THERMAL TEST OF A CUBIC DUCTILE CAST IRON CONTAINER FILLED WITH AN ION EXCHANGER RESIN

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SUMMARY

The thermal test described in this paper is related to a more severe fire test criterion for the German repository "Konrad" (BfS 1995) in relation to the IAEA type B package fire test conditions. A container is tested without an impact limiter and has to withstand an 800°C-fire over one hour. The test container was made of ductile cast iron (GGG40) and filled with 2360kg of an inactive spherical ion exchanger resin with 50% moisture. The maximum temperature of ion exchanger resin in contact with the container wall was 392°C, 145°C at the bulk centre and the maximum inner pressure was 0.93 MPa. The maximum seal temperature was 238°C.

For a complete safety assessment it was necessary to verify that the content of the test container had a thermal stability less than ion exchanger resin after use in nuclear power plants. This was done by using thermogravimetry and small scale autoclave tests.

INTRODUCTION

The cubic container design for transport, interim storage and final disposal of non heat generating nuclear waste may be profitable because of the maximum utilisation of the available space of the storage and disposal facilities. Depending on the level of radioactivity of the waste products different requirements are defined for the packages which they have to fulfil according to the requirements for the German "Konrad" repository, a former iron ore mine which is within the running licensing process.

The thermal test is related to a more severe fire test criterion for the repository in comparison with the IAEA Type B package fire test conditions. This means that a so-called "Konrad"-container is tested *without* an impact limiter and has to withstand an 800°C-fire over *one* hour. BAM decided to perform a fire test with an original prototype container loaded with an inactive ion exchanger resin because of two uncertainties of the safety assessment. The first reason was according to leaktightness of the elastomere seals at high temperatures and pressure, and the second question was related to the maximum overpressure caused by water vapour and decomposition gases.

This paper presents current results of pre-test heat flux measurements with a water-filled cubic steel container, design tests and safety analysis for the full scale cubic ductile cast iron (DCI) container of the Konrad "Type VI" with outer dimensions of 2.0 m x 1.7 m x 1.6 m,150 mm wall thickness, a structural net mass of approximately 18.3 Mg and a maximum gross weight of 20 Mg which is manufactured by Gesellschaft für Nuklear-Service (GNS). The temperatures of the fire, at the container and inside the ion exchanger resin and the inner pressure were measured during and after the fire test. A thermogravimetry analysis (TGA) with different kinds of ion exchanger resins, and heating tests in an electrical furnace with a 0.5 litre pressure vessel were carried out with the aim to define a representative content for the safety assessment. The results of the prototype test can be used to verify finite element models especially for the heat and mass transfer inside an ion exchanger resin.

CONTAINER FIRE TEST

According to the requirements defined by the responsible German Federal Office for Radiation Protection (BfS) for the Konrad repository the container conservatively has to withstand an "IAEA-temperature-fire" over one hour. The leakage rate must be $< 1.0 \cdot 10^{-5}$ $Pa \cdot m^3/s$ before, and $< 1.0 \cdot 10^{-4}$ $Pa \cdot m^3/s$ after the thermal test. During the fire the pressure inside the container has to be measured and no unsteadiness of the pressure curve indicating undue leakage is permitted (BfS 1995).

A description of the BAM open fire test facility using propane burners and the method to verify the fire conditions is found in the previous paper (Droste et al.). In a first step we used a 1:1-container model made of welded steel sheets and filled with water to find essential parameters for the burner configuration and a necessary propane consumption rate (BAM1995). The actual test container (BAM1996) was made of ductile cast iron (GGG40), see Fig.1. It was filled with the spherical ion exchanger "LEWATIT S100 KR/H-chlorfrei" from BAYER with around 50% moisture content.

For measuring pressure and temperatures of the ion exchanger and seals inside the container the measuring cables of the pressure gauges and thermocouples were led out through an additional orifice in one side wall. The cables were protected against the fire by using an isolated pipe. The orifice was closed by a flange which was sealed with a metallic gasket. Most of the thermocouples inside the container were fixed on a steel rack at the three symmetric axes of the container. The measuring points at the container wall, at the lid and in the fire are positioned on the same axes (Fig.2).

Fig. 3 shows the fire temperatures and demonstrates that the test conditions fulfilled the requirements. It is also a good example of an "IAEA-fire" with an “average” fire temperature of about 800°C and a total heat flux of approximately 75 KW/m^2. The helium leakage rate of the lid system was $<10^{-8}$ $Pa \cdot m^3/s$ before and $<3.0 \cdot 10^{-6}$ $Pa \cdot m^3/s$ after the fire test. During the fire the inner pressure increased but reached its maximum of 0.93 MPa after 5 hours. No discontinuity in the pressure curve occurred. After 4 days the internal pressure decreased to about 0.43 MPa. The maximum wall temperature inside the container reached 392°C after 73 minutes. The maximum seal temperatures reached 238°C for the main seal after 2.6 hours and 210°C for the cover plate seal after 5 hours. Fig. 4 shows the temperature distribution inside the ion exchanger along a horizontal symmetric axis. It shows a delayed heat transfer and a temperature distribution strongly influenced by mass transfer, see e.g. the thermocouple with 215 mm distance from the container wall where the temperature increased in a very short time to about 100°C. The maximum temperatures of ion exchanger resin occur in the edges and corners of the cubic container and was estimated to be more than 400°C.

SMALL-SCALE FIRE TESTS

The small-scale fire tests were carried out in an autoclave of 0.5 litre volume (Fig. 5) inside an electric furnace (BAM1997). The content was fresh (unloaded) ion exchangers of mostly spherical shape. Only one test was carried out with a loaded powder mixture of anion and cation exchangers, which represents a typical mixture of ion exchangers used in the German nuclear power plant "Krümmel". Figure 6 for cation exchanger and figure 7 for anion exchanger and a mixture of both show the pressure rise as a function of the inner ion exchanger resin temperature. It was found that a decomposition of an ion exchanger resin can cause high pressure even though the loss of mass is small. Information according to mass loss and the corresponding temperature range can be given by the thermogravimetry method. Fresh anion exchanger resin e.g. already at around 120°C have a mass loss of approx. 10%, which causes in combination with an exothermic reaction a dramatic pressure rise (see Fig. 7, the curve for Levasorp A50). But the two curves for Levasorp A50 (fig. 7) show also the influence of the heating rate.

CONCLUSIONS

A thermal test with a DCI type VI container filled with a representative ion exchanger resin in an one hour 800°C-fire has demonstrated that distribution of inner temperatures and pressure are a complex matter not only during the fire but also during the cooling down phase. The effects of water and shape of the exchanger resin (powder or sphere) are of great importance for the heat transfer mechanisms and thus for the thermal distribution inside the container content. This shows the comparison of test data with a pre-test numerical calculation done by GNS neglecting the mentioned effects, e.g. the water contents. The maximum container and seals temperatures agree well, but the maximum estimated inner filling temperature was only 70°C instead of 145°C. The maximum pressure is a synthesis of water vapour pressure and decomposition gas pressure and is hard to calculate.

The heat capacity of the container is also very important because the decomposition depends on the heating rate.

Thermogravimetry can be used to investigate if a mixture of or an unique ion exchanger resin has decomposition products at very low temperatures, e.g. below 200°C.

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Figure 1. Test container in the fire test

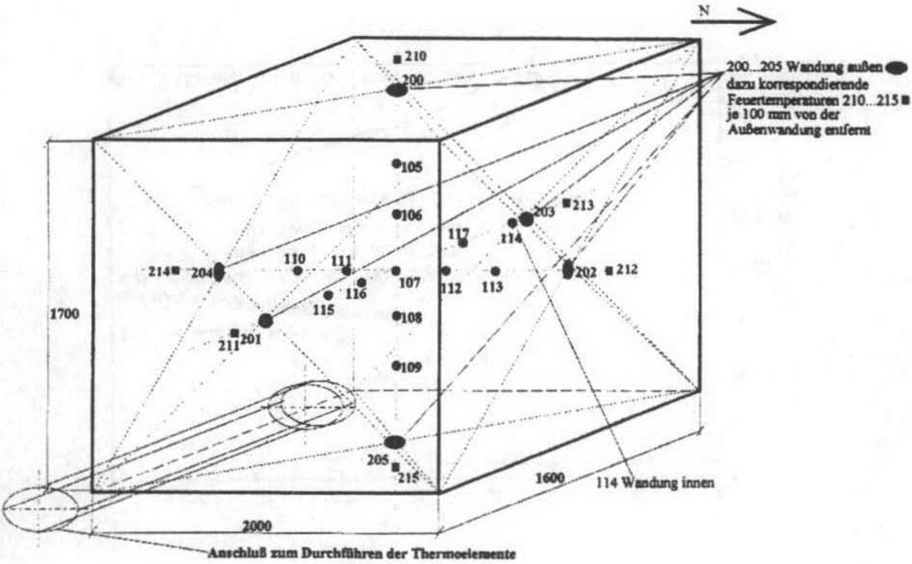

Figure 2. Scheme of measuring points in the container fire test

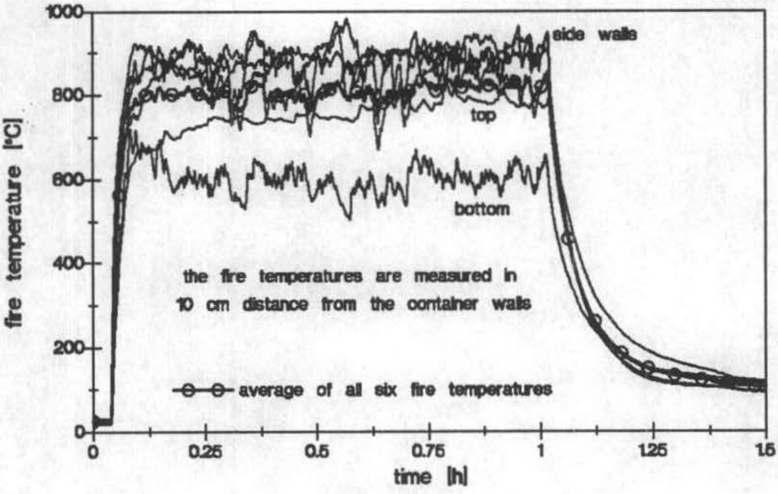

Figure 3. Fire temperature during DCI container fire test

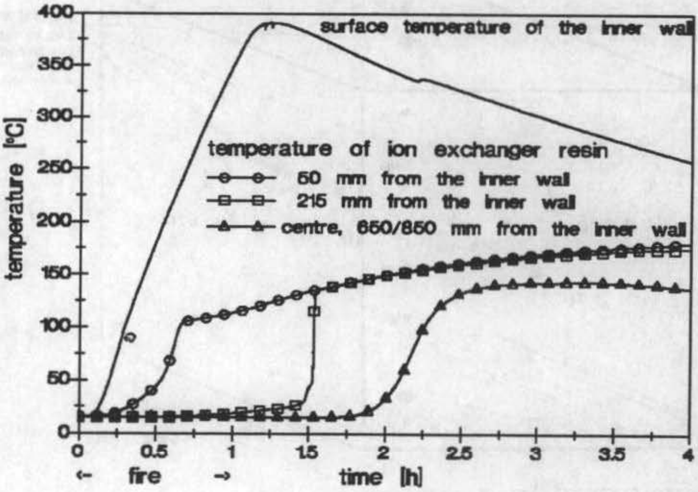

Figure 4. Temperature distribution inside the ion exchanger in the container fire test

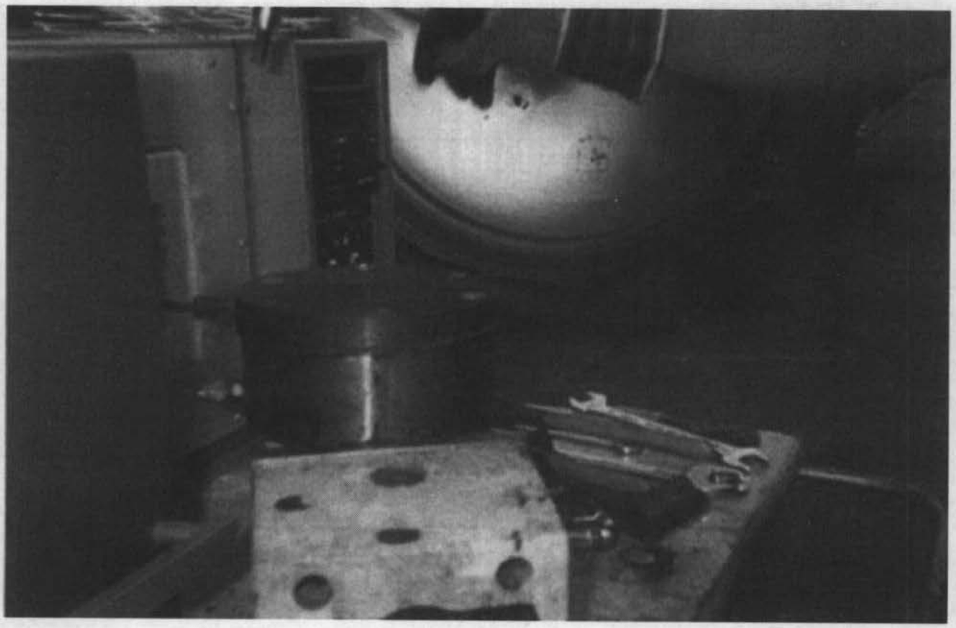

Figure 5. Furnace and autoclave for the scale test

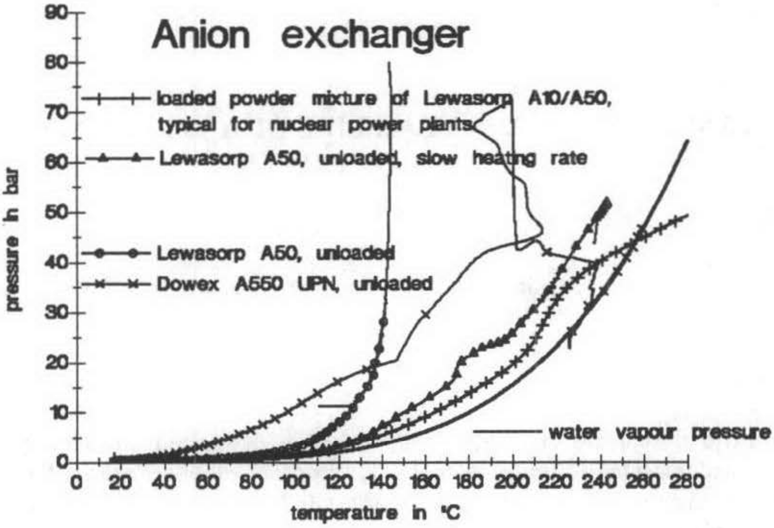

Figure 6. Temperature vs. pressure curves for anion ion exchanger materials

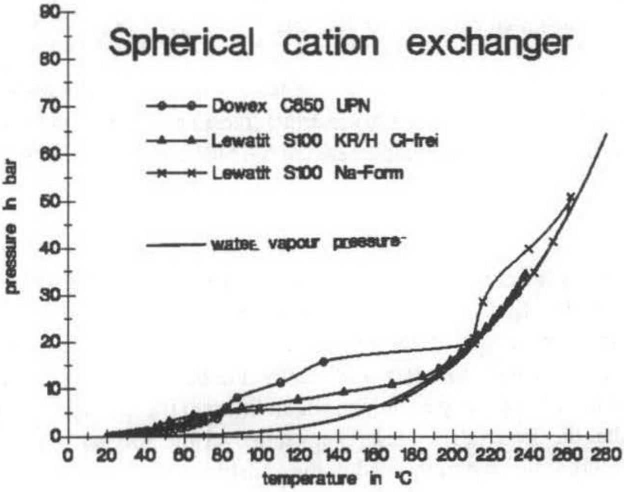

Figure 7. Temperature vs. pressure curves for cation ion exchanger materials