Kraftfahrt-Bundesamt (Federal Motor Transport Authority)

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Report on flammability and HF exposure trials with vehicle air conditioning systems using R1234yf

The findings in this report have essentially been drawn up on the basis of the attached documents.

1. Introduction

Under EU Directive 2006/40/EC, from 1 January 2011 new EC type-approvals may only use a refrigerant with a GWP (Global Warming Potential) value of less than 150 in passenger vehicle (M1) air conditioning systems. For EC type-approvals issued before 1 January 2011, the existing refrigerant R134a may continue to be used until the end of 2016.

The choice of refrigerant under these regulations is entirely a matter for vehicle manufacturers. In 2010, the automotive industry declared itself in favour of the new refrigerant R1234yf, which complies with the Directive. Owing to problems with the delivery of R1234yf, all vehicle manufacturers continued to use the old refrigerant R134a until the end of 2012 with the acquiescence of the European Commission and the Member States.

In addition to issuing type approvals, the Federal Motor Transport Authority (KBA) is the body responsible in Germany for market surveillance, and hence for product safety for road vehicles. In this capacity, since 2009 it has been following up reports from well-known institutions indicating that the use of R1234yf as a refrigerant in mobile air conditioning systems could present new hazards in motor vehicles. The Authority has provided information on this on numerous occasions at the regular meetings of the European type-approval authorities, to which representatives of the European Commission were also regularly invited. It also asked the Commission back in April 2012 to include safety requirements for air conditioning systems in the motor vehicle type-approval procedure.

In September 2012, the vehicle manufacturer Daimler expressed concerns about the safety of R1234yf as a result of its own test results (risk of fire in the vehicle, release of hydrofluoric acid). Daimler AG therefore questioned its use. As a result, the firm has continued to use R134a in its vehicles even after 1 January 2013.

Owing to contradictory assessments by various vehicle manufacturers of the reaction of R1234yf to fire, the KBA has now carried out its own tests. The results have already been published in a preliminary report, subject to a detailed evaluation. The evaluation has produced no fundamental changes to the findings.

2. Background

Once the Daimler AG vehicle trials in September 2012, followed by those of the VDA (German Association of the Automotive Industry) in December 2012, which involved a significant hazard incident (vehicle fire and hydrogen fluoride (HF) exposure), had come to the public's attention, suspicions were raised concerning the increased risk of using R1234yf in vehicles. The KBA launched a product safety investigation and informed the Commission accordingly. The investigation initially yielded contradictory statements from various manufacturers concerning the occurrence and likelihood of ignition. It was clear from discussions with the automotive industry that the increased fire risk with R1234yf was generally recognised, even if views differed as to the likelihood of fire actually occurring. The persisting disagreement on the subject and lack of any testing by an impartial body prompted the KBA to conduct its own risk assessment tests. The aim of these tests was to determine whether, in a realistic accident scenario, there could be an increased risk of fire and/or exposure to hydrofluoric acid.

In order to do this, a project group was set up with experts from the federal authorities specialised in this area. These included the *Bundesanstalt für Materialforschung und -prüfung* (BAM) (Federal Institute for Materials Research and Testing), which has been carrying out tests for years on the flammability of refrigerants within its own specialised area of gas and gas appliances, the *Bundesanstalt für Straßenwesen* (BASt) (Federal Highway Research Institute), which has particular competence in the area of accident research and passive vehicle safety and, as technical adviser, the *Umweltbundesamt* (UBA) (Federal Environment Agency), which also has long experience of providing support for investigations of this nature. Overall coordination was ensured by the KBA's product safety division, which commissioned TÜV Rheinland's technical service, recognised by the KBA, to carry out the practical testing. This technical service has crash simulation facilities and a proven track record at the KBA in all areas of vehicle type approval, and has extensive experience at international level in flammability testing of refrigerants in vehicles.

For reasons of transparency, the European Commission and the vehicle manufacturers concerned have been kept continuously involved in the process.

3. Choice of test scenario

The tests at Daimler reproducibly demonstrated the occurrence of ignition in B-class vehicles and other manufacturers' vehicles. This raised doubts about product safety, in that a leak of the refrigerant in a hot engine compartment could cause a vehicle fire, putting the vehicle occupants and first aiders at risk. Burning R1234yf can also release hydrogen fluoride, presenting a further danger to occupants and first aiders.

Although the most likely scenario creating these circumstances would be a collision situation such as a motorway pile-up, the Daimler tests were carried out on undamaged vehicles. In order to recreate a real-life accident scenario as accurately as possible, the investigation should therefore take into account proven damage from crash tests.

In order to do this, the BASt described and evaluated collision configurations potentially causing this kind of damage based on actual accident data from the GIDAS (German In-Depth Accident Study) data bank, and identified a test set-up. This was tested for relevance to the total accident population, and the probability of its occurrence estimated.

The set-up selected was a crash test based on ECE R94 using a reduced speed of 40 km/h which, in the initial phase of testing with the engine warmed up and running, created a

realistic damage simulation. Based on analysed accidents in Germany, the probability of occurrence of this scenario is estimated at 2.9*10-4 per vehicle/year (3 out of 10 000 vehicles registered in Germany) and is therefore of significance for vehicle product safety. An impact speed of 40 km/h was assessed as the critical speed, as on the one hand damage to the corresponding air conditioning system elements was to be expected, while on the other there was still sufficient clearance (air volume) in the engine compartment to create the conditions necessary for the mixing of the relevant quantities required for ignition. This set-up was confirmed in consultations with vehicle manufacturers as well as by the SAE CRP team.

In a second phase, the refrigerant was then to be released through the damaged original system components and tested for flammability and hydrogen fluoride formation. Engine coolant was also to be released from the damaged radiator in parallel with the refrigerant in order to take its influence on a possible hazard incident into account. As it is already known from tests in the automotive industry that refrigerant can only ignite if the engine compartment reaches very high temperatures, the test vehicles were to be restored to driving condition after the crash test and brought to very high – but realistic – operating temperatures (determined in preliminary tests at high motorway speeds) by being driven with a braked trailer. The engine was then to be switched off and refrigerant from the air conditioning system released through the components damaged in the crash. The formation of flames and hydrogen fluoride would be monitored by means of measurement technology and documented using cameras.

4. Selecting the test vehicles

Following product safety principles, the vehicles initially selected were those most likely to display the problem under investigation on German roads. The only vehicles considered were those which, according to their type approval, use R1234yf as the refrigerant in their air conditioning systems. It was not possible to differentiate risk according to vehicle construction, as tests by manufacturers and the VDA had already demonstrated that refrigerant ignition is not restricted to individual engine or drive train designs. All vehicles registered in Germany as of 1 April 2013 which had the equipment concerned were therefore considered, and one of each of the four most commonly registered vehicle types selected. Where possible, within these types, the variant which, on the basis of its engine design, was likely to have the highest operating temperatures was chosen, i.e. a low-capacity petrol engine, preferably with turbocharger. Two vehicles with and two without turbocharger were chosen.

5. Test procedure

Once the vehicle types had been selected, the individual vehicles were bought normally on the market via the technical service. The manufacturers concerned were subsequently informed and invited to an information meeting and presentation of the vehicles in Cologne on 24 May 2013. As well as the project participants and manufacturers concerned, the manufacturers' representative organisations VDA and VDIK and a European Commission representative also attended and were informed about the purpose of and reasons for the tests, the vehicle and crash scenario selection process, the test procedure and the HF measurement methods. The purpose of presenting the vehicles was to ensure that they did not have any abnormalities prior to testing.

TÜV Rheinland prepared the vehicles for the tests, the temperature measurement system was installed and the temperature progression at full load on the motorway registered for replication during the refrigerant release test.

The crash tests with the four selected vehicles took place at TÜV Rheinland's facilities on 10 and 11 June 2013. The vehicles were examined after the tests and taken apart to determine the damage to the air conditioning systems. On 28 June 2013 the manufacturers were informed individually of the damage analysis and the procedure for the planned refrigerant release tests.

Depending on their crash test damage pattern, the vehicles were assigned to different levels for the refrigerant release tests. Only levels 1 and 2 were regarded as relevant for the purposes of the product safety investigation, as the necessary specific probability could only be assigned to those levels.

Level 1 – empirically observed damage

Level 2 – minimum extrapolation of the damage within the known result distribution

Level 3 – more extensive extrapolation to confirm the findings

In the **level 1** tests, the refrigerant was released only through the components which leaked as a result of the crash damage. **Level 2** also subjected components to the release test that had been damaged in the crash test but had not leaked, but which are known – and have been shown in manufacturers' own tests – to have leaked after damage in similar tests, although there is scattering of the results due to component tolerances, etc. **Level 3** is intended to confirm the findings. This level considers damage to system components which are assumed to remain leakproof in the given crash parameters if in new condition but in more severe conditions, such as ageing of the tubing material and/or higher collision speed, are likely to be destroyed. In addition, it assumes higher temperatures in the engine compartment on the basis of expected developments in engine technology, such as the use of supercharged engines in the test vehicles, which in this test were fitted with a naturally aspirated engine.

The test conditions at level 3 allowed an assessment to be made from the test result of the potential for serious accidents, without determining their probability or significance. They indicate a need for further testing.

On the basis of the above, levels 1 and 2 can be used to make an official assessment of potential risk within the statutory remit of the product safety authority (assessment of a specific product). By contrast, level 3 is in the nature of a more general risk assessment. The aim is to test whether the current safety requirements are sufficient.

The refrigerant release tests took place in calendar week 28 at the BAM's test facilities in Baruth/Mark. A total of 22 tests were carried out at the individual levels. Using a braked trailer, the vehicles were brought up to the operating temperature determined in the preliminary tests, less 50 degrees Celsius, by driving them at high speed on the motorway, and then parked at the test site. The outflow elements of the stationary vehicles were then opened immediately. The 50 degrees Celsius temperature difference referred to is based on the assumption that a vehicle crashing into the rear of a queue of traffic at 40 km/h from a high motorway speed is able to cool down accordingly while braking without load.

6. Results

The crash tests showed that, on all four vehicles, the condenser at least was damaged. In addition, refrigerant circulation components were damaged to varying degrees.

At levels 1 and 2, there were no cases of ignition with any of the vehicles tested. Some measurements at these levels identified low, non-critical concentrations (Annex A5 *Bundesinstitut für Risikobewertung* (Federal Institute for Risk Assessment, BfR)) of pyrolytically released hydrogen fluoride.

In the level 3 tests there were two cases of the engine compartment fully catching fire (V15 and V18, Annex A1 TÜV-Rheinland), during which significant quantities of hydrogen fluoride were measured. In two further cases involving different vehicles, non-negligible concentrations of hydrogen fluoride were measured (Annex A5 BfR) without any detectable flame formation (V20 and V22, Annex A1 TÜV-Rheinland).

In those cases where the engine compartment fully caught fire, the fire was extinguished by the previously installed CO_2 extinguishing system. The complementary test using R134a did not result in a fire, significant hydrogen fluoride formation or any other hazard incident.

The HF concentrations measured are assessed as critical for tests 15 and 18 (full fire) and for 20 and 22 (point 3.3, Annex 5 BfR), where a person is exposed to and inhales these concentrations. It should be emphasised, however, that these measurements took place within the engine compartment; it can be assumed that the concentration will decrease rapidly in the vicinity of the vehicle. In any event, there was no evidence of HF in the passenger compartment, although measurements could only be carried out for approx. 30 seconds after the start of the release owing to the measurement principle used. Any HF concentrations occurring after this period were therefore not detected.

7. Conclusions and next steps

Analysis of the test results basically confirms the findings of the preliminary report. The findings can be summarised as follows:

The results at levels 1 and 2 (no ignition and no critical hydrogen fluoride exposure) do not provide sufficient supporting evidence of a serious risk within the meaning of the Product Safety Act (ProdSG) with the vehicle types tested here to warrant the taking of any immediate measures by the KBA, as product safety authority, pursuant to that Act. The possibility of a hazard incident as described cannot be completely excluded, however, although no significant probability could be determined either. In such cases, responsibility for product safety naturally continues to lie with the manufacturer.

The comparative measurements at level 3 with the refrigerant R134a used to date indicate that using R1234yf tends to reduce motor vehicle safety performance, since no form of critical damage incident was produced in the tests using R134a.

As the crash-sensitive location of air conditioning system components is determined by their function (front condenser and refrigerant lines), vehicle fires could occur in situations which have not arisen in vehicles to date. In modern vehicle designs, other flammable materials are made as crash-safe as possible (e.g. fuel lines at the rear of the engine compartment). The use of R1234yf thus goes against the European aims of reducing road traffic risks.

However, since the conditions and factors determining whether a refrigerant can catch fire and hydrogen fluoride exposure occur in vehicles are not yet fully known, but such occurrence could present a direct and serious health risk for vehicle occupants and first aiders, further research into these circumstances is strongly recommended. Such research should also investigate whether these findings should in future be included in vehicle approval procedures and safety requirements for vehicle air conditioning systems laid down in law. As type approval legislation is based on European law, the *Bundesministerium für Verkehr, Bau und Stadtentwicklung* (BMVBS) (Ministry of Transport, Building and Urban Development) and the KBA are in contact with the European Commission to determine how to proceed in this matter.

8. Summary

During the product safety investigation on possible risks presented by air conditioning systems in vehicles, the KBA was unable to rule out a general safety problem associated with the use of the refrigerant R1234yf before conducting its own tests. In order to gain further information, the KBA initiated and directed its own tests. These independent tests and investigations were carried out by a technical service appointed for the purpose by the KBA and monitored by federal authorities and research institutes. This formed a broader basis on which to assess the potential safety risk presented by the use of the refrigerant R1234yf in passenger car air conditioning systems.

One vehicle from each of the four most commonly registered vehicles type-approved for the use of R1234yf was initially selected for the tests. The vehicles were crash-tested at a collision speed of 40 km/h using a test facility simulating real driving conditions based on ECE regulation 94, and their refrigerant circuits then examined for damage. The damage observed was then simulated in separate refrigerant release tests in vehicles in which the engine had been run to a high temperature, then tested for flammability and HF exposure.

The results of the tests do not provide sufficient supporting evidence of a serious risk within the meaning of the Product Safety Act (ProdSG) with the vehicle types tested here to warrant the taking of any immediate measures by the KBA pursuant to that Act.

However, in further tests performed by the KBA in addition to the product safety investigations, instances of flammability and hydrogen fluoride exposure were observed, although no critical incidents were observed in comparative tests using R134a.

This is a clear indication of unresolved problems with the use of R1234yf as a refrigerant in motor vehicle air conditioning systems. Imperative safety considerations therefore lead us to strongly recommend further investigation in order to better assess potential risks.

9. Annex

- A1 – report TÜV-Rheinland
- A2 – report BASt
- A3 – review of KBA registration figures (as basis for vehicle selection)
- A4 – reports by BAM: gas analysis, ignition delay time
- A5 – opinion of BfR