

Investigation Report

Identification

| | |
|----------------------|---------------------------------|
| Type of occurrence: | Serious incident |
| Date: | 12 March 2005 |
| Location: | Stuttgart |
| Aircraft: | Transport aircraft |
| Manufacturer / Type: | British Aerospace / BAe 146-300 |
| Injuries to persons: | No injuries |
| Damage: | Aircraft not damaged |
| Other damage: | None |
| Information Source: | Investigation by BFU |

problem the crew opted for an ILS approach to Stuttgart Airport because of the better weather situation. To control altitude and touchdown the manual elevator trim was used.

Aircraft information

The BAe 146-300 is a high wing airplane with a T-tail, powered by four turbofan jet engines. Its maximum capacity is 130 passengers or 10,727 kg cargo.

| | |
|-------------------------|---|
| Year of manufacture: | 1990 |
| Maximum take-off weight | 44,225 kg |
| Total flight time | 22,866 hours |
| Cargo on board | 6,274 kg |
| Last cleaning: | 8 March 2005 |
| Last de-icing: | 12 March 2005 (twice) with SAE Type II, 50 : 50 |

Factual information

History of the flight

The airplane experienced a slow pitch oscillation with increasing amplitude during climb from flight level (FL) 80 to FL100 with engaged autopilot. The airplane was on a cargo flight from Frankfurt to Stuttgart. The oscillation resulted in a positive angle of attack of up to 18 degrees and in a rate of descent of up to 4,500 ft/min.

The crew regained control of the airplane in instrument meteorological conditions (IMC) and under icing conditions with disengaged autopilot and the help of the manual elevator trim. A prolonged flight in FL130 under visual meteorological conditions (VMC) and free of icing conditions did not change the control problems they experienced with the airplane.

Since the checklists for abnormal and emergency situations did not contain any solution to the existing



Findings on the aircraft

The airplane was examined immediately after the landing and significant amounts of frozen and swollen up de-icing fluid residues were found in the gap between elevator and horizontal stabilizer and in the area of ailerons and rudder.



Frozen residues between elevator and horizontal stabilizer on a BAe 146

The airplane's elevator and wings were cleaned according to the airplane manufacturer's specifications. During the flights conducted afterwards autopilot and controls functioned properly again. The operator's documentation showed that the airplane in question had the most de-icing procedures per cleaning cycle.

Tests and research

Residue development

The de-icing and anti-icing fluids mostly used in Central Europe are so called thickened de-icing fluids SAE Type II, Type III or Type IV. Unlike the unthickened de-icing fluid SAE Type I which is relatively seldom in Europe, these fluids have a small portion of a polymer added to adjust their viscose-elastic properties to the requirements for prolonged re-icing protection.

As long as the airplane stands still or moves slowly the thickener ensures that enough fluid remains on the airplane and prevents its re-icing during a given time period. During take-off, the form of the polymer thickener aggregates in the fluid is changed contingent upon their exposure to the airflow. The de-icing fluid's viscosity decreases during the take-off run and it can drain off the airplane's surface completely.

During the de-icing procedure the de-icing fluid reaches parts of the airplane which are not subject to airflow. During the flight the remaining de-icing fluid dries up at low temperatures, low atmospheric

pressure and low humidity. Water and glycol portion of the fluid dry up and the polymer thickener is left as residue.

The polymer residue is very hygroscopic, i.e. it can absorb, from the surrounding air, a multiple of its own weight of water (re-hydration) and thus become a gel-like mass. Depending on the ambient air temperature this over saturated gel freezes. The resulting ice can restrict control surface movements.

Tests

Several years ago SR Technics, Switzerland, developed a procedure (Buehler test) to compare the various thickened de-icing fluids regarding the deposits left after drying-up and their re-uptake of water. This test was incorporated into standardisation.

Using this test, de-icing fluids from different manufacturers were compared with each other. The test was to show what effect the alternate application of de-icing fluids from different manufacturers has on the development of residues and their re-hydration.

The Bundeswehr Research Institute for Materials, Explosives, Fuels and Lubricants (WIWEB) in Erding was asked to conduct these tests and to assess the results. The BFU and the above-mentioned Swiss company agreed on written and telephonic support for WIWEB in test conduct matters.

Four manufacturers were asked to participate in the test with their products. Three manufacturers complied. A total of nine de-icing fluids were made available for testing; five Type II and four Type IV fluids.

WIWEB conducted the tests in accordance with the specifications of the Society of Automotive Engineers (SAE) AMS 1428E:

- Conduct of the test – dry out and residue formation

For about four seconds three test panels were dipped into each of the de-icing fluids. This was done so that reproducibility of the results could be checked and proven. After 30 minutes draining the test panels were weighed and dried for 24 hours in a climatic exposure test cabinet with exhaust fan.

The temperature used to dry the test panels dipped into undiluted de-icing fluids was +30° C and relative humidity was 40%. The temperature used to dry the test panels dipped into the 50 : 50 diluted de-icing fluids had to be increased to +35° C in order to achieve total drying.

After 24 hours the test panels were removed from the climatic exposure test cabinet, allowed to cool for 30 minutes and then weighed to an accuracy of 0.1 milligram; the weight was recorded. This procedure was repeated five times so that all panels were dipped into de-icing fluid a total of six times.

- Test realisation - Rehydration

After weighing the residues each panel was dipped into deionised water for 30 ± 1 seconds. After 60 ± 2 seconds draining the panels were weighed and the results documented. Each test panel was subject to this process a total of 10 times.

Besides testing individual products (undiluted and in 50 : 50 dilution) the potential effects of the successive application of different products were tested. For better analysis of the effects of the individual products two-thirds of the immersions were done in a single product and one-third in one or two other products.

Test results

A comprehensive list of all test results is compiled in Annex 1 of the WIWEB report No 05/56335/00001-000. For confidentiality, the names of manufacturers (A, B, C) and products (1 – 9) were anonymised.

The following tables show the calculated mean values of the residues and the gel masses (re-hydration). For better illustration Appendices 1 – 4 show the results as diagrams.

1. Undiluted products and their mixed application

| Product (100 : 0) | Residue (mg) | Gel mass (mg) | Quality factor ¹ |
|-------------------|---------------|----------------|-----------------------------|
| | 1. – 6. Value | 1. – 10. Value | |
| A1 (II) | 2,0 – 5,4 | 1632 – 1401 | 302 |
| B3 (II) | 1,2 – 3,9 | 2286 – 1970 | 586 |
| C7 (II) | 2,3 – 6,0 | 1505 – 1841 | 251 |
| B8 (II) | 2,9 – 10,6 | 3334 – 2249 | 315 |
| A5 (II) | 2,0 – 9,4 | 2833 – 1823 | 301 |
| B4 (IV) | 1,5 – 4,7 | 2271 – 1286 | 483 |
| C2 (IV) | 2,2 – 5,2 | 1382 – 1766 | 266 |
| C6 (IV) | 2,5 – 4,4 | 900 – 1526 | 205 |
| A9 (IV) | 3,3 – 11,6 | 1364 – 707 | 118 |

¹ In prior consultation with WIWEB the BFU added a calculated value called quality factor. The factor stands for the product's water absorptivity per mg of residue. It is the ratio of the first (re-hydrated) gel mass weighing result divided by the last residue weighing result.

| Product (100 : 0) | Residue (mg) | Gel mass (mg) | Quality factor ¹ |
|-------------------|---------------|-----------------|-----------------------------|
| | 1. – 6. Value | 1. – 10. Values | |
| B3 (II) / A1 (II) | 1,1 – 5,5 | 2356 – 1726 | 428 |
| C7 (II) / B8 (II) | 2,0 – 6,0 | 1564 – 1940 | 261 |
| A9 (IV) / B4 (IV) | 3,6 – 9,3 | 2577 – 1593 | 277 |
| B4 (IV) / A9 (IV) | 1,4 – 5,1 | 1662 – 1420 | 326 |
| A5 (II) / C7 / B8 | 3,1 – 7,9 | 3492 – 1079 | 442 |
| B4 (IV) / A1 / C7 | 2,3 – 4,4 | 1331 – 1292 | 303 |
| B3 (IV) / A1 / C7 | 1,0 – 3,5 | 1608 – 1495 | 459 |
| C6 (IV) / C2 / A9 | 1,3 – 4,1 | 1260 – 1314 | 307 |

2. 50 : 50 Diluted products and their mixed application

| Product (50 : 50) | Residue (mg) | Gel mass (mg) | Quality factor ¹ |
|-------------------|--------------------------|-----------------|-----------------------------|
| | 1. – 6. Value | 1. – 10. Values | |
| A1 (II) | 13,8 ² – 3,8 | 1135 - 947 | 299 |
| B3 (II) | 1,4 – 4,4 | 2461 - 2620 | 559 |
| C7 (II) | 1,6 – 5,7 | 1442 - 1875 | 253 |
| B8 (II) | 13,1 ² – 20,7 | 4352 - 2702 | 210 |
| A5 (II) | 4,8 – 13,9 | 2662 – 1914 | 192 |
| B4 (IV) | 1,9 – 5,1 | 2054 - 1387 | 403 |
| C6 (IV) | 2,1 – 3,9 | 888 - 1302 | 228 |
| A9 (IV) | 3,8 – 7,9 | 1058 - 735 | 134 |

² The first weighing data obtained could not be used because obviously the test panels had not fully dried.

| Product (50 : 50) | Residue (mg) | Gel mass (mg) | Quality factor |
|----------------------|-----------------|------------------|-------------------|
| | 1. – 6. Value | 1. – 10. Values | |
| B8(II) / C7 / A1 | 2,5 – 7,8 | 2031 - 1988 | 260 |
| C7(II) / B8 / B3 | 1,9 – 5,1 | 1423 - 2205 | 279 |
| A9(IV) / C6 / C2 | 2,8 – 7,0 | 1190 –1425 | 170 |
| C2(IV) / A5 / B4 | 1,3 – 5,7 | 1425 -1892 | 250 |

Test result assessment

Based on the test results WIWEB has come to the following conclusions:

- The mass of the dry residues is independent of the de-icing fluid's type (II or IV). Examples: A1 and C2*
- The mass of the residues is independent of the de-icing fluid's viscosity and therefore also independent of the amount of fluid that remains on the test panels 30 minutes after immersion. Examples: A5 and C6 as well as B3 and B4*

C6 showed an average of 4.4 mg residue while A5 showed 9.4 mg even though C6 has more than twice the viscosity of A5. The products B3 and B4 showed only a slight difference in their residue masses (3.9 mg versus 4.7 mg). But B4 has almost three times the viscosity of B3.
- The mass of the dry residues is not proportional to the amount of water the residue can absorb, i.e. a lot of residue does not necessarily mean a lot of water can be absorbed. This leads to the conclusion that the ability to absorb water depends to a greater degree on the chemical structure of the respective polymer thickener. – Examples A9 and B8*
- With the successive application of various products (mix) three different observations were made:*
 - The application of different products has no influence on residue development and their water absorption – examples: C7 and B8.*
 - If low residue but higher water absorptivity products are applied following high residue but low water absorptivity products the resulting residue may be lower but absorb more water. – Examples A9 and B4*
 - Applying high residue and water absorptivity products in turn with low residue and water absorptivity products may reduce the amount of residue and the resulting water absorptivity. Examples: B8 (50 : 50) and B8 / C7 / A1 (50 : 50)*

In summary, it can be stated that the use of different products may have a minor effect. The

frequent application of a low residue and water absorptivity product and the occasional application of higher residue and water absorptivity products tend to result in higher residue and water absorption than may be expected if the original product was used, only. If the sequence in application of products is reversed the observation was made that in this case residue development and water absorption ability decreases.

- The residue mass obtained from 50 : 50 water diluted de-icing fluids is in the same order of magnitude as that obtained from the undiluted products when the measuring accuracy is duly considered. Consequentially, the residue's water absorptivity results are comparable with those of undiluted products.*
- Strikingly, the mass of residual de-icing fluid present after 30 minutes of test panel draining is significantly higher for 50 : 50 water diluted de-icing fluids (even low viscosity products) than for undiluted fluids.*
- The formation of residues is to be ascribed to the reaction of the metal surface with the polymer thickeners contained in the de-icing fluid. The assumption that residue mass is dependent upon the amount of polar fractions and therefore the active centres of the polymer is substantiated by the test results listed under points 1 to 6. Therefore residue mass is also independent of the quantity, viscosity and dilution of the de-icing fluid applied on the test panel.*

Organisations and their procedures

Operators

Just a few operators still de-ice and anti-ice their aircraft themselves. Operators not conducting their own de-icing and anti-icing, commission this task to departments responsible for de-icing (de-icing companies) at airports.

Contractual agreements with these de-icing companies stipulate that de-icing is conducted according to the newest version of approved standards and quality assurance provisions. Since de-icing companies as contractual partners of operators are not subject to aeronautical regulations, operators are obliged to control their contractors for compliance with contractual agreements.

As contractual agreement with and control of de-icing companies is mandatory for all operators the airlines organised in the Association of European Airlines (AEA) and other associated airlines have

formed a group. Representatives of this group have major say in contract design and controls.

Several times a year the review organisation De-icing/Anti-icing Quality Control Pool (DAQCP) conducts quality checks on behalf of its members at de-icing companies. For market economy considerations, the provision of unthickened (Type I) de-icing fluids by all stations used by member airlines could not be adopted in the contractual agreements.

The operator involved stated that usually de-icing and anti-icing were covered in one step and thickened Type II or Type IV fluids, often diluted with water, used. As often as possible and if in stock a de-icing procedure conducted in two steps was favoured; step one consisted of water or Type I fluid and the second step of Type II or Type IV fluid.

In order to minimise residue development the operator had, at the end of the 1980s, prohibited the use of "pre de-icing" or "over night de-icing" (Application of thickened Type II / IV fluids on clean surfaces with long hold-over time in order to avoid delays in the morning due to de-icing procedures).

In times when aircraft were de-iced daily inspections for residues were carried out as often. Inspections over the past years had shown minor residue development only. Prior to the incident the airplane was cleaned every 14 days based on the experiences mentioned above. When de-icing became necessary less frequently the cleaning and inspection schedule was modified accordingly.

Airports / de-icing companies

As a regional airline, the operator flies to domestic and European destinations meaning bigger and smaller airports. A station overview of the regional airlines organised in the pool shows that of the 86 used and checked regional stations only three stations have Type I, 25 have Type I and Type II or Type IV and 58 have Type II and Type IV fluids in stock. The 25 airports which have not only Type II or Type IV fluids in stock but also Type I do so mostly for environmental protection.

On smaller airports de-icing takes place right before take-off whereas on large airports like Frankfurt it is not possible to de-ice all aircraft right before take-off due to organisational reasons and lack of space. De-icing procedures on these airports usually occur with thickened de-icing fluids at the aircraft's parking or ramp position.

Annually, airports revise their working procedures and regulations based on the newly published recommendations of the Association of European Airlines (AEA) on how, in the upcoming season, aircraft have to be de-iced. The aim is to conduct

de-icing efficiently with little de-icing fluid consumption, the utmost flight safety in mind and a consequential environmental protection. De-icing companies and representatives of the operator and the air transport control services are often involved in the planning.

The airports' de-icing procedures are based on the internationally approved standards for de-icing methods of the Society of Automotive Engineers (SAE) and on AEA specifications with the incorporated recommendations and specifications of aircraft manufacturers.

Legal guidelines for aircraft de-icing

JAR-OPS 1.345 "Ice and other residues" states:

- (a) *An operator shall establish procedures to be followed when ground de-icing and anti-icing and related inspections of the aeroplane(s) are necessary.*
- (b) *A commander shall not commence take-off unless the external surfaces are clear of any deposit which might adversely affect the performance and/or controllability of the aeroplane as permitted in the Aeroplane Flight Manual.*
- (c) *A commander shall not commence a flight nor intentionally fly into expected or actual icing conditions unless the aeroplane is certificated and equipped to cope with such conditions.*

JAR-OPS 1, Subpart D, Section 2 includes the following statements concerning JAR-OPS 1.345:

- Fluids used for de-icing and/or anti-icing shall be acceptable to the operator and the aircraft manufacturer. These fluids normally conform to specifications such as SAE AMS 1424, 1428 or their equivalent (ISO). Use of non-conforming fluids is not recommended due to their characteristics not being known.
- The operator should take proper account of the possible side-effects of fluid use. Such effects may include, but are not necessarily limited, to: Dried and/or re-hydrated residues, corrosion and the removal of lubricants.
- The operator should establish procedures to prevent, or detect and remove residues of dried fluid. If necessary the operator should establish appropriate inspection intervals based on the recommendations of airframe manufacturers and/or own experience.
- Operators are strongly recommended to request information about the fluid dry-out and re-hydration characteristics from the fluid

manufacturer and to select products with optimised characteristics.

The use of fuels, oils, lubricants and other substances for aeronautical purposes is generally governed by specifications agreed with the civil aviation authorities. Such substances are normally approved for aeronautical use after the manufacturer has demonstrated that they are effective and do not pose any short or long term risks for flight safety.

Aircraft manufacturer

The BAe 146 manufacturer has issued numerous notices and technical bulletins to caution against the problems involved in the use of thickened de-icing fluids and the importance of inspections for and the removal of de-icing fluid residues. The documentation includes comprehensive instructions where on the aircraft type such residues are to be expected and how they can be removed.

Precise instructions that the BAe 146 should only be de-iced with Type 1 fluids or if thickened de-icing fluids are used de-icing is to be done only in connection with Type 1 fluids and heated water, are not given. The application of inspection and cleaning programmes are left to the experience of the operator.

Additional information

The BFU received additional incident reports during the investigation regarding aircraft de-icing:

- **25 March 2005:**
The crew of an AVRO RJ 100 on a scheduled flight from Zurich to Prague realised during climb to cruising level that movement of the elevator required increased effort. In FL230 the crew informed air traffic control (ATC) and requested a precautionary landing in Munich. During descent to Munich the elevator's controllability improved. Below FL100 the airplane was controllable again. The approach was normal and the landing safe.
- **30 March 2005:**
On a scheduled flight from Munich to Birmingham an AVRO RJ 85 experienced slow pitch oscillations during climb. As the aircraft's behaviour did not change during cruise flight the crew disengaged the autopilot. The pilot flying realised that an unusually high effort was necessary for pitch and roll control. The crew opted for a precautionary landing in Frankfurt. During descent the aircraft's controllability improved. Approach and landing were normal.
- **March 2006:**
The crew of an Italian Embraer 145 declared an

emergency in cruising level due to jammed elevator controls and opted for a precautionary landing in Munich. During approach the aircraft's controllability improved. The landing was normal. After the removal of de-icing fluid residues in the area of the elevator the airplane continued to its destination.

- **26 March 2006:**
During a scheduled flight from Dortmund to Munich an incorrect elevator trim position was indicated in a DHC-8-300 cruising in FL190. After the crew had disengaged the autopilot they discovered that the control column and the elevator trim wheel were jammed. The procedure described in the emergency checklist did not solve the problem.

Using the STBY-Elevator-Trim it was possible to change the setting of the elevator trim. Together with power adjustments a controlled descent was possible. Based on the limited controllability the crew decided to declare an emergency and opted for a precautionary landing in Frankfurt. During approach the aircraft's controllability improved continuously. The landing was normal.
- **28 March 2006:**
On a scheduled flight from Basel to Düsseldorf the pilot of an ATR 72-200 realised during climb that roll control was rough-going. During approach with engaged autopilot and after several heading changes, incorrect aileron trim position was indicated. The check of all remaining aircraft of the operator involved showed that three other airplanes had accumulated significant amounts of re-hydrated de-icing fluid residues.
- **30 March 2006:**
On a scheduled flight from Düsseldorf to Zurich the crew of a BAe 146-300 realised unusual pitch oscillations during climb. After reaching cruising altitude the pilot disengaged the autopilot because the airplane did not maintain the pre-selected altitude. He then realised that the elevator controls were jammed. The airplane could only be controlled by using elevator trim. The crew noticed full controllability in FL80. The landing in Zurich was normal.

BAe 146-Forum in Prestwick

In May 2005 the manufacturer of the BAe 146 held a forum for operators of the aircraft type to discuss the subject of de-icing fluid residues. This meeting was attended by the British Civil Aviation Authority CAA, the British Aircraft Accidents Investigation Branch (AAIB), representatives of de-icing fluid

manufacturers, of the European Regions Airline Association (ERA) and nine regional airlines.

At the meeting the manufacturer spoke of 40 reported incidents in the year 2004 in connection with aircraft de-icing. In 2005, 88 incidents were reported. All incidents occurred in Europe. Not all operators had experienced incidents.

The meeting showed that significant difference in the use of de-icing fluids and the application of inspections and cleaning programmes existed. The operators conducting inspections and cleanings after a defined number of de-icing procedures experienced fewer incidents.

According to the de-icing fluid manufacturers the demand for Type II / Type IV de-icing fluids on European airports rose sharply in late February/early March 2005 because of the prolonged intense de-icing period. During this time period some airports sold the amount of de-icing fluids they would usually sell during a whole year. This information corresponded with a weather evaluation of the manufacturer that showed that the weather in 2005 had indeed been different to the weather of the previous years (many days below / around freezing point with freezing / frozen precipitation).

Analysis

Properties of thickened de-icing fluids

Comparison of the undiluted products shows that each de-icing procedure increases the amount of dried fluid residue. Furthermore, the test results show quite clearly that Type IV fluids do not generally produce more dried fluid residues than Type II fluids. Under consideration of water absorptivity the evaluation sequence may reverse totally like Type IV fluid A9 shows.

The quality factor is only then an evaluation factor for the product if water absorptivity is the basis for the evaluation. In this case, the product A9 would rank first. Since the control problems are caused by the freezing of the gel mass it is legitimate to favour the product with the least gel formation. In this case C6. It is remarkable, however, that with both evaluation criteria a Type IV fluid ranks first. Merely if the dried fluid residues are the evaluation criteria the Type II fluid B3 would rank first.

Another important realisation is the fact that dilution of the products does not reduce the amount of dried fluid residues. If anything, the opposite is the case like the product B8 shows. The performance of undiluted products and the outcomes of diluted and mixed product application, as discussed above,

show very large variation which may be one reason for the airline's inability to timely identify and remove de-icing fluid residues using their standard practices.

Inspections conducted may fail to identify dry de-icing fluid residues due to narrow gaps between elevator and horizontal stabilizer, the appearance of the residue, or improper inspection practice. This is why the application of a thickened de-icing fluid, either Type II or Type IV, is mandatorily followed by a cleaning process. How often a thickened de-icing fluid can be applied until cleaning is necessary shall not be decided by the operator but must come from the aircraft manufacturer.

Thereby is expected that a product having passed prescribed procedures for aeronautical certification does not pose any risk for safe operation of an aircraft any more. So far this confidence was justified through an internationally common modus operandi and through specifications and standardisation. After these incidents the necessary confidence level is not there any more where thickened de-icing fluids are concerned. Although all de-icing fluids tested have demonstrated compliance with SAE AMS 1428, which was agreed with the civil aviations authorities, the test results show significant variations in the properties of products of the same type from both the same and different manufacturers. The cogent conclusion is that the specifications, i.e. the standardisation, has so far failed to define the properties of these fluids with adequate accuracy.

Additional quality determinants, such as test procedures, or dried and re-hydrated residue limits, will have to be adopted in the specifications so that the use of de-icing fluids will not continue to be a risk the operators may not easily assess. Only if standardisation specifies more detailed requirements to be met and ensured by all fluid manufacturers will aircraft manufacturers be able to establish reliable maintenance intervals and may be reasonably expected to do so.

Even more detailed definition of de-icing fluid properties by standardisation, however, would not eliminate the fact that thickened de-icing fluids form hygroscopic residues and may, thus, trouble not only aircraft with non-powered flying controls. Airport operators and de-icing companies must be made aware that the design features of such aircraft, in particular, require that they be given priority for de-icing immediately before take-off and that a two-step de-icing process be used with the first step invariably involving the application of unthickened (Type I) fluid or heated water.

Design effects on aircraft de-icing

As thickened de-icing fluids become less viscous and drain off the aircraft when subjected to the airflow they are not suitable for use on aircraft other than those which exceed the take-off run speed required for effective draining. Therefore thickened de-icing fluids are not used for de-icing of aircraft with a low V_R .

The power necessary to control large transport aircraft cannot be applied through mechanical controls like in small transport aircraft or business airplanes. Therefore a hydraulic system generates the power necessary to move control surfaces (elevator, rudder and aileron).

These aircraft also accumulate dry fluid residues in aerodynamically quiet areas which can absorb water and freeze if de-icing was carried out with thickened fluids. These aircraft experience fewer control problems because the hydraulic system overrides the movement resistance caused by the mechanical system and the control surfaces.

Aircraft serving long-range routes are not de-iced as often due to the flight cycle structure specific to long-range operation and climatic conditions at their destinations. The tests have shown that this affects the amount of dry fluid residue. Most of the re-hydrated residues and any components which have become unserviceable due to their exposure to de-icing fluids are identified and removed upon periodical flying-hour based maintenance.

The aircraft types involved are transport airplanes with a seating capacity of 40 to 130 passengers serving short-range and medium-range routes. Due to their size the necessary pilot forces to move control surfaces are not so high that only a hydraulic system could generate them. In order to reduce pilot forces a servo tab (Flettner) is moved mechanically. The resulting aerodynamic forces move the elevator tab into the intended direction and keep it there.

In principle this very effective and smooth-running control is very sensitive to any resistance on elevator tab surfaces. A stiff elevator tab or servo tab, a change in elevator tab mass, e.g. by entrapped condensed water, adhering ice or frozen de-icing fluid residues, will significantly raise the pilot forces required with resulting delay in control response.

The tests of the fluids have shown that the control problems of aircraft with non-powered flying controls are caused by the properties of de-icing fluids to form hygroscopic residues and to absorb water. This currently unavoidable side-effect of thickened de-icing fluids can pose a risk for flight safety which is not acceptable to airlines.

If the Properties of the thickened de-icing fluids to form hygroscopic residues cannot be ameliorated or eliminated, the handling of the identified problems for aircraft with non-powered flying controls must be regulated so that the risk for flight safety is minimised.

In order to minimise the risk actions to eliminate causes and to reduce effects are necessary. It is indispensable to establish procedures to reduce the use of thickened de-icing fluids on such aircraft to the minimum extent mandated by the weather situation. In cases where Type II or Type IV fluids were used a mandatory maintenance procedures must be applied. The aircraft manufacturer must provide operators and maintenance organisations with the necessary explanations and instructions by including them into their aircraft manuals.

Organisation of aircraft de-icing

De-icing fluids clearly cause the global problems after aircraft de-icing. The causes for the European problems (excluding Scandinavia) after aircraft de-icing are clearly due to the circumstances in Europe. In the USA aircraft with non-powered flying controls experience significantly fewer control problems after de-icing than in Europe. Comparison shows that this does not reside in the weather or the de-icing fluids but rather in an unsound trend of the European de-icing fluid market.

The increase of control problems after de-icing of aircraft with non-powered flying controls has its origin in the fact that de-icing with unthickened de-icing fluids (Type I) has decreased due to the ever reduced supply. Only one third of all European stations has Type I fluids in stock. If it is not possible to increase the supply and use of Type I fluids in Europe unacceptable risks for flight safety due to aircraft de-icing will remain.

As long as aircraft de-icing was accomplished by technical services of certified airlines or an approved maintenance organisation, this ground service – as an integral part of the organisations' business – had to comply with the flight operation safety regulations, which are still applicable to maintenance operations. National civil aviation authorities supervise maintenance organisations concerning the performance of their technical duties in aviation. Since the ground operation aircraft de-icing is accomplished through organisations specially established for this purpose aeronautical regulations and their supervision do not apply any more. What remains is the contractual connection with the certified operator.

The wish to have one de-icing fluid suitable for all aircraft exists since aircraft de-icing is accomplished with more than one fluid. The option to realise this

wish emerged just from the documentation which has always been the basis for the annual review of the de-icing planning on airports. Special features in the design of aircraft with non-powered flying controls and their effects have, so far, not been mentioned in SAE standards or AEA specifications. Even aircraft manuals of the aircraft involved do not differ in regards to de-icing problems from manuals for aircraft with powered flying controls. They do allow almost unlimited use of thickened de-icing fluids.

Under the given circumstances it was just a matter of time when aircraft de-icing only with thickened fluids would develop due to costs and the wish of many operators in Europe to have prolonged holdover times. The justified objections of operators operating aircraft with non-powered flying controls against this development was warded off with the reference to costs. The market situation cannot and will not be influenced by contractual regulations between de-icing companies and operators.

Safety must come from within the system. Transferred to the flight operation of a transport aircraft this means that all departments within the operator involved in transport performance must be committed to this common goal. Control problems after de-icing of aircraft and the unsound development of the European de-icing fluid market, in particular, are ample evidence for the mandatory requirement that de-icing technicalities, too, be integrated in the overall aeronautical system in order to ensure safe wintertime flight operations. Currently this incorporation does not exist because de-icing companies as contractual partners of operators are not subject to aeronautical regulations.

Conclusions

Immediate causes for the serious incident were:

- Several de-icing procedures with thickened de-icing fluids (Type II) caused an accumulation of dry fluid residues (polymer residues) in the gap between elevator and horizontal stabilizer.
- Due to atmospheric exposure these highly hygroscopic residues absorbed, from the surrounding air, a multiple of their own weight of water, became a gel-like mass and swelled-up to many times their original volume.
- With low ambient air temperatures the oversaturated gel froze increasing its volume to such an extent that it jammed the elevator and horizontal stabilizer.

- Elevator control was jammed due to ice formation because the aircraft did not have powered flying controls and the necessary power to move the elevator tab mechanically could not be generated.

The systemic causes for the serious incident were:

- Stockpiling and use of a unthickened de-icing fluid is not part of the annual de-icing strategy at airports because de-icing specifications for aircraft with non-powered flying controls do not mention their special design features and their effects.
- If aircraft de-icing is organised along economical lines the use of unthickened fluids becomes ever less practicable because of the low demand for such fluids and the high complexity cost incurred.
- Ever more frequent thickened fluid de-icing of aircraft in the parking or ramp position added to the lower demand for unthickened fluids.
- Cleaning of aircraft was conducted at scheduled and perennial experience-based service day intervals which did not adequately reflect the number of thickened de-icing fluid applications; measured on the current level of knowledge.
- The manufacturer's documentation for operation and maintenance did not sufficiently indicate removal intervals for dry fluid residues.
- The specified, standardised and duly certificated thickened de-icing fluids showed significant variations in drying and re-hydration properties.
- The large variation in the properties of the standardised thickened de-icing fluids added to the difficulty in establishing adequate cleaning procedures for the airplane.

Safety Recommendation

Based on the results of the investigation, the BFU has issued the following safety recommendations:

- 07/06 The Federal Ministry of Transport, Building and Urban Affairs should agree with the Laender aviation authorities responsible for the airports on a joint procedure of the cognizant supervisory authorities designed to urge the ground services responsible for de-icing to apply not only thickened (Type II or Type IV) but also unthickened (Type I) de-icing fluids on airports regularly used by aircraft with non-powered flying controls and offering de-icing services.

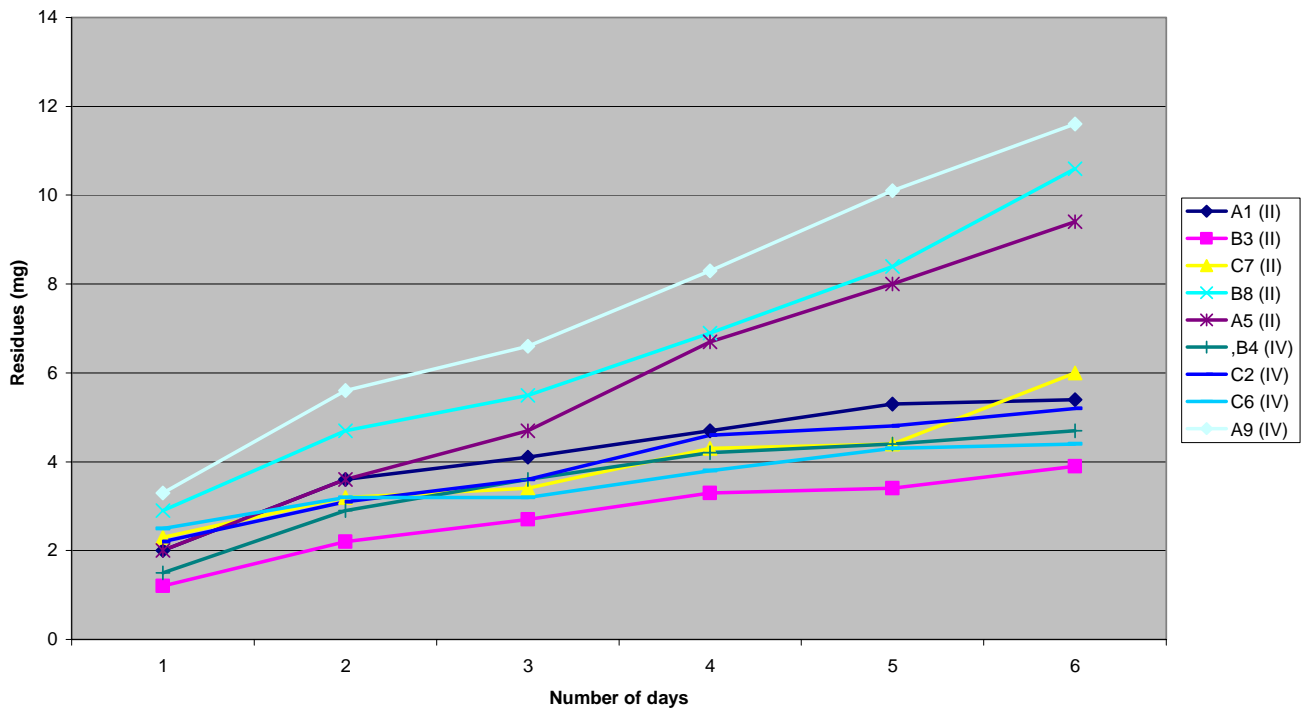
- 08/06 The European national accident investigation authorities should recommend to their respective aviation authorities to see that not only thickened (Type II or Type IV) but also unthickened (Type I) de-icing fluids are applied on airports regularly used by aircraft with non-powered flying controls and offering de-icing services.
- 09/06 Aircraft de-icing to maintain the airworthiness of aircraft during winter operation should be accomplished by certified and approved companies under the supervision of civil aviation authorities. If aircraft de-icing is not accomplished by an operator or an approved maintenance organisation the ground service "aircraft de-icing" should be subject to appropriate aeronautical regulation. EASA should agree with the European national authorities on establishing such regulations.
- 10/06 The expected drying and re-hydration properties of thickened de-icing fluids (Type II, III, IV) for aircraft de-icing should be described and defined by standardisation in such detail as to eliminate significant quality variations among the products of different manufacturers. EASA should develop certification criteria to establish mandatory limits for and require evidence of unrestricted suitability of such fluids for aircraft with non-powered flying controls.
- 11/06 Considering the thickened de-icing fluids currently available EASA should impose a mandatory requirement on non-powered flying controlled aircraft manufacturers to develop reliable procedures for their aircraft types to ensure the identification and removal of re-hydrated de-icing fluid residues in such time as to prevent any risk to the safety of flight operation.

Investigator-in-charge K. Büttner

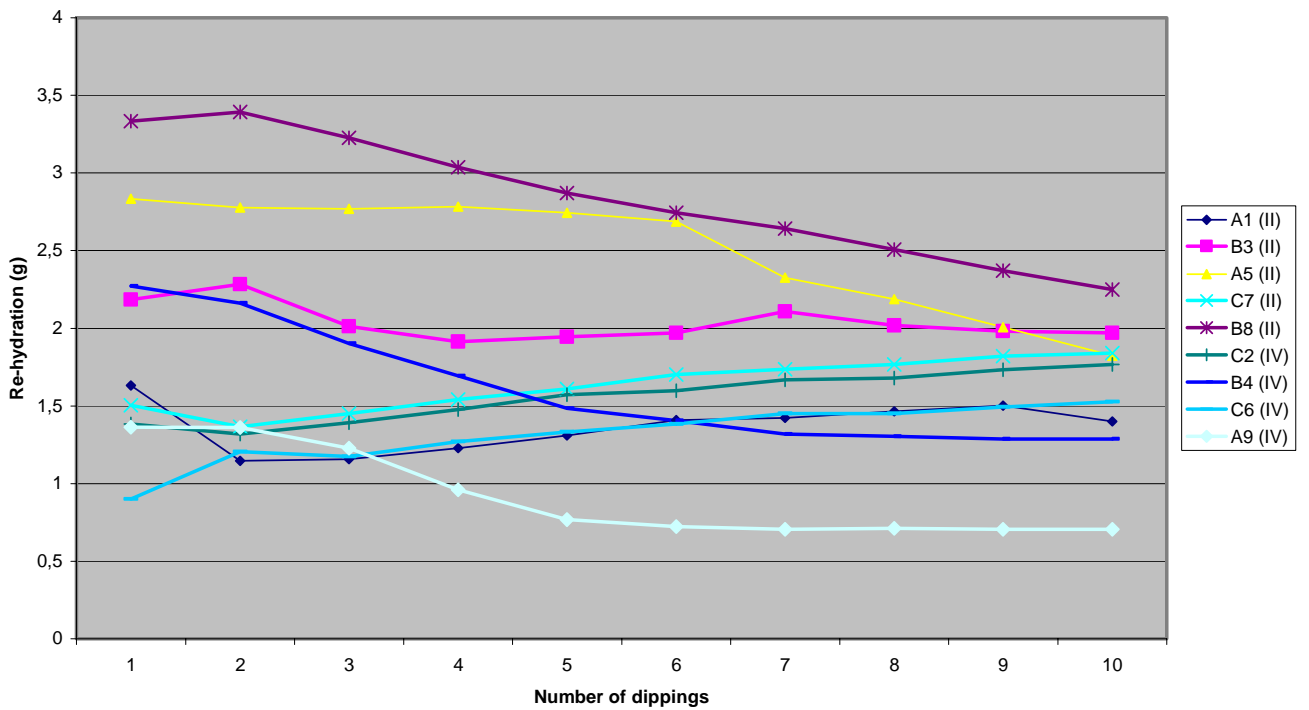
Appendices: Diagrams

Appendix 1

Residue - Type II / IV (100 %)

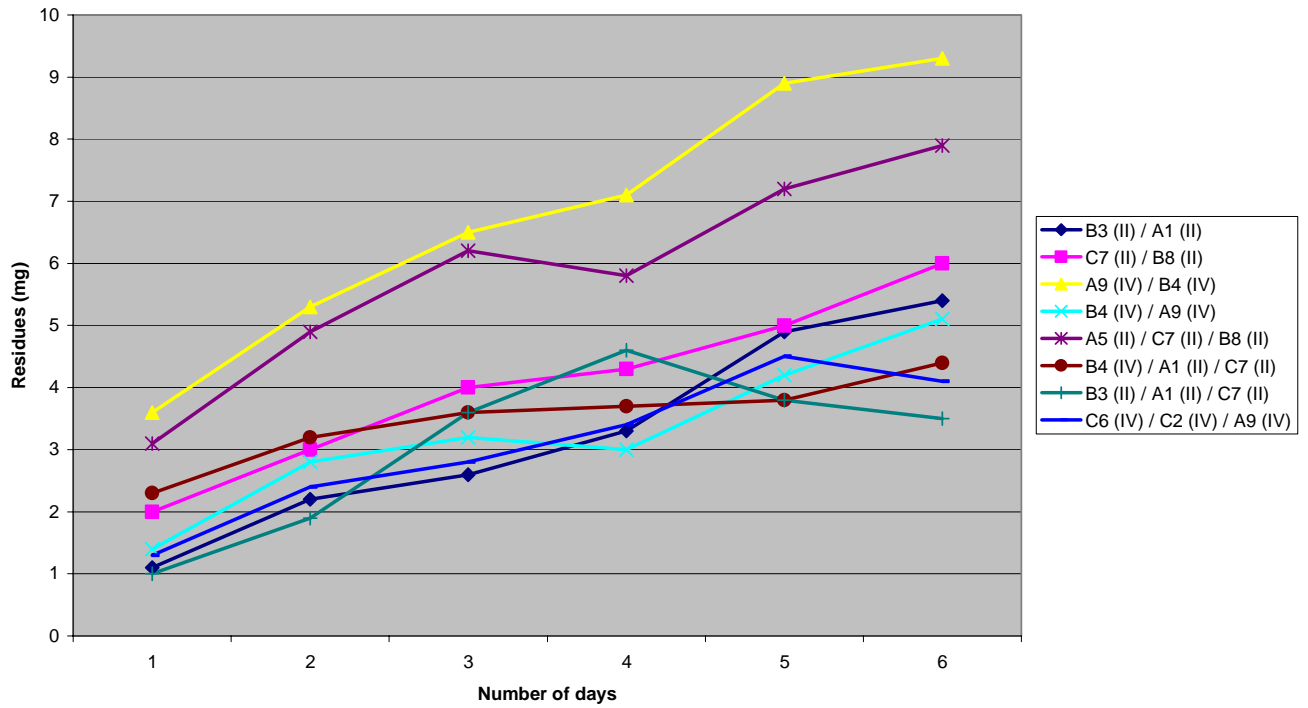


Rehydration - Type II / IV (100 %)

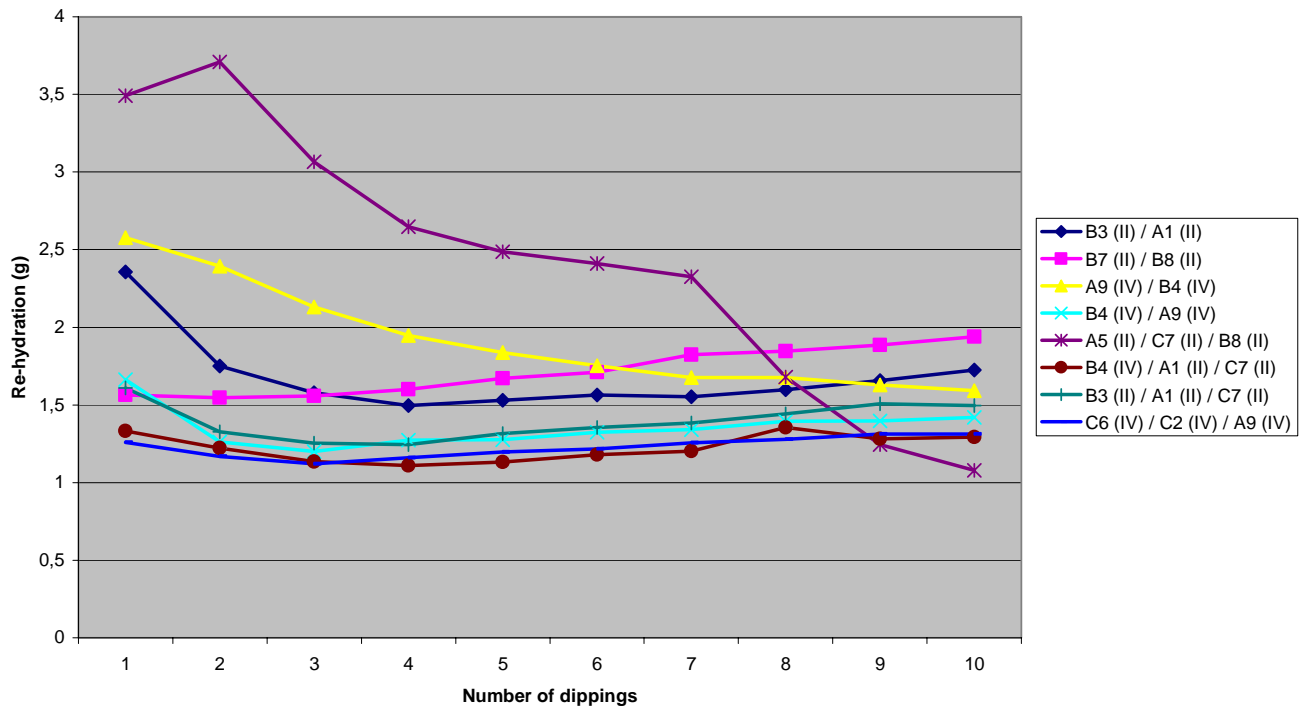


Appendix 2

Residue - Type II/IV-mix (100 %)

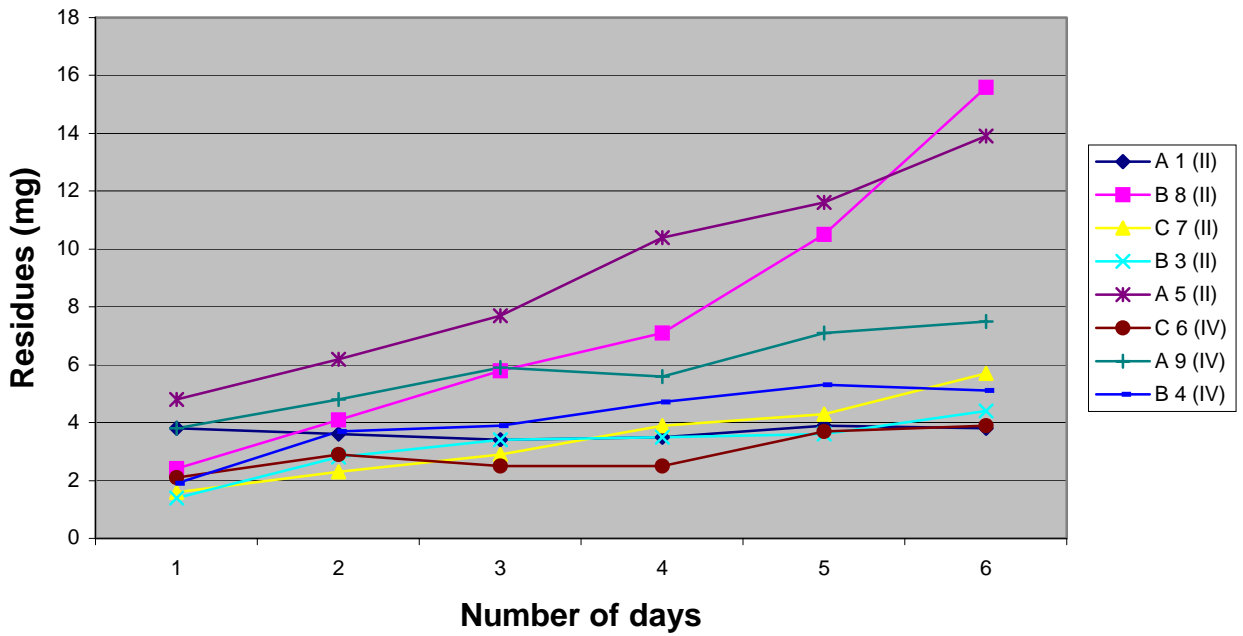


Rehydration - Type II/IV-mix (100 %)

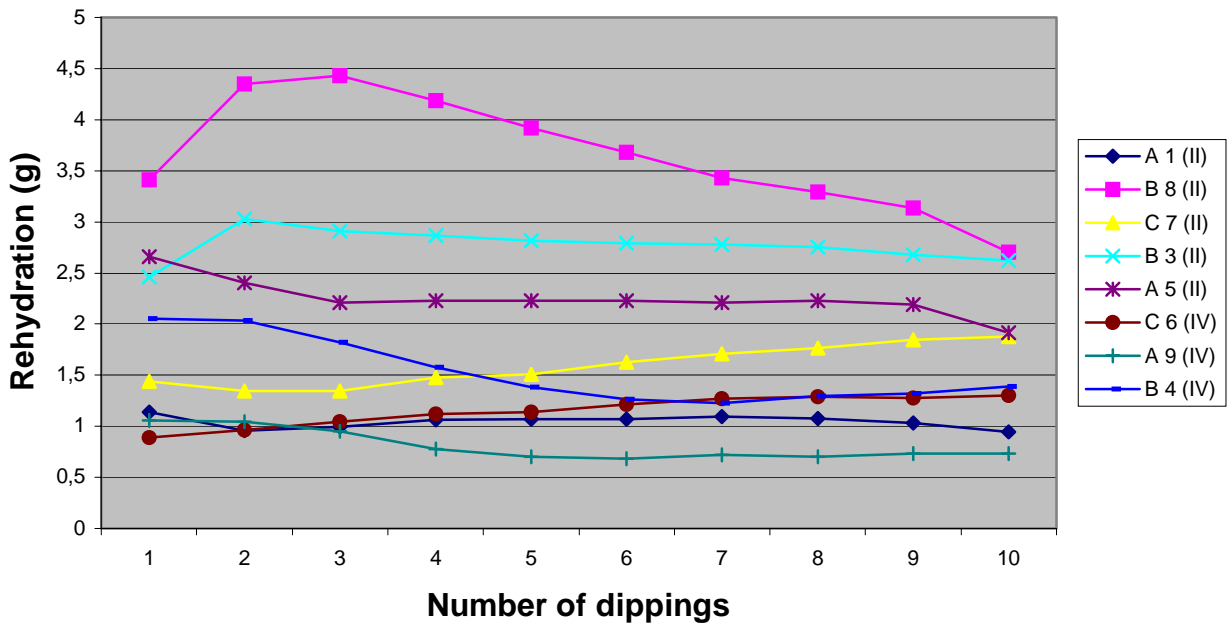


Appendix 3

Residue - Type II / IV (50 : 50)

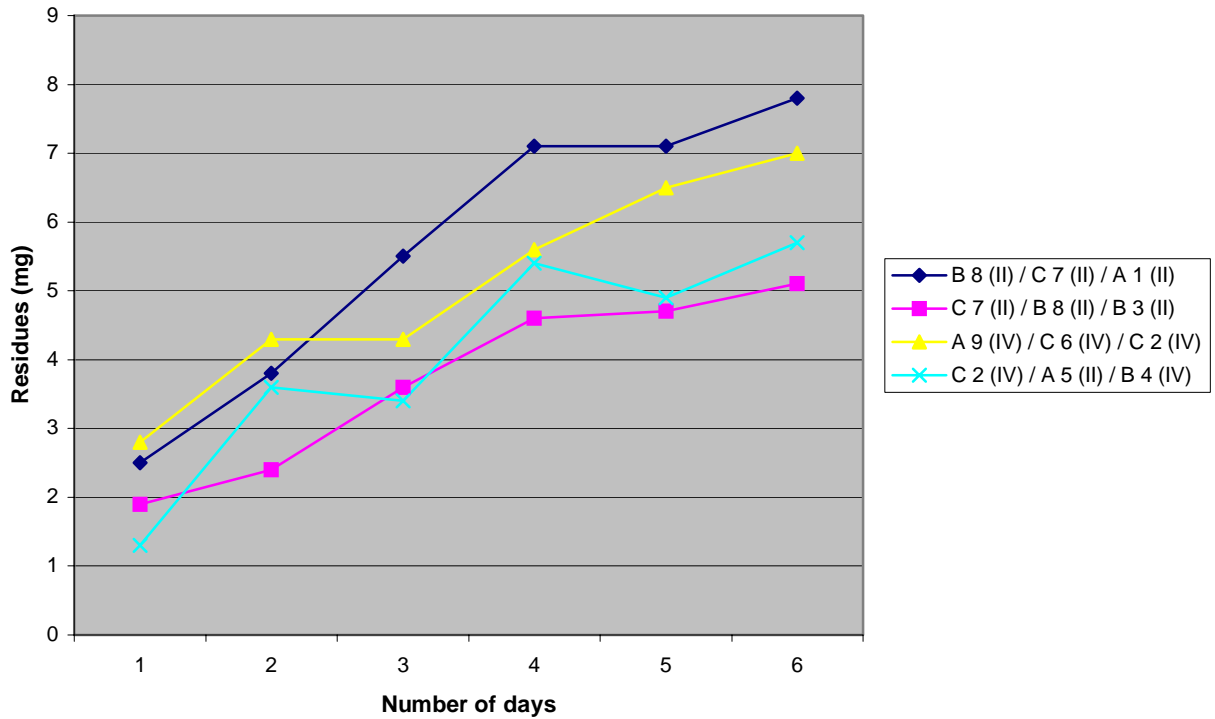


Rehydration - Type II/IV (50 : 50)



Appendix 4

Residue - Type II/IV- MIX (50 : 50)



Rehydration - Type II/IV- MIX (50 : 50)

