1] = Chemical Safety Sheets (Netherlands Assoc. of Chem Industry).
[2] = Safety Assessment of DME Fuel, M. Paas Consulting Ltd., Winnipeg, Manisota, Canada, April 1997.
[3] = SC Sorenson, M. Glensvig, DL Abata, **Dimethyl Ether in Diesel Fuel Injection Systems**, Soc. of Automotive Engineers 981159, 1998.

The main property of DME which clearly distinguishes the substance from LPG is its reactivity with synthetic materials. DME will severely affect most elastomers, causing it either to weaken or to brittle. This puts an important limitation to systems fuelled by DME, where possible metal-to-metal connections or sandwich constructions should be used or DME resistant elastomers for seals of valves, flanges etc.

4. FMEA results

On assessing the safety and reliability of the DME storage system components, to a large extent reference may be made to existing LPG guidelines. Nevertheless, since no full scale FMEA of an LPG storage tank was known at the time of the study, a systematic inventory has been made of the failure modes of the individual components of the DME storage system. This is reported in the tables in Annex 1.

The consequences have been assessed to the categories:
- H - health effects (injuries or death, caused by a release of DME followed by ignition of the cloud, resulting in a fire or explosion);
- C - damage to the car, including engine operation;
- E - environmental impact.

On a total of about 50 failure occurrences, approximately 50% belongs to category H, 40% to category C and some 10% to category E. This means that both human risk and material losses can be significantly reduced by taking proper countermeasures. Environmental impact provides for a relatively small percentage of the total failures.

From the technical information about the storage tank systems and the physical and chemical properties it is obvious that DME vehicle storage tanks are to a very large extent comparable with LPG vehicle storage tanks. Most LPG regulation will hold for DME tanks as well. This impression is confirmed by the results of the FMEA. The failure modes that have been identified, are to a large extent the same as the ones that are expected for LPG storage systems.
The only, very specific problem of DME tanks is the incompatibility of DME with synthetic materials. In fact this is the most important issue when considering DME tank safety.

The most important recommendation is that DME tank systems should be constructed using DME resistant materials only. In view of the highly flammable and also toxic nature of DME (that is to say the contaminants of DME such as methanol, as DME itself is considered to be harmless at high concentrations), no concessions should be accepted to this principle. This will probably mean that only metal-to-metal connections should be applied.

Below, a summary is given of the specific recommendations that were drawn up:
- Observe LPG/pressure vessel design and installation regulations in order to minimise tank failure probability (LPG rules are expected to be also applicable to a large extent for DME).
- All appendages should be placed in a gas-tight housing with a vent to ambient.

- Consider use of non-return or failure-to-close valves, where appropriate (in order to prevent leakage during standstill from a part of the system into another part, where it may give problems during restart for example).
- Prevent fouling of discharge valve by using a proper filter system.
- The carbon canister should be (high) pressure resistant.
  NB: The carbon canister may be applied in the experimental set-up, but probably will not be part of the system set on the market.
- Prevent errors by providing tanks with fuel specific filling nozzle.
- The vent outlet should be installed at a spot which is remote from hot (engine) parts.
- Apply a proper installation and repair program and procedures.
- Use DME resistant materials
  NB: The present DME resistant material on the market is rather expensive. In order to evaluate alternative options it is necessary to have available:
  - a worksheet with material requirements and
  - adequate test procedures.

5. Authentication

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Names and establishments to which part of the research was put out to contract:

-

Date upon which, or period in which, the research took place:

June 1998 - November 1998

Signature:

M.Th. Logtenberg (M.Phil.)
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Approved by:

J. Schaafsma (M.Sc.)
head of department

Annex 1 Study drawings and worksheets FMEA

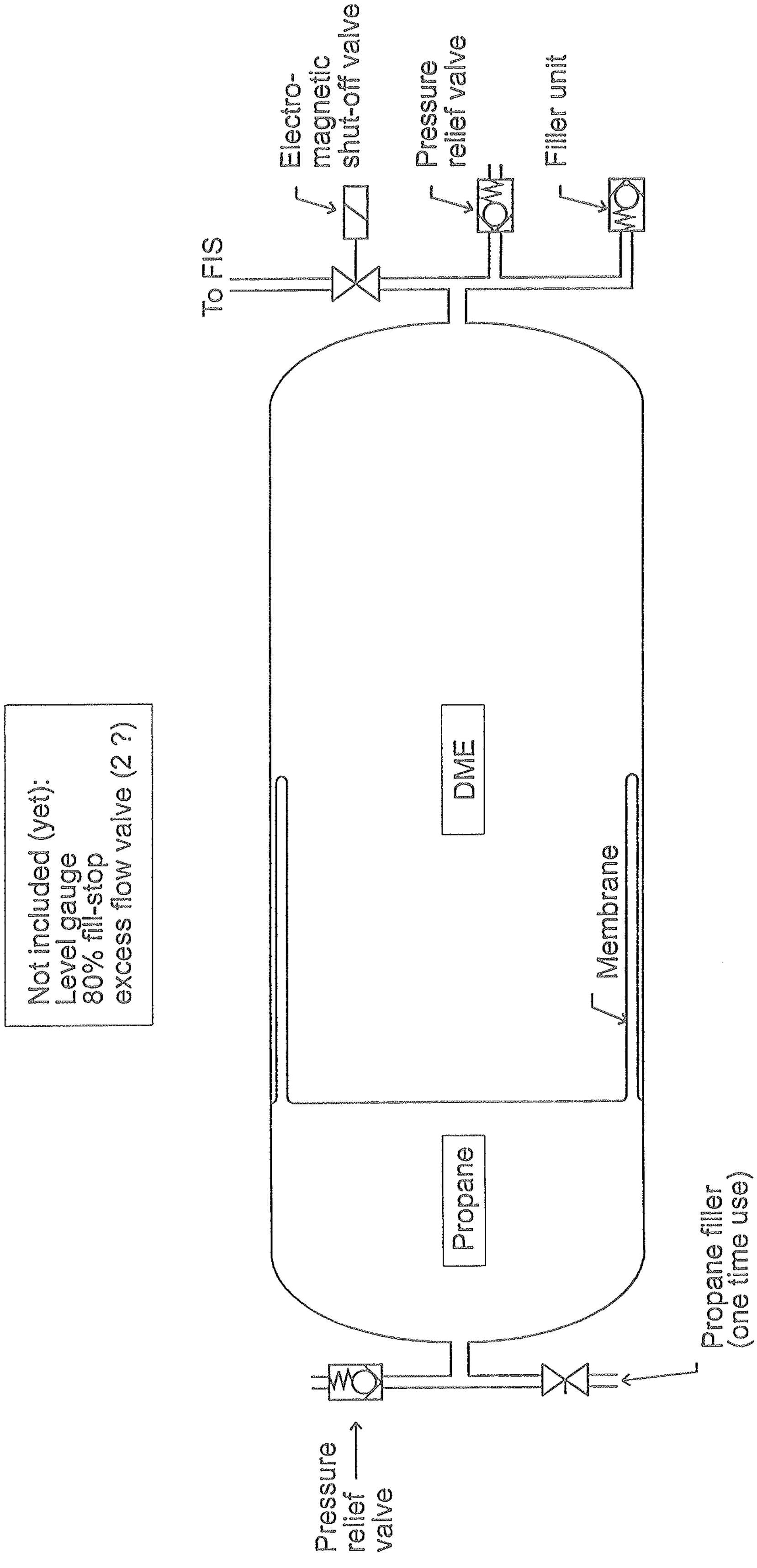

Figure 1 Schematic representation of membrane tank system. System 1: membrane tank.

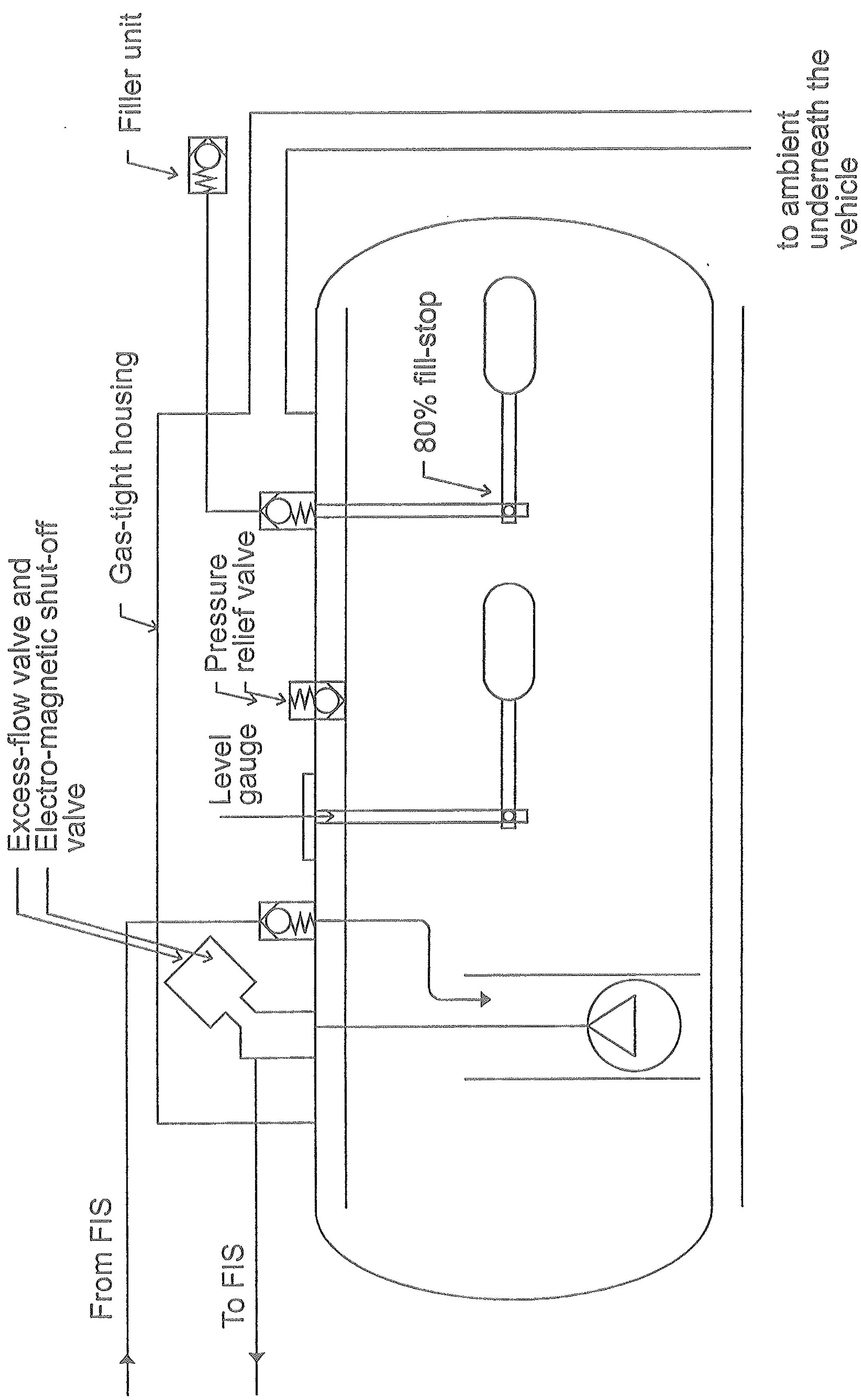

Figure 2 *Schematic representation of in-tank pump system. System 2: In-tank pump.*

Membrane tank

Form no. :	DME 01	*Date:*	17 July 1998	*System:*	Membrane tank (see Figure 1)
Version:	1.2	*Analyst:*	team / DDW/LTG	*Component:*	Tank

Failure Mode	Cause	Effect	Consequence (H = human, C = car, E = environmental impact)	System reaction	Remarks/recommendations
Tank rupture	- Penetration by external source (car accident) - Material fault - Corrosion - External fire	Leakage of propane or DME in car trunk	(H) fire in car / explosion (if ignition source is present)	None	- Failure probability is very low if tank is designed and installed in compliance with (LPG/pressure vessel) regulations - Ignition probability is generally very high
Failure of connection of both tank parts	- Use of wrong sized bolts - Bolt twisting error (e.g. After repair) - Material fault - Corrosion - Membrane damage (see form DME 02)	Leakage of propane or DME in car trunk	(H) fire in car / explosion (if ignition source is present)	None	- Failure probability is very low if tank is designed and installed in compliance with (LPG/pressure vessel) regulations - Ignition probability is generally very high
Failure of flange weldings	- Welding error - Material fault (e.g. By corrosion)	Leakage of propane or DME in car trunk	(H) fire in car / explosion (if ignition source is present)	None	- Failure probability is very low if procedures are properly applied (quality assurance!) - Ignition probability is generally very high
DME section filled with wrong fuel (most probably LPG)	- Customer error - Fuel station storage tank filling error	Delivery of LPG to FIS	(C) sub-optimal combustion / engine operation	None	- No safety problem - Prevent error by providing tank with fuel specific filling nozzle
Propane section filled with DME	- Delivery error of producer	Damage of propane filler unit and/or pressure relief valve	(H) leakage of DME in car; fire / explosion in car	None	- Failure probability is very low if procedures are properly applied (quality assurance!) - Ignition probability is generally very high

Membrane tank

Form no. :	DME 02	*Date:*	17 July 1998	*System:*	Membrane tank (see Figure 1)
Version:	1.2	*Analyst:*	team / DDW/LTG	*Component:*	Membrane

Failure Mode	Cause	Effect	Consequence (H = human, C = car, E = environmental impact)	System reaction	Remarks/recommendations
Loss of membrane integrity	Membrane affected by DME (by dissolving)	Mixing of propane and DME	(C) DME at its own vapour pressure or slightly higher	Undefined multiple reactions possible	Apply DME resistant membrane materials only
		Contact between DME and propane servicing parts; damage of propane filler unit and/or pressure relief valve	(H) leakage of DME in car; fire / explosion in car upon ignition	As above	- Ignition probability is generally very high - Apply DME resistant materials and/or constructions only
		Contact between propane and the DME servicing parts	None	As above	
	Brittling of membrane	Small pieces of membrane block appendages (hose, filler unit, valves)	(C) filler unit blocked	As above	No safety problem
			(H) pressure relief valve blocked; possibility of pressure build-up and explosion (if temp and pressure exceed limit values)	As above	See form no. Dme 03
			(C) electro-magnetic shut-off valve blocked; no fuel delivery	No combustion; engine will switch off	See form no. Dme 03
Disformation of membrane	Membrane stretched by partial dissolution in DME	Blocking of the outlet to FIS	(C) no fuel delivery to FIS	No combustion; engine will switch off	--

Membrane tank

Form no. :	DME 03	*Date:*	17 July 1998	*System:*	Membrane tank (see Figure 1)
Version:	1.2	*Analyst:*	DDW/LTG	*Component:*	Appendages

Failure Mode	Cause	Effect	Consequence (H = human, C = car, E = environmental impact)	System reaction	Remarks/recommendations
Loss of integrity of propane pressure relief valve, filler unit or connection hoses	- Exposure to DME after membrane loss of integrity	- Leakage of propane inside car (probably mixed with DME)	(H) fire in car / explosion (if ignition source is present)	None	- Ignition probability is generally very high - Place all appendages in gas-tight housing with vent to ambient - Use DME resistant materials
		- Loss of propane pressure	*No significant consequences expected*		
	- Use of wrong equipment (producer error) - Welding error - Material fault	- Leakage of propane	(H) fire in car / explosion (if ignition source is present)	None	- Place all appendages in gas-tight housing with vent to ambient - Probability very low if procedures are properly applied (quality assurance!) - Ignition probability is generally very high
	- Installation error (e.g. After repair) - Corrosion				- Apply proper repair and testing program and procedures
Rupture of propane pressure relief valve, filler unit or connection hoses	Penetration by external source (e.g. Car accident)	Leakage of propane in car trunk	(H) fire in car / explosion (if ignition source is present)	None	- Place all appendages in gas-tight housing with vent to ambient - Failure probability is very low if tank is designed in compliance with (LPG/pressure vessel) regulations - Ignition probability is generally very high

Membrane tank - DME 03 (continued)

Failure Mode	Cause	Effect	Consequence (H = human, C = car, E = environmental impact)	System reaction	Remarks/recommendations
Loss of integrity of DME pressure relief valve, filler unit or connection hoses	- Use of wrong equipment (producer error) - Welding error - Material fault	Leakage of DME in car trunk	(H) fire in car / explosion (if ignition source is present)	None	- Use DME resistant materials - Place all appendages in gas-tight housing with vent to ambient - Probability very low if procedures are properly applied (quality assurance!) - Ignition probability is generally very high
	- Installation error (e.g. After repair) - Corrosion				- Apply proper repair and testing program and procedures
Rupture of DME pressure relief valve, filler unit or connection hoses	- Penetration by external source (car accident)	Leakage of propane or DME in car trunk	(H) fire in car / explosion (if ignition source is present)	None	- Place all appendages in gas-tight housing with vent to ambient - Failure probability is very low if tank is designed in compliance with (LPG/pressure vessel) regulations - Ignition probability is generally very high

Membrane tank

Form no. :	DME 04	*Date:*	17 July 1998	*System:*	Membrane tank (see Figure 1)
Version:	1.2	*Analyst:*	team / DDW/LTG	*Component:*	Carbon canister valves 1, 2 and 3

N.B.: During operation, the carbon canister valves will hold the following configurations:
a) engine not running: valve 1 and 2 closed, valve 3 open
b) engine running, purge-mode: valve 1 and 2 open, valve 3 closed
c) engine running, no purge-mode: valve 1 open, valves 2 and 3 closed

Valves config.	Failure Mode	Additional specification	Effect	Consequence (H = human, C = car, E = environmental impact)	System reaction	Remarks/recommendations
a)	Valve 1 open		DME to engine	(C) possible early combustion in engine at restart or slow start, high HC emission ???	None	Consider use of failure-to-close valve 1
	Valve 2 open, purge air from turbo		DME to engine	(C) uncontrolled ??? combustion in engine at restart or slow start, high HC emission ???	None	Consider use of failure-to-close valve 2
	Valve 2 open, purge air from brakes	Pressure in brake system	DME to engine	(C, H?) uncontrolled ??? combustion in engine at restart or slow start, high HC emission ???	None	
		No pressure in brake system	DME to brake system	(C) brake rubber materials affected by DME	None	Install non-return valve
	Valve 3 closed		Build-up of pressure in canister (probably to a limited extent: canister is not a closed system)	(C, E) DME will flash off		No safety problem; Canister should be pressure resistant

Membrane tank - DME 04 (continued)

N.B.: During operation, the carbon canister valves will hold the following configurations:
a) engine not running: valve 1 and 2 closed, valve 3 open
b) engine running, purge-mode: valve 1 and 2 open, valve 3 closed
c) engine running, no purge-mode: valve 1 open, valves 2 and 3 closed

Valves config.	Failure Mode	Additional specification	Effect	Consequence (H = human, C = car, E = environmental impact)	System reaction	Remarks/recommendations
b)	Valve 1 closed		Build-up of pressure in canister (probably to a limited extent: canister is not a closed system)	(C, E) DME will flash off		no safety problem; canister should be pressure resistant Pressure in canister is normal during operation. When engine is switched off, valve 3 opens and over-pressure will build up, or relieve to engine intake manifold
	Valve 2 closed		None	None	None	= normal "engine running, no purge-mode" situation
	Valve 3 open		All injector leakage to engine via air inlet	(C) engine control out of order	Fuel cut-off; deceleration	Does not seem a real safety issue ***NB: How fuel cut-off is achieved is not known***
c)	Valve 1 closed		Build-up of pressure in canister (probably to a limited extent: canister is not a closed system)	(C) DME will flash off		No safety problem; canister should be pressure resistant
	Valve 2 open		None	None	None	= (undesired) purge mode; no problem
	Valve 3 open		All injector leakage to engine via air inlet	(C) engine control out of order	Fuel cut-off; deceleration	Does not seem a real safety issue

Membrane tank

Form no. :	DME 05	*Date:*	17 July 1998	*System:*	Membrane tank (see Figure 1)
Version:	1.2	*Analyst:*	team / DDW/LTG	*Component:*	Carbon canister

Failure Mode	Cause	Effect	Consequence (H = human, C = car, E = environmental impact)	System reaction	Remarks/recommendations
Canister leakage	Wear	DME evaporation and release	(E) DME to atmosphere	None	In light duty cars this is not a safety issue, provided that the leak is not near hot spots. DME leakage is an environmental issue (however, released amounts generally will be small).

In-tank pump

Form no. :	DME 11	*Date:*	17 July 1998	*System:*	In-tank pump (see Figure 2)
Version:	1.2	*Analyst:*	DDW/LTG	*Component:*	Tank

Failure Mode	Cause	Effect	Consequence (H = human, C = car, E = environmental impact)	System reaction	Remarks/recommendations
Tank wall failure	- Penetration by external source (car accident) - Material fault - Corrosion	Leakage of propane or DME in car trunk	(H) fire in car / explosion (if ignition source is present)	None	- Failure probability is very low if tank is designed in compliance with (LPG/pressure vessel) regulations - Ignition probability is generally very high
Failure of man-hole flange welding	- Welding error - Material fault (e.g. By corrosion	Leakage of DME in car trunk	(H) fire in car / explosion (if ignition source is present)	None	- Failure probability is very low if procedures are properly applied (quality assurance!) - Ignition probability is generally very high
Failure of man-hole connection	- Use of wrong sized bolts - Bolt twisting error (e.g. After repair) - Material fault - Corrosion	Leakage of DME in car trunk	(H) fire in car / explosion (if ignition source is present)	None	- Failure probability is very low if tank is designed in compliance with (LPG/pressure vessel) regulations - Ignition probability is generally very high
Tank filled with wrong fuel (most probably LPG)	- Customer error - Fuel station storage tank filling error	Delivery of LPG to FIS	(C) sub-optimal combustion / engine operation	None	- No safety problem - Prevent error by providing tank with fuel specific filling nozzle

In-tank pump

Form no. :	DME 12	*Date:*	17 July 1998	*System:*	In-tank pump system (see Figure 2)
Version:	1.2	*Analyst:*	DDW/LTG	*Component:*	In-tank pump

Failure Mode	**Cause**	**Effect**	**Consequence (H = human, C = car, E = environmental impact**	**System reaction**	**Remarks/recommendations**
No or insufficient pump capacity	- Wrong pump type installed	No or insufficient DME delivery to FIS	(C) no combustion; engine will switch off	None	- Observe design requirements and installation procedures
	- DME lubrication capacity insufficient				- Use DME compatible pump components
Pump overheated	- Tank empty	Ignition of remaining DME vapours (only in case of oxygen supply through secondary leak)	(H) explosion / fire	Usually engine will switch off when out of fuel	- Observe pump design requirements (use proper pump type)
Discharge valve does not close	- Fouling	Insufficient flow to FIS	No combustion, engine switches off	Low power of engine	A proper filter system should be used
Discharge valve does not open	- Fouling	Pump load too high	Break down of pump, no delivery	None till pump failure	A proper filter system should be used
Malfunctioning of level detector A	- Material fault - Dme lubrication capacity insufficient	Improper level indication	(C) car unexpectedly out of fuel	Engine switches off	No safety problem
Malfunctioning of level detector B (80% fill stop)	- Material fault - Dme lubrication capacity insufficient	Overfilling	(E) DME spill at filling station	None	- Local fire/explosion hazard; - Health hazards: freezing upon contact with evaporating liquid; skin and eye irritation; central nervous system effects upon exposure to high concentrations (may be reached quickly [1])
			(E) build-up of pressure inside tank; leakage upon warming up in the sun or in confined space	Excess vapour vented through relief valve to ambient	- If relief valve is out of order venting is blocked; this may pose a safety problem; - If vent outlet to confined space, explosion and fire may occur

In-tank pump

Form no. :	DME 13	*Date:*	17 July 1998	*System:*	In-tank pump system (see Figure 2)
Version:	1.2	*Analyst:*	DDW/LTG	*Component:*	Appendages

Failure Mode	Cause	Effect	Consequence (H = human, C = car, E = environmental impact	System reaction	Remarks/recommendations
Loss of integrity of appendages inside gas-tight housing	- Exposure to DME - Use of ill-sized equipment (producer error) - Welding error - Material fault	Leakage of DME inside gas tight housing; explosive mixture vented to ambient	(H) fire / explosion if contact with hot parts possible	None	- Use DME resistant materials - Probability very low if procedures are properly applied (quality assurance!) - Vent outlet remote from hot parts
	- Installation error (e.g. After maintenance) - Corrosion	Leakage of DME inside gas tight housing; explosive mixture vented to ambient	(H) fire / explosion if contact with hot parts possible	None	- Probability very low if procedures are properly applied (quality assurance!) - Vent outlet remote from hot parts - Apply proper maintenance program and procedures
Rupture of appendages inside gas-tight housing	Penetration by external source (e.g. Car accident); **will include rupture of housing!**	Leakage of DME in car trunk	(H) fire in car / explosion (if ignition source is present)	None	- Failure probability is very low if tank is designed in compliance with (LPG/pressure vessel) regulations - Ignition probability is generally very high
Loss of integrity of hoses and/or filler unit outside gas-tight housing	- Exposure to DME - Material fault	Leakage of DME in car trunk	(H) fire in car / explosion (if ignition source is present)	None	- Use DME resistant materials - Failure probability is very low if tank is designed in compliance with (LPG/pressure vessel) regulations - Ignition probability is generally very high

In-tank pump

Form no. :	DME 13 (continued)	*Date:*	17 July 1998	*System:*	In-tank pump system (see Figure 2)
Version:	1.2	*Analyst:*	DDW/LTG	*Component:*	Appendages

Failure Mode	Cause	Effect	Consequence (H = human, C = car, E = environmental impact	System reaction	Remarks/recommendations
Excess-flow valve and/or el. magnetic shut-off valve does not close	- Exposure to DME - Use of ill-sized equipment (producer error) - Material fault - Failure of electronic equipment ?? *Instrumentation of these valves is not clear from available drawings*	DME outflow downstream in engine compartment	(H) fire / explosion in engine compartment	None	- Use DME compatible material - Observe design requirements and installation procedures
Excess-flow valve and/or el. magnetic shut-off valve does not open	- Exposure to DME - Use of ill-sized equipment (producer error) - Material fault - Failure of electronic equipment ??	No DME delivery to FIS	(C) no combustion; engine does not start	None	- Use DME compatible material - Observe design requirements and installation procedures
Non-return valve does not open	- Exposure to DME - Use of ill-sized equipment (producer error) - Material fault	No flow from FIS	Probably malfunction of FIS	Loss of power	- Use DME compatible material - Observe design requirements and installation procedures
Non-return valve does not close	- Exposure to DME - Use of ill-sized equipment (producer error) - Material fault	Vapour to FIS	Probably malfunction of FIS	Loss of power	- Use DME compatible material - Observe design requirements and installation procedures

In-tank pump

Form no. :	DME 13 (cont. 2)	*Date:*	17 July 1998	*System:*	In-tank pump system (see Figure 2)
Version:	1.2	*Analyst:*	DDW/LTG	*Component:*	Appendages

Failure Mode	Cause	Effect	Consequence (H = human, C = car, E = environmental impact	System reaction	Remarks/recommendations
Malfunctioning of level gauge	Material fault *(precise way of gauge's operation is not known)*	Improper level indication	(C) car unexpectedly out of fuel	Engine switches off	No safety problem
Pressure relief valve does not open	- Exposure to DME - Use of ill-sized equipment (producer error) - Material fault	Build-up of pressure inside tank	(H) tank rupture and explosion / fire	None	- Use DME resistant materials - Probability very low if standards are observed and procedures are properly applied (quality assurance!)
Pressure relief valve does not close	- Exposure to DME - Use of ill-sized equipment (producer error) - Material fault	Leakage of DME inside gas tight housing; explosive mixture vented to ambient	(H) fire / explosion upon contact with hot parts	None	- Use DME resistant materials - Probability very low if procedures are properly applied (quality assurance!) - Locate vent outlet remote from hot parts
Non-return valve filler unit does not open	- Exposure to DME - Use of ill-sized equipment (producer error) - Material fault	Build-up of pressure in hose between filler unit and non-return valve	(C, H) hose rupture, possibly followed by fire and / or explosion	None	- Use DME resistant materials - Probability very low if standards are observed and procedures are properly applied (quality assurance!)
Non-return valve filler unit does not close	- Exposure to DME - Use of ill-sized equipment (producer error) - Material fault	Build-up of pressure in hose between filler unit and non-return valve	(C, H) hose rupture, possibly followed by fire and / or explosion	None	- Use DME resistant materials - Probability very low if standards are observed and procedures are properly applied (quality assurance!)