CONCRETE AS A SECOND SURROUNDING SYSTEM AGAINST HAZARDOUS ORGANIC FLUIDS

BETON ALS SEKUNDÄRES UMSCHLIESSUNGSSYSTEM GEGENÜBER UMWELTGEFÄHRDENDEN FLÜSSIGKEITEN

BETON EN TANT QUE BARRIERE CONTRE DES LIQUIDES ORGANIQUES POLLUANTS

Michael Aufrecht - Hans-Wolf Reinhardt

SUMMARY

Facilities for production, storage and handling of hazardous fluids need a second barrier in case of leakage of the primary containment. The second barrier may be a concrete structure which should be impervious to hazardous fluids at least during the period of hazard. In a controlled plant, this period is about 72 hours.

Tests have been performed to measure the capillary suction and the uptake at elevated pressure. Various organic fluids and different concrete compositions have been tested. A new testing device is described. It is shown that concrete is a suitable and impervious material for the required time.

ZUSAMMENFASSUNG

Anlagen zur Produktion, Lagerung oder Verwendung umweltgefährdender Flüssigkeiten werden mit einer zweiten Barriere im Falle einer Leckage des primären Dichtsystems erstellt.

Als sekundäres Umschließungssystem kommt häufig eine Betonbaukonstruktion zum Einsatz, die gegenüber der ausgetretenen Flüssigkeit mindestens für die Dauer des Störfalls undurchlässig sein soll.
In überwachten Anlagen ist hierfür ein Zeitraum von 72 h anzusetzen.

Um die kapillare Flüssigkeitsaufnahme und die Flüssigkeitsaufnahme unter erhöhtem äußerem Druck zu messen, werden Versuche durchgeführt. Verschiedene organische Flüssigkeiten und Beton mit unterschiedlicher Zusammensetzung werden geprüft.
Eine neue Prüfmethode wird näher vorgestellt.
Es wird gezeigt, daß Beton ein geeigneter und undurchlässiger Werkstoff für den erforderlichen Zeitraum darstellt.

RESUME

Les installations pour la production, le stockage et la manutention de liquides polluants demandent une seconde barrière pour le cas d'une fuite du premier recipient. La seconde barrière pourrait être une construction en béton imperméable aux liquides polluants au moins pendant la perturbation. Pour les installations contrôlées c'est une période d'environ 72 heures.

On a réalisé des essais pour mesurer la succion capillare et la succion sous pression élevée. Des liquides organiques et des compositions de béton différents ont été étudiés. Un nouveau dispositif d'essai est décrit. Il est montré que le véton est un matériau approprié et imperméable pendant un délai demandé.

Key words: Hazardous fluids, Penetration, Concrete, Uptake, Testing method, Porosity

1. INTRODUCTION

There are numerous structures in the chemical industry which have to provide the necessary safety against the pollution of soil and ground water. It is usual to split up the safely provisions into two barriers the first of which is the primary containment of the liquid and the second is a secondary wall or a catching basin. The secondary barrier has its tightening function only in case of leakage of the primary containment.

A collecting vessel is a multifunctional structure. In most cases, the floor of the basin is also the foundation of the storage tanks, it serves as an industrial floor during mounting of installations and may also be a production site. On the other hand, it has to ensure impermeability of toxic fluids. The moment being, it is very common to split up the functions, i.e. to use the concrete structure as a load bearing facility and to use a coating, a plastic of metal layer for tightening purposes. However, such a design has its disadvantages which may be technical or economic. This led to the single layer approach utilizing concrete as load bearing <u>and</u> fluid tight material.

Since concrete is known as a porous material which is not absolutely impervious to fluids one has to investigate the physical properties with respect to the requirements. In the following, the testing method which has been developed and the testing results will be presented and discussed.

2. TESTING PROGRAMME

2.1 Testing method

German regulations for the approval of collecting basins and other safety relevant secondary barriers require that the barrier is impervious under a fluid pressure of 1.4 m during 72 h. This requirement takes into account that infrastructure of the plant is such that the accident is detected within 48 h and that the fluid is pumped out within 72 h. These conditions led us to a testing method with a constant pressure head.

2.1.1 Penetration under pressure

The specimen is a cylinder with 100 mm diameter and 200 mm height. The cylinder may be drilled from a slab or casted in a mould. The cylinder jacked is coated with an epoxy resin while the ends remain free. At the upper end of the vertical cylinder, a glass funnel is fixed with an opening equal to the cylinder. The funnel is connected to a reservoir of compressed air or an inert gas. At the beginning of the test, a certain amount of the fluid is poured into the funnel and the pressure is applied via a pressure reducing valve. Fig.1 shows the device schematically.

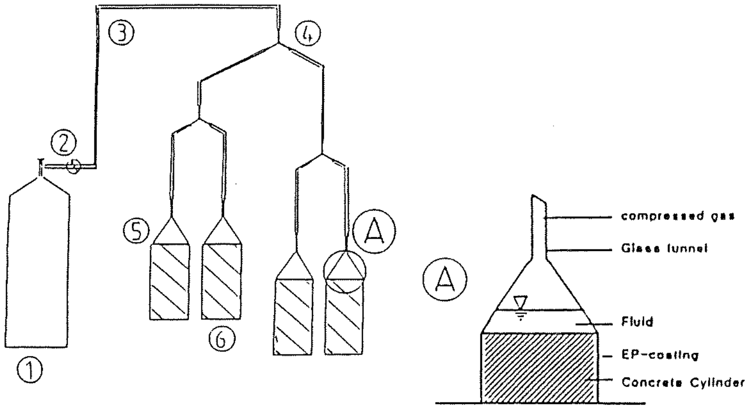

Fig. 1 Testing device with constant pressure.
1) Compressed air or inert gas, 2) Pressure reducing valve, 3) Plastic tube, 4) Manifold, 5) Glass funnel, 6) Specimen

The fluid penetration is measured gravimetric. To this end, the tube is disconnected, the fluid is poured from the funnel and the specimen is weighed. After weighing, the fluid is poured back to the same level and the test continues. Such an operation takes 30 s. After the whole test is completed the specimen is split mechanically and the penetration front is inspected visually.

There are several other testing methods with the same requirements [1] which differ in size, measuring technology and user friendlyness. The new testing method as described above combines a few characteristic features:

- Short mounting and demounting time.
- Universal use for various pressures, temperatures and humidities.
- Great security during handling and operation.
- Small fluid quantity.
- Great accuracy and reproduceability.
- Simple standard elements.

After many tests, reliability and cost efficiency have been experienced.

2.1.2 Capillary suction

The fluid transport in a porous medium like concrete under external pressure is a combination of capillary suction and penetration. In a semi-infinite space, penetration and capillary suction are due to mechanical forces - external pressure and capillary forces - which can be superimposed. It depends on the ratio between external pressure and capillary traction which mechanism is more important. Generally speaking, a material with small size pores like concrete will be more likely governed by capillary suction. This is the reason why the rather simple capillary suction test has been also applied to other fluids than water.

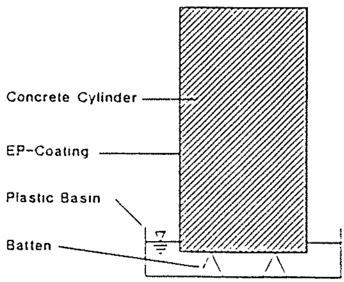

Fig. 2. Schematics of the capillary suction test

Cylindrical concrete specimens have been used with 100 mm diameter and 200 mm height. The specimens are coated at the cylinder jacket, they are immersed in the fluid as shown by Fig. 2.

The adsorbed fluid is measured gravimetrically. A measuring operation takes 15 s.

The testing results of both types of tests will be compared and it will be discussed which type of test is most suited for practical purposes.

2.2 Testing fluids

During this exploratory study, three fluids have been used which are specified in Table 1.

Table 1. Relevant properties of three testing fluids

Fluid	Chemical formula	Dyn. viscosity mPa s	Surface tension mNm^{-1}	Specific gravity kgm^{-3}	Water solubility at 20°C
Butanol	$CH_3(CH_2)_3OH$	2.93	33.5	809.4	about 8 %by mass
n-Heptane	C_7H_{16}	0.4048	20.3	680	non-soluble
Water	H_2O	1	72.75	998.2	infinitely soluble

These fluids have been chosen because dynamic viscosity and surface tension differ greatly. The expression $(\sigma/\eta)^{1/2}$ is the governing parameter for capillary suction which is 3.38, 7.08, and 8.53 $(m/s)^{1/2}$ resp. The effect of this parameter can be overshadowed by the water solubility which, however, will not be investigated in detail.

2.3 Concrete

This exploratory study contains several mixes aiming at the influence of water/cement ratio and grading curve on the fluid penetration. The first two concrete mixes were made with a water/cement ratio of 0.53 and 0.70 resp. in order to generate a large difference in capillary porosity. The maximum aggregate size was 16 mm, the cement content 385 and 290 kg/m^3 resp. The mean cube compressive strength at 28 days amounted to 40 MPa and 22 MPa resp.

The second series of concrete mixes used a constant w/c ratio of 0.54 but varied in maximum aggregate size between 2,8,16 and 32 mm. The cement content was 483, 346, 325, and 315 kg/m^3 which led to very similar consistency. The mean cube compressive strength varied only little, between 46 and 49 MPa at an age of 28 days.

The specimens were prevented from drying during the first 10 days whereafter they were stored in the laboratory at about 20°C and 65% r.h. Penetration testing took place at an age of about 90 days.

3. TESTING RESULTS AND DISCUSSION

3.1 Penetration of butane alcohol

The two types of tests as described in chapter 2.2 were carried out with butane alcohol on concrete with w/c ratio of 0.53 and 0.70. The test duration was 24 h.

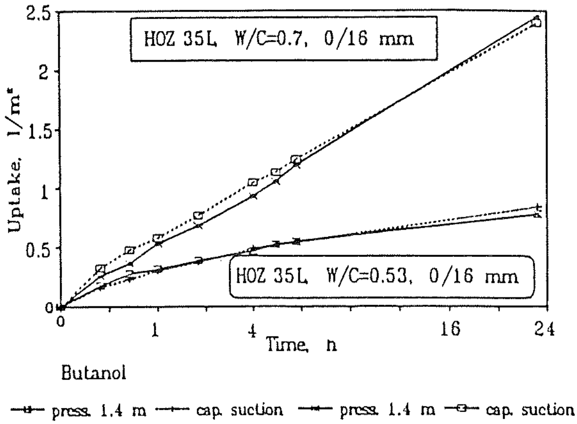

Fig. 3. Uptake of butanol during 24 h

As can be seen from Fig. 3. there is a continuous fluid uptake which follows almost a straight line in the linear square-root plot. During the first 15 min the uptake rate is a little larger which can be attributed to an instant wetting of the large compaction and air voids near the concrete surface. The results follow closely the theoretical square-root relation.

The influence of the w/c ratio is quite obvious. Whereas the uptake of the concrete with w/c = 0.70 amounts 2.5 l/m² after 24 hours the concrete with w/c = 0.53 shows only a third of that amount. This result confirms the fact that a lower w/c reduces the capillary pores and thus makes the concrete less pervious.

Fig. 3 shows that the type of test had almost no influence on the result, i.e. the additional hydrostatic pressure of 1.4 m did not accelerate the fluid uptake. Obviously, the pore system of the concrete is such that capillary forces are decisive for the fluid transport.

3.2 Penetration of n-heptane and water

The second series of tests aimed at the influence of the maximum aggregate size on the fluid penetration. Fig. 4 shows, as an example, the uptake of n-heptane and water during 72 h in a linear - √t plot for a concrete with 32 mm maximum aggregate size. It can be seen that n-heptane penetrates almost twice as fast into concrete than water.

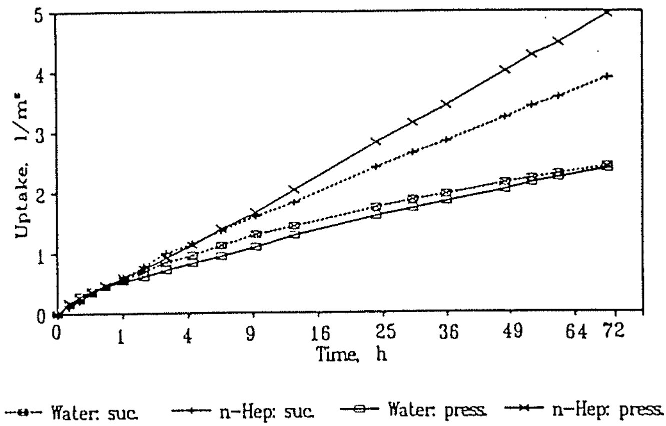

Fig. 4. Uptake of n-heptane and water during 72 h

These experiments confirm also the square root relation of the fluid uptake. Opposite to the results with butane alcohol, the pressure test leads to larger uptake of n-heptane than the capillary suction test. Recalling Table 1 makes it presumable that the lowest viscosity has caused such a difference.

With varying aggregate size the uptake differed strongly as can be seen form Fig. 5.

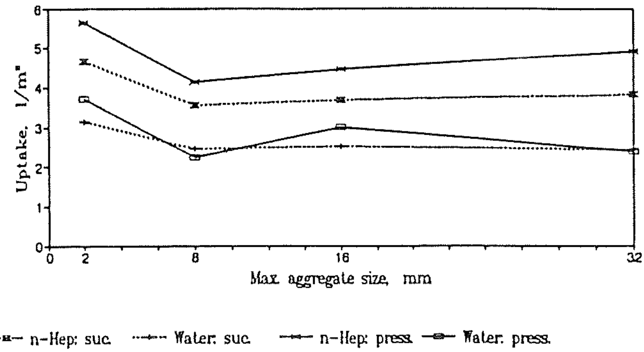

Fig. 5. Mean uptake after 72 h as function of maximum aggregate size

The upper line represents the pressure test results of n-heptane which have the largest value at an aggregate size of 2 mm, the lowest at 8 mm and increasing values for larger aggregates. This typical relation is also valid for the other results, with one exception, the pressure test result for water and 16 mm grain size. Since no reason could be found justifying this deviation it can only be attributed to scatter.

The relation shown in Fig. 5 can partly be explained by the porosity and partly by technological effects. As given in chapter 2.3 the cement content was largest for the small grain size and since the w/c ratio was the same the amount of paste is larger with smaller grain size.

Fig. 6 shows that the porosity as determined by mercury intrusion is about 0.24 for 2 mm max. aggregate size and drops to about 0.17 for 8 mm and 0.14 for 32 mm grain size.

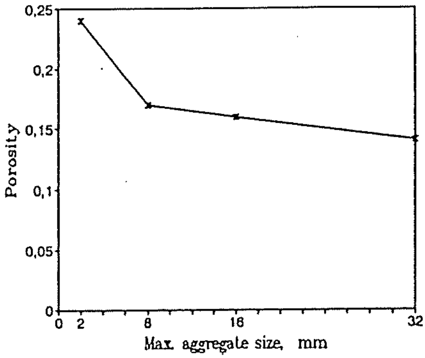

Fig. 6 Porosity vs. maximum aggregate size

Thus, there is a steep decrease in the first range and less in the second. This steep decrease explains the drop in fluid uptake for the 8 mm grain. However, this does not explain the increase of fluid uptake from 8 to 32 mm. This increase can be attributed to inhomogeneous paste structure under the larger grains in the concrete [2] and to micro-cracking around grains due to shrinkage of the hydrated cement paste. Although both arguments are valid in general they have not yet been verified by experiments in this testing series.

Looking to Fig. 5 in a practical oriented way, it can be concluded that aggregate size has only a minor influence on the fluid uptake of concrete.

4. CONCLUSIONS

A main goal of the study was to develop a reliable, accurate and simple testing method for the penetration of an arbitrary fluid into concrete under constant pressure. The device is described in chapter 2.2.1 meets this goal.

The exploratory study on a few concrete mixes has shown that

- the water/cement ratio has a large influence on the fluid penetration;

- the maximum aggregate size between 8 and 32 mm has only a minor influence while 2 mm max. aggregate size enhances the fluid suction.

- the uptake under a pressure of 1.4 fluid column is almost the same as the capillary suction except for very low viscosity of the fluid. Since the capillary suction test is the easiest to perform it is recommendable in most cases.

The results demonstrate that a concrete barrier can be made impervious to organic fluids if the water/cement ratio is low enough and if only a limited duration of imperviousness is required.

REFERENCES

[1] Fehlhaber, T.;Reinhardt, H.-W.; Transport organischer und anorganischer Flüssigkeiten und Gase in Beton. DAfStb, Bulletin 416, Berlin, 1991, pp 21 -46.

[2] Hoshino, M.; Difference of the w/c ratio, porosity and microscopical aspect between the upper and the lower boundary paste of the aggregate in concrete. Materials and Structures, 21, (1988), pp 336-340.

[3] Ziegeldorf, S; Kleiser, K.; Hilsdorf, H. K.; Vorherbestimmung und Kontrolle des thermischen Ausdehungskoeffizienten von Beton. DAfStb, Bulletin 305, Berlin 1979.

[4] Aufrecht, M.: Planung und Konstruktion der Versuchsaufbauten FMPA Baden-Württemberg, 1991, unveröffentlicht.