

# **SIMULTANEOUS TRANSPORT OF AN ORGANIC FLUID AND GAS IN CONCRETE**

## **GLEICHZEITIGER TRANSPORT EINES ORGANISCHEN STOFFES IN FLÜSSIGEM UND GASFÖRMIGEM ZUSTAND IN BETON**

### **TRANSPORT SIMULTANE DE FLUIDES ORGANIQUES ET GAZ DANS LE BETON**

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#### **SUMMARY**

Organic fluids are widely used in our personal and technical world. Since most of them are hazardous for the groundwater concrete structures are built for environmental protection. Due to its porosity, concrete is not a priori impervious and it has to be tested which requirements should be met for technical applications. Testing techniques are presented to measure the capillary absorption and the diffusion coefficient continuously. Five concrete mixes were examined with acetone as testing fluid. The testing method is presented and results are given and discussed.

#### **ZUSAMMENFASSUNG**

Organische Flüssigkeiten werden heute vielfach in Haushalt und Industrie eingesetzt. Da die meisten davon wassergefährdend sind, werden heute Betonbauten für den Grundwasserschutz gebaut. Weil Beton wegen seiner Porosität nicht a priori undurchlässig ist, werden Versuche durchgeführt und Grenzen der technischen Anwendung ermittelt. Versuchsmethoden für die gleichzeitige Messung des kapillaren Saugens und der Diffusion werden vorgestellt. Fünf Betonzusammensetzungen wurden mit Aceton geprüft. Ergebnisse werden mitgeteilt und erläutert.

## RÉSUMÉ

Des fluides organiques sont largement utilisés dans notre monde personnel et technique. Etant donné que la plupart d'eux sont nuisibles pour les eaux souterraines des structures en béton sont construites comme protection de l'environnement. Grâce à sa porosité le béton n'est pas a priori imperméable et il est nécessaire d'examiner quelles exigences doivent être remplies pour l'application technique. Des techniques d'essai sont présentées pour mesurer l'absorption capillaire et le coefficient de diffusion.

Cinq mélanges de béton sont examinés avec acétone en tant que fluide d'essai. La méthode est présentée et les résultats sont donnés et discutés.

## 1. INTRODUCTION

Man-made organic fluids are part of our personal and technical world, as fuel for cars, as solvents in paint and glue, as fluids for cleaning of cloth, metal and ceramic, as oil for heat and energy plants, as raw material for the production of plastics etc. There are thousands of organic fluids which are produced in refineries and chemical plants, stored, handled, transported, and used. Since the vast majority of these liquids is harmful to the human health and to the environment there is a need for control. During each step from production to end use it has to be assured that the organic fluid does not contaminate soil and ground water.

It is common that production facilities, storage tanks and pipes are tight and that they are checked in regular intervals. However, it may happen during an unforeseen event that fluid escapes from the facilities and that it would reach soil and ground water. Since this is not acceptable a second barrier has to be built

which collects the fluid in such a - seldom - case. The fluid will stay there for a certain time and will be removed and stored or treated elsewhere. In Germany, the responsible authorities agreed that catching basins should be impervious for 72 hours if the infrastructure guarantees the removal of the liquid within 48 hours [1]. Other boundary conditions may require other durations.

Many existing catching basins and production floors are made of reinforced concrete, and current design is often based on reinforced concrete because concrete is rather economic, weather proof, abrasion resistant, and load resistant. On the other hand, concrete is a porous material and a priori not impervious. Whether it is impervious enough for a certain time is the subject of current research. This paper will deal with some testing devices which have been developed. First results will be presented and discussed.

It is also well known that concrete has only little ductility and that cracks develop when the tensile strength is reached. However, the aspect of the permeability of cracks will be treated later. The present study is confined to uncracked concrete.

## 2. PROBLEM DEFINITION

It should be investigated how fast and how deep an organic liquid penetrates into concrete if the liquid is in contact with concrete under atmospheric pressure or with a small hydraulic head. There are the mechanisms of capillary absorption, diffusion, and hydraulic permeation. The amount of fluid which penetrates can be measured gravimetrically or volumetrically. The depth of penetration is

usually not visible during the test and has to be detected by special devices or measured at the end of the test.

Besides the liquid phase it should be assumed that there is a gaseous phase precursory of the liquid phase. In a rigorous approach to environmental protection, it has also to be known if and when gas reaches the outer face of the barrier.

The paper deals with two test methods which enable measuring the absorbed volume and penetration depth of a fluid and with one method which allows also measuring gas permeation.

### 3. ABSORPTION AND PENETRATION MEASUREMENTS

There are various testing methods in use which have been reviewed in [2]. They can be distinguished into capillary absorption tests and in those with additional hydraulic head. Because concrete contains very small pores in the hydrated cement paste the capillary pressure is rather high compared to the hydraulic head of a few meters. It has been shown theoretically and experimentally that the results of both tests are the same within the scatter band. Only in case of high water/cement ratio (i.e. large capillary pores and total porosity > 15 %) and/or low viscosity of the fluid (dyn. viscosity < 0.5 mPa s), additional hydraulic head leads to deeper a penetration.

A testing device has been developed at our institute [3] which allows the application of any hydraulic head between zero and 50 kPa. The schematic is

shown in Fig. 1. A concrete cylinder with 100 mm diameter and an arbitrary length is coated by a gas tight epoxy layer. A glass funnel is glued on top of the specimen and sealed to the epoxy coating. The funnel contains a small amount of liquid which can be easily removed when the specimen is weighed. The funnel is connected to a compressed gas reservoir via a manifold and pressure reducing valve. The main advantages compared to other methods are the small amount of liquid (which is usually harmful) in the system, the choice of hydraulic head, and the compact arrangement of specimens and devices which have to be placed in an exhaust (maybe explosion-proof).

The fluid absorption is measured by weighing the specimen after certain intervals. For that purpose, the glass funnel is disconnected from the pipe and the fluid is poured out.

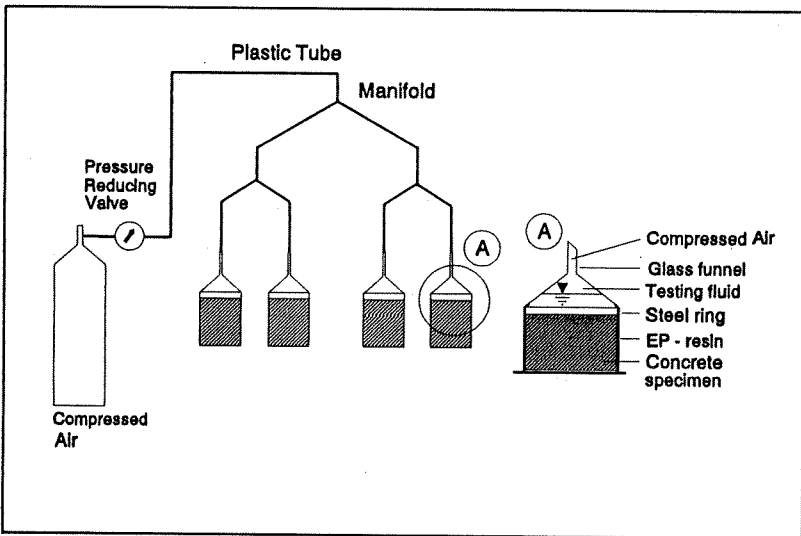
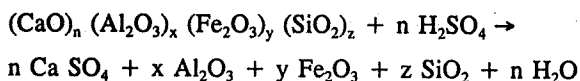
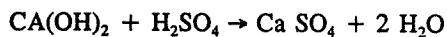


Fig.1 Testing device for penetration measurements with hydraulic head

The depth of penetration can be measured only once at the end of the test. (If a transparent epoxy coating is used and if the cylinder has a cast surface the penetration depth shows up at the cylinder surface and can be measured continuously.) The specimen is split through the cylinder axis in two halves and the penetration depth can be observed either visually or by applying concentrated (98 %) sulphuric acid [4].

Visual inspection is not possible if volatile organic fluids are tested. In that case, sulphuric acid is sprayed on the cylinder halves immediately after splitting and dried with the flame of a Bunsen burner. Sulphuric acid carbonizes organic material and turns to a black colour. Calcium compounds react with sulphuric acid according to the following equations:



Gypsum loses its combined water due to the heat of the flame. The remaining anhydrite has a white colour. The result is a rather sharp and well visible line at the penetration front.

Test results have shown the accuracy, reproduceability, and usefulness of the methods [2,4] if only the absorbed volume and/or the wetting front are important. The main result is the square root relation between volume and depth vs. time as expected from theory of capillary absorption [5,6]. The second is the scaling of liquids according to  $\sqrt{(\sigma/\eta)}$  with  $\sigma$  = surface tension and  $\eta$  = dyna-

mic viscosity. The general results are given in the schematic of Fig. 2. Deviations from these general results will be discussed in a separate paper.

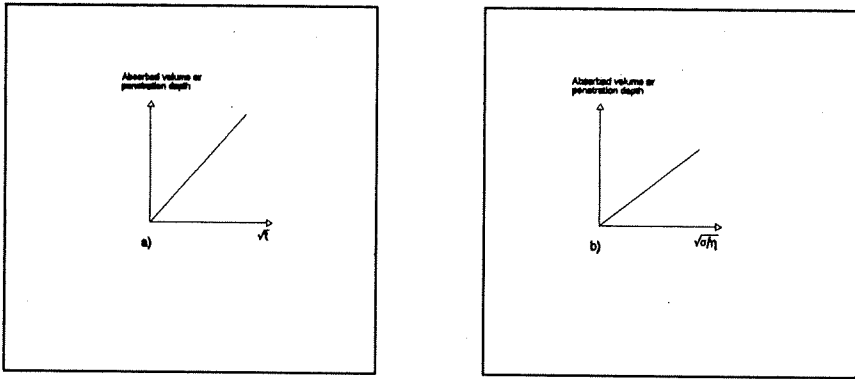


Fig.2 Schematic of absorbed volume or penetration depth vs. square root of time (a) and surface tension divided by dynamic viscosity (b)

#### 4. CONTINUOUS MEASUREMENT OF FLUID ABSORPTION AND GAS TRANSPORT

##### 4.1 Testing device

The testing device is designed to enable continuous measurements of absorbed volume of fluid and of diffusing gas through the specimen in one direction. Fig. 3 shows the arrangement. The upper part concerns the fluid absorption while the lower part reflects the gas diffusion. The specimen is positioned vertical and in contact with the fluid on the upper surface. By means of compressed air and a pressure reducing valve, additional pressure simulates a hydraulic head between

zero and 50 kPa. The fluid level is monitored by a photoelectric beam through the glass pipette on the funnel. If the fluid level in one of the samples is lowered the valve is positioned and the pump is triggered to operation until the original level is reached. The supplied amount of fluid is monitored by the MCU (Measure and Control Unit). Monitoring and control frequency can be chosen between once a few seconds and days.

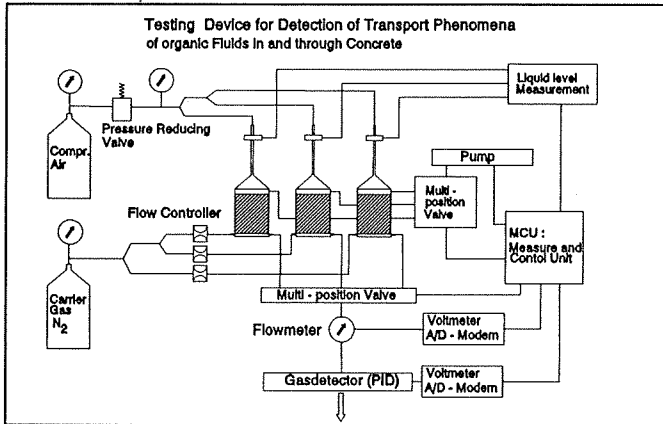


Fig.3 Testing device for simultaneous detection of transport phenomena of organic fluids in and through concrete

Along the lower face of the specimen, nitrogen circulates and flushes gas which diffuses through the specimen to a gas detector. The total gas flow is measured in a flowmeter and controlled by a flow regulator. The amount of diffusing gas can be calculated from the results of the flowmeter and the gas detector. Preliminary tests have resulted in an optimal continuous flush rate of 4 ml/min.

The gas detector is a photo-ionization detector (PID) which operates as follows.

The flush gas is contaminated by the diffusing gas. The gas is exposed to UV light and the organic molecules are irradiated by photons of the UV light. The energy of the photons is such that air and flush gas (oxygen, nitrogen, carbon oxide, carbon dioxide, water) are not affected. The ionized gas passes a gap between two electrodes and generates an electric current between them which is amplified and measured. The measuring signal is proportional to the concentration of the contaminating gas, i.e. to the gas to be tested.

There are several advantages of the PID. The ionization energy can be adjusted to the gases according to Table 1. Second, the measuring range stretches from 0.1 ppm (for Isobuten) up to saturation at standart pressure and 20°C.

Table 1. Ionization potential (eV) for media

Fluid/gas	Potential (eV)
acetone	9.69
n-heptane	10.07
n-hexane	10.18
acetic acid	10.37
methanol	10.85
water	12.59

Third, the response time is only three seconds. Fourth, if the gas flow is further diluted via a bypass the measuring sensitivity can be optimized.

The PID is usually calibrated by flushing gas along a liquid surface. This concentration represents gas saturation at the given pressure and temperature. In this investigation a dummy concrete with water/cement ratio of 0.6 is prepared. A disk of 15 mm thickness is exposed to the testing fluid until the

remote face turns to a dark colour which means that the wetting front has reached the non-exposed face. The measurement at this stage leads to the same results as on the fluid surface and corresponds to saturation at a given temperature and pressure.

#### 4.2 Specimen

The concrete specimen is a cylinder with 100 mm diameter and variable length according to the testing aim (see Fig. 4). The cylinder surface is coated by a gas tight and 3 mm thick epoxy layer which seals also a steel ring on top of the specimen. A glass funnel with pipette is attached to the steel ring and carries the photoelectric beam sensor. The 2 mm thick steel ring is connected to the liquid supplying pump. The lower end of the specimen is connected to a glass plate by the epoxy sealant. Two flexible 1/16" wide PTFE tubes are connected to the flush gas reservoir and the PID, respectively.

Before testing the specimens were stored at 20°C and 65 percent relative humidity during 9 to 12 months after casting. They were prepared for testing about 4 days in advance.

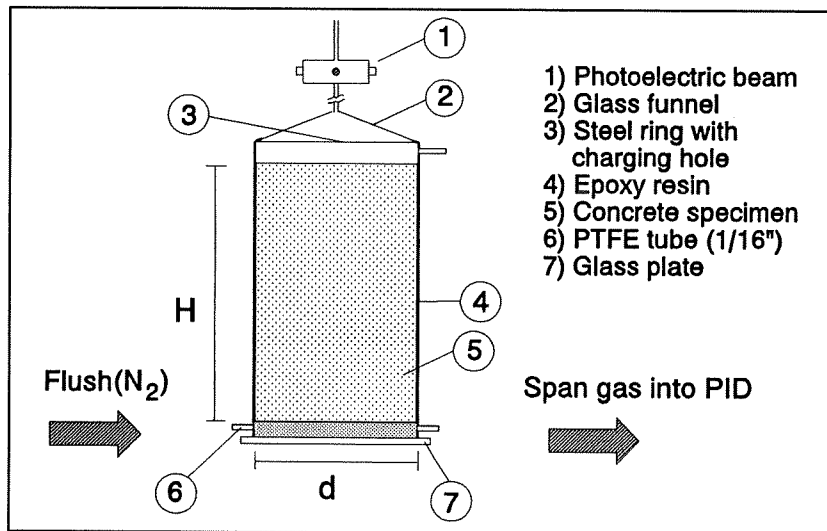


Fig.4 Sample construction

## 5. TESTING PROGRAMME

A limited testing programme has been carried out containing five concrete mixes and one testing fluid.

### 5.1. Concrete

Table 2 shows the composition of the five concrete mixes, the standard properties at 28 days and the age at testing. The cement of all mixes is a medium rapid hardening Portland cement type PZ 35 F which is the most used in Germany.

Table 2. Properties of the concrete tested

Concrete no.	1	2	3	4	5
Cement content, kg/m <sup>3</sup>	320	328	320	313	311
Water content, kg/m <sup>3</sup>	130	148	160	188	218
Water/cement ratio	0.40	0.45	0.50	0.60	0.70
quartzitic aggregate, kg/m <sup>3</sup>					
fraction 0-2 mm	1913	1905	1857	1818	1803
2-8 mm	670	667	650	636	631
8-16 mm	670	667	650	636	631
	573	571	577	546	541
Paste content, m <sup>3</sup> /m <sup>3</sup>	0.233	0.254	0.263	0.289	0.318
Workability, cm (Spread table test)	1)	39	37	41	58
Vibrating time, s	90	45	40	35	25
Density at 28 d, kg/m <sup>3</sup>	2350	2340	2310	2310	2290
Compressive strength <sup>2)</sup> at 28 d, MPa	63	60	51	44	33
Age of testing, months	9	10	13	12	11

1) not measurable

2) of 150 mm cubes, mean of 3 results

The paste content is calculated from

$$V_{paste} = V_{water} + M_{cement}/\rho_{cement} \quad (1)$$

with  $\rho = 3100 \text{ kg/m}^3$ ,  $V = \text{Volume}$ , and  $M = \text{mass}$ .

## 5.2 Testing fluid

The testing fluid is acetone [C<sub>3</sub>H<sub>6</sub>O] which is miscible with water and very

polar. The relevant properties are shown in Table 3. The boiling point is at 56°C.

Table 3. Properties of acetone at 20°C [7]

Vapour pressure	23.3 kPa
Density	790 kg/m <sup>3</sup>
Surface tension	23.7 mN/m
Dynamic viscosity	0.316 mPa s

These properties should lead to quick and deep penetration into concrete.

## 6. TEST RESULTS FROM CONCRETE SPECIMENS WITH A HEIGHT OF 100 MM

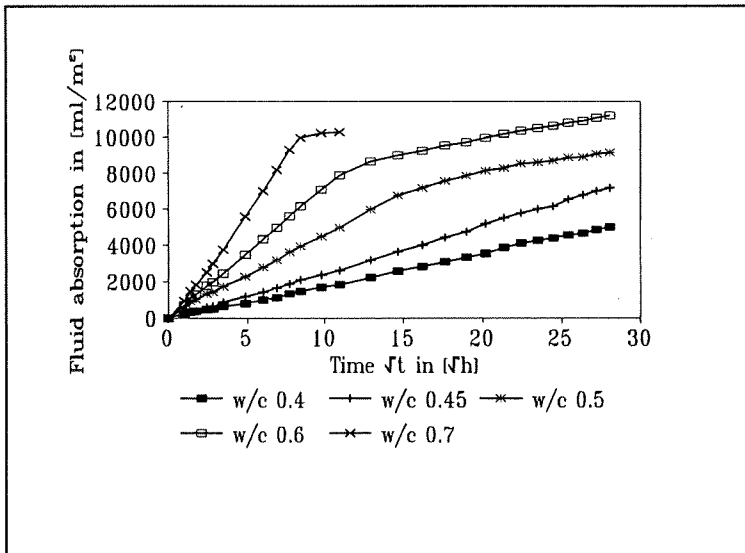


Fig. 5 Fluid absorption

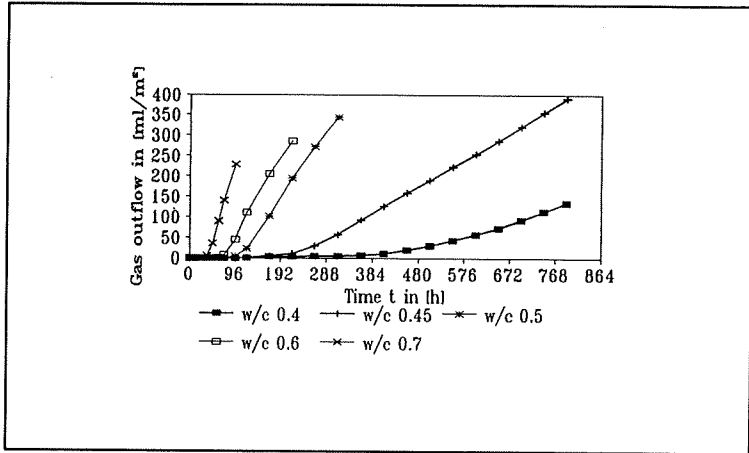


Fig. 6 Gas outflow

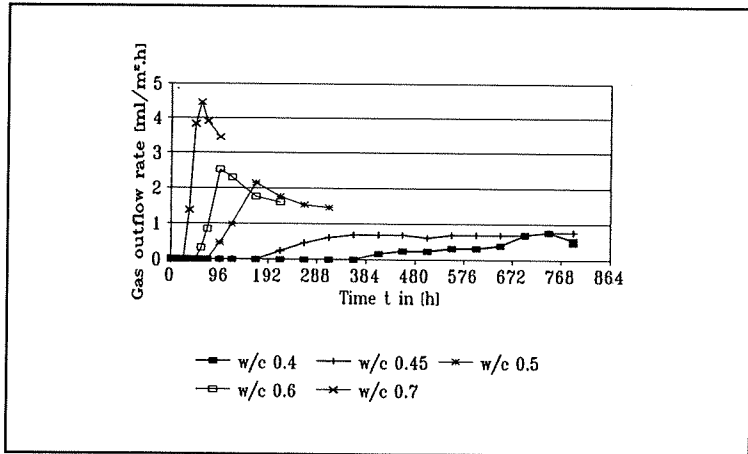


Fig.7 Gas outflow rate

The specimen length was 50 and 100 mm, respectively. Figs. 5 to 7 show the fluid absorption and the gas outflow of one specimen size. Each line is one individual measurement. The tests were carried out with a hydraulic head of about 2.5 kPa.

The fluid absorption follows clearly a straight line in the linear-square root plot. This holds for all concrete mixes for both sizes of specimen.

The gas outflow starts only after a certain time. Then a progressive increase is shown which turns later to an almost straight line in the linear plot. This behaviour has been found for all concrete mixes and for both specimen sizes.

## 7. OUTLOOK

The test results are currently evaluated with respect to the penetration coefficient and diffusion coefficient. Without showing details, preliminary data shows that the simultaneous transport of fluid and gas can be modelled analytically assuming a weighed summation of both phenomena. A subsequent publication will be devoted to this subject.

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