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TWO-PHASE TRANSFER EXPERIMENT ON A THICK CONCRETE WALL UNDERGOING A RAPID INCREASE OF TEMPERATURE AND PRESSURE

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TEST EQUIPMENT

The accident conditions (LOCA) consist of a rise from ambient temperature to a dew point of 140°C and a pressure of 5.0 10^5 Pa in approximately 20 seconds, followed by two possibilities :
- one, for the LOCA (loss of coolant accident), is a lowering of the temperature after 1000 seconds, with an exponential return to the initial temperature at t=100,000 seconds ;
- the other, more severe, for the OD (Off Design accident conditions), is a continuation of the rise of the temperature, at a rate of 3° K/hour, and of the total pressure, By 2.17×10^4 Pa/hour, up to 7.4 10^5 Pa after 40,000 seconds, followed by cooling.

Since the intensity of the signal is large and the energy is transported in the latent form of condensation. This necessitates heating the surface of the shell uniformly to a temperature slightly above the dew point and producing the steam signal by burn-out on the superheated hearth.

The various sensor outputs are recorded during the testing process, but the instantaneous data from these points are sampled by microcomputer that, using the program implanted in it, constantly compares the evolution of the ambience of the steam generator (P, Pa, Tr, T f(t)) and orders the necessary corrections. This thus simulates a dimensionless containment in spite of the transfer flowrates.

The pressure tap consists simply of a pure drawn copper pipe having an inside diameter of 0.4 mm and an outside diameter of 0.8 mm. This is the minimum usable diameter. Near the end of the pressure tube is welded a constantan wire 0.5 mm in diameter that forms, with the tube, a calibrated thermocouple. The arrangement is diametrical and located at the center.

The measurement span is divided among 5 flow meters, from 1.3 10^{-3} m^3/s to 3,33 10^{-9} m^3/s.

Preceding the flow meters is the measurement chamber of an automatic dew point hygrometer.

The assembly is controlled by a microcomputer that calculates the temperature, pressure, and flowrate data as a function of time.

TEST PROCEDURE

The concrete chosen for this study was made with the aggregates used for the containment of the Penly power station.

Two compositions were selected : one very close to that used on site and another in which the fines content was deliberately reduced by screening to 0.63 and eliminating the filler and the plasticizer to obtain a high permeability.

21 tests were performed according to the same general principles : measurement of permeability to isothermal air before and after the LOCA stresses. Let"s look at figs. concerning the results of the pressure and temperature measurements of the steam test on specimen 5.6.

It can be seen first that the simulated LOCA signal was imposed using our means and that the steepness of the basic data signal, which would impose a rise time of 25 seconds, is reflected in practice by a rise in 250 to 300 seconds. The recommended temperature plateau, a hundred or so seconds, is maintained for 1000 to 1500 seconds to satisfy the minimum of 600 to 1000 seconds corresponding to the pressure plateau of the basic signal. The thermal response of the steam generator to cooling, on the other hand, is faster than that of the real containment, making it necessary to compensate a little for the evolution of the temperature to avoid a drop of steam pressure.

It is also possible to hold the plateau for a very long time, not because this type of signal corresponds to any specified accident, but to yield a better judgment of the evolution of the phenomena.

Thus, figures 1, 2 and 3, for test 5.6, show that a signal sustained in temperature and pressure in the containment makes it possible to observe clearly that the measured pressures inside the concrete go through a maximum at t = 1000 s, indicating that there is plugging of the pores by the liquid phase, which reduces the pressure of the porous body downstream of the condensation barrier. As the tempreature gradient is established, this barrier moves like the 100°C isotherm and the pressures upstream of the barrier rise when the spaces are freed of the liquid phase.

Figure 3 shows the air flowrate coming out of the wall, with a maximum slightly shifted with respect to the pressure since the flowrate measurement is separated from the event (plugging of the pores) by a wall thickness. It will be noted that the flow ceases at 11,000 s and that the pressure rise at a depth of 10 centimetres did not affect it.

In the 0.9-meter wall (fig.1),when the permanent regime has been established the temperature of 100°C reaches the thickness of 0.25 m ; the isotherm stops advancing and the air flowrate is zero at the outlet of the wall. There is now established, following the variable regime, a regime of internal exchange under temparature and partial vapor pressure gradients by diffusion towards the structure to establish the distribution of water contents in the latter. There follows a partial unplugging and the air flowrate is more hesitant -of the order of 2.8×10^{-7} m^3/s at 28 hours- after remaining at zero for 9 hours. The transfer by vapor diffusion is very slow and the damp air flowrate very low, as shown by specimen 5.6, which was dried before the test and still produced a dew point of the gas at the outlet of -15°C, or a small partial pressure of 180 Pa.

The concrete exhibited a permeability to air of 2.1×10^{-17} m^2 before the first steam test 5.1. After this test, the global permeability was $K=8,9.10^{-17}$ m^2. The concrete was then stoved before test 5.6, which we have just looked at. It lost 6.9% water and its permeability was then $K=4,4.10^{-15}$ m^2. At the end of the steam test, maintained for 28 hours, its permeability was $K=2,15.10^{-16}$ m^2.

We shall now consider composition no 2, which is gap-graded.

The results of the first steam test, 7.1, show that the temperature signal was held for 22 hours (80,000s) and that the final temperature gradient is nearly identical to that recorded for concrete 5.6, but the time of establisment was 60,000s in that case. The 100°C isotherm reaches 25 cm. Show that the pressure measurements of test 7.1 are quite comparable to those of test 5.6,with pressure levels approximately 20% greater. The pressure drops are of the same order of magnitude but the time to onset of the events is, as in the case of the temperature, longer than in 5.6 and for the air and vapor flowrates, the phenomenon already encountered.

To compare a few results refer to the table below.

CONCR	TESTS	Air flowrate $m^3.s^{-1}.10^6$ m^{-2}		vapor flowrate $kg.s^{-1}.10^8$ m^{-2}		Cumulative flows air.10^2	Cumulative flows vapor.10^3	Duration écoulement measured	K $m^2.10^{17}$	
		max.	mean	max.	mean	$m^3.m^{-2}$	$Kg.m^{-2}$	secondes	Before	After
1	5,1	3,18	1,2			3,8		38 000	2,1	8,9
1	5,2	4,8		6,4	6,3		1,6		5,0	0,58
1	5,6	199	14	17,7	4,34	133	4,12	95 000	440	21,5
2	7,1	184,7	16,6	26,8	4,29	79,8	2,06	48 000	560	51
2	7,2	38,8	4,9	17,95	3,5	26	1,84	52 800		70
2	7,3	34,5	5,56	18,4	3,1	29	1,63	52 800	69	32,7

What should be borne in mind as essential concerning the mechanisms observed is that :

- depending on the initial state of the material, the transfer humidifies it or drains its humidity ;
- in the flow, three zones must be analysed (wet, saturated (or nearly) and dry) ;
- the two-phase flow loses part of its vapor by condensation on a moving phase-change front, reducing the flowrate, under some conditions to the extent of stopping the flow of the uncondensable phase ;
- the displacement of the front is governed by the establishment of the thermal gradient in the skeleton, the characteristics of which depend on the other three phases and vice versa [1].

MASS TRANSFER THROUGH A CRACK

In our tests,the diametrical crack of the sample leads to a very high ratio of crack length to area tested, 3 linear meters per square meter, making it possible, in the measurement of the sum of the flowrates, to neglect the diffusion of the gas via the concrete and to state the results as flowrates per linear meter of crack.

It will be noted that the crack does not seem to impose a faster local temperature rise. The temperatures near the surface and at 1 cm rise rather rapidly in the first 300 seconds, as with the other specimens, but that this rise is checked, with a slump at 1500 seconds reflecting plugging.

The shape of the pressures (fig.4) shows that the maximum pressure is located at 2000 seconds. As shown by the somewhat chaotic distribution, the distance from the crack to the sensors probably varies according to the level of the sensors. Thus, the sensor located at 15 cm detects an increase of pressure faster than the other sensors, probably because its orifice is located right in the crack.

In the OD part, after 5000 seconds, the containment pressure increases continually by $2x10^4$ Pa/h. The decrease of the internal pressures of the concrete continues for nearly 20,000 seconds in spite of the continuous increase of the pressure and temperature of the containment following the OD signal.

After 15,000 seconds at 0.05 m, then later at 20,000 seconds at 0.1 m, the local pressure rises under the influence of the pressure increase in the containment, which reaches 6.7 bars at this time. The temperature at 0.05 m or 0.1 m has not reached 100°C.

No changes are observed in the flowrate curves, their decrease following the passage of the maximum pressure leads to a flowrate that becomes smaller and smaller until the end of the accident. At the time of the accident, when the flowrate is maximum, the flowrate is $9.5x10^{-7}$ $m^3.s^{-1}.ml^{-1}$, while the minimum flowrate is $2.16x10^{-7}$ $m^3.s^{-1}.ml^{-1}$ at the end of the OD, when the containment pressure is 0.75 MPa. For the same pressure, the air flowrate, before the test, was $5.03x10^{-6}$ $m^3.s^{-1}.ml^{-1}$, 23 times as large.

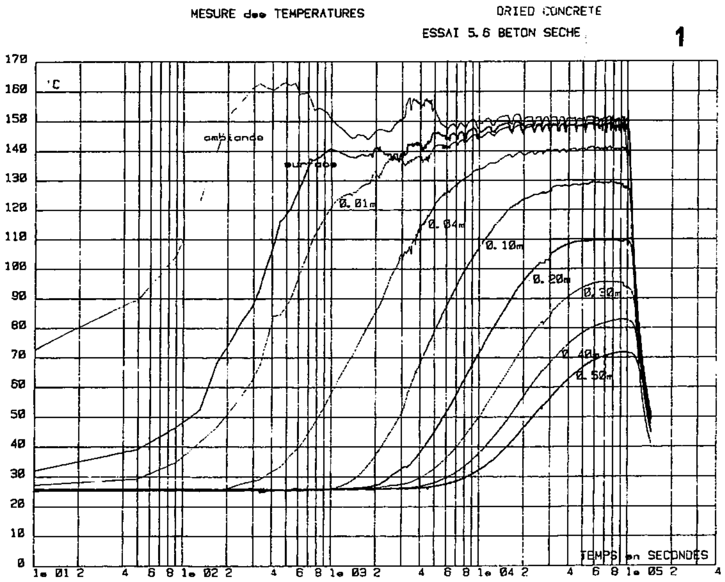
	Débit d'air mesuré		Débit d'air massique	Pression	Fissure calculée
Essai	m^3 s^{-1}	m^3 s^{-1} ml^{-1}	kg s^{-1} ml^{-1}	10^5 Pa	x 10^{-6} m
Initial à l'air	8,5 . 10^{-7}	2,3 . 10^{-6}	2,79 . 10‾6,1	5,2	20,20
	1,86 . 10^{-6}	5,03 . 10-6	. 10-6	7,5	22,70
Vapeur t = 3000 s	3,5 . 10^{-7}	9,46 . 10^{-7}	1,148 . 10^{-6}	5,5	14,90
Vapeur t = 10 Ks	1,5 . 10^{-7}	4,05 . 10^{-7}	4,91 . 10^{-7}	5,8	11,30
Vapeur t = 30 Ks	8 . 10^{-8}	2,16 . 10^{-7}	2,62 . 10^{-7}	7,50	9

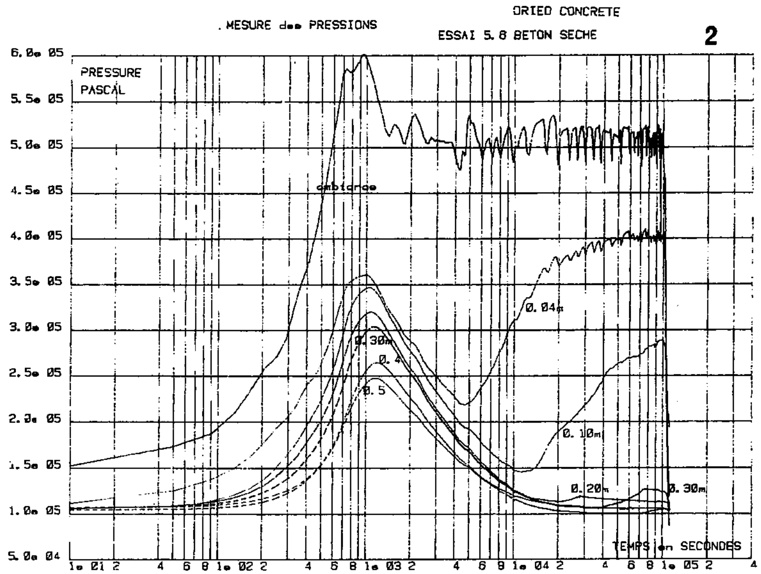
CONCLUSIONS

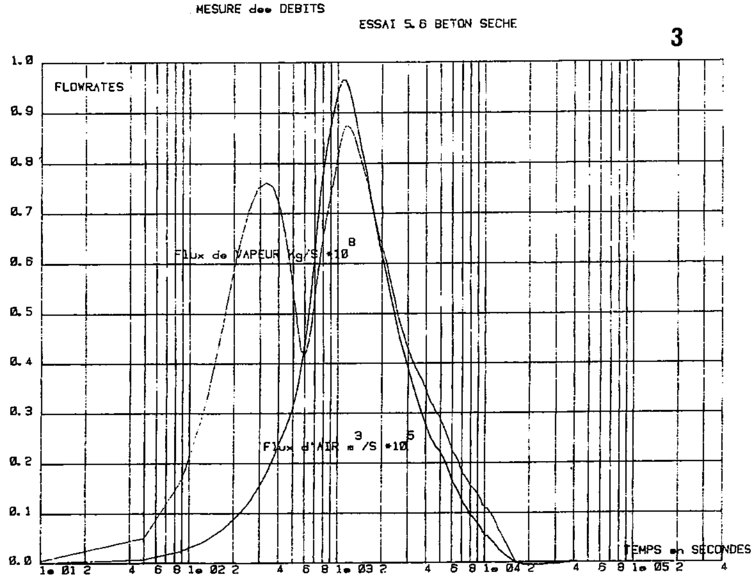
From the few experiments that have been presented, something must be attributed to the very severe conditions of testing, such as the prior drying at high temperature and the hold of the accident for a long time.

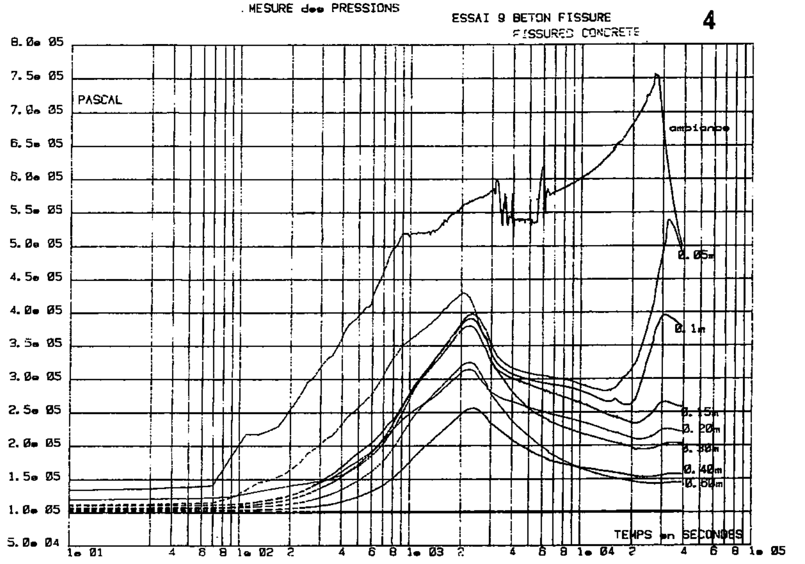
These conditions were imposed not as an exercise in prediction, but only, at least in the case of the hold time of the signal, to yield a better picture of the evolution of the transfers, which is very slow compared to accident times, which are very short.

The artificial isothermal drying desorbed the water more or less bonded to the structure over the whole thickness of the wall, which is unfavorable compared to natural drying under an established thermal gradient found in an actual containment. In


1
MESURE des TEMPERATURES
DRIED CONCRETE
ESSAI 5.6 BETON SECHE
°C
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ambiance
surface
0.01m
0.04m
0.10m
0.20m
0.30m
0.40m
0.50m
TEMPS en SECONDES
1e 01 2 4 6 8 1e 02 2 4 6 8 1e 03 2 4 6 8 1e 04 2 4 6 8 1e 05 2 4


2
. MESURE des PRESSIONS
DRIED CONCRETE
ESSAI 5.6 BETON SECHE
PRESSURE
PASCAL
6.0e 05
5.5e 05
5.0e 05
4.5e 05
4.0e 05
3.5e 05
3.0e 05
2.5e 05
2.0e 05
1.5e 05
1.0e 05
5.0e 04
ambiance
0.04m
0.30m
0.4
0.5
0.10m
0.20m
0.30m
TEMPS en SECONDES
1e 01 2 4 6 8 1e 02 2 4 6 8 1e 03 2 4 6 8 1e 04 2 4 6 8 1e 05 2 4


3
MESURE des DEBITS
ESSAI 5.6 BETON SECHE
FLOWRATES
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Flux de VAPEUR Kg/S *10^8
Flux d'AIR m^3/S *10^5
TEMPS en SECONDES
1e 01 2 4 6 8 1e 02 2 4 6 8 1e 03 2 4 6 8 1e 04 2 4 6 8 1e 05 2 4


4
. MESURE des PRESSIONS
ESSAI 9 BETON FISSURE
FISSURED CONCRETE
PASCAL
8.0e 05
7.5e 05
7.0e 05
6.5e 05
6.0e 05
5.5e 05
5.0e 05
4.5e 05
4.0e 05
3.5e 05
3.0e 05
2.5e 05
2.0e 05
1.5e 05
1.0e 05
5.0e 04
ambiance
0.05m
0.1m
0.15m
0.20m
0.30m
0.40m
0.60m
TEMPS en SECONDES
1e 01 4 6 8 1e 02 2 4 6 8 1e 03 2 4 6 8 1e 04 2 4 6 8 1e 05

the treatment of our specimens beyond 50°C, the action of the heat decreases the internal energy and cohesion of the concrete, leading to a reduction of thermal conductivity and mechanical strength values (microcracking) and an increase of geometrical permeability as shown by the exponential of K versus the inverse of the temperature, resulting from the energy of activation introduced by the heat treatment. Drying increases the internal space, and it has been seen that, the larger the free space, the faster the plugging of the pores by condensation and the reduction of permeability in relative terms.

But the comparison with measurements on walls that are not dried shows that the residual permeability after an accident remains dependent on the original permeability before the accident. The permeability of a dried wall can be reduced by a factor of 10 to 20 in an accident. That of an undried wall can be reduced from 1 to 4 times, and the reduction will be smaller if its permeability before the accident is very low.

The total permeability of an undried concrete having a very low permeability to air may be very slightly increased by the modification of a small part of its thickness stressed by the thermal signal. During the accident, the temperature of the concrete rises and the initial properties of a thickness of the concrete, primarily upstream of the zone of plugging where the saturated steam dries the concrete, are changed by the momentary increase with the displacement of the saturated front but does not exceed, even in a sustained LOCA, a quarter of the thickness for the characteristics of the concrete tested.

The LOCA signal consists of imposing a dew point in a mass of air that is very large with respect to the exchange areas. Water vapor condenses on the cold wall from the start of the accident. It can even be assumed that, if the permeability of the concrete is low, a film of water seals the wall and the air outflow may be explained solely by the expansion of occluded air in the spaces of the concrete during the establishment of the temperature gradient. It can for example be checked that the establishment of test 5.1, sealed on the containment side, would produce the same total air and steam flow for 4 % air spaces in the concrete.

The low relative humidity of the gas outflows and the dew point that was substantially constant for the duration of the flow, found in each test, even the longest, confirm the role of the concrete as condensing filter and the fact that the steam from the containment has no access beyond the liquid barrier that forms.

In spite of the severe conditions applied, since the OD followed the LOCA, the test on a crack having an apparent opening between 20 an 40µm, of which the fictive width calculated from the measured flowrates in 20µm, also shows plugging by condensation that substantially reduces the flowrate (1/23).

The observed mechanisms seem the same, but the total pressure of the containment has a more direct action on the displacement of the plug, by making it precede the 100°C isothermal, so that plugging at 1 cm is practically immediate.

REFERENCES

MARECHAL J, BEAUDOUX M, 1992 Transfert Diphas Exp, ANNALES ITBTP,506 EM 241