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Report No 358E

CEMENTITIOUS LININGS AND WATER QUALITY

PART 2

SOLUTIONS TO THE PROBLEMS CAUSED BY ORDINARY PORTLAND CEMENT

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PREFACE

This report covers work undertaken by the Water Research Centre for the Department of the Environment to investigate the change in water quality following the cement mortar lining of water mains.

The work began in April 1985 and was extended for a further year after March 1988 and is due for final completion by the end of April 1989. This document forms Part 2 of a report to cover the work carried out between April 1985 and March 1988. A final report will be issued on completion of the project in April 1989.

SUMMARY

I OBJECT

To develop methods to overcome the water quality problems observed when small diameter water mains are relined with ordinary Portland cement (OPC).

II REASON

Previous work has shown that following the lining of small diameter water mains with OPC, in areas with a very low alkalinity supply water, pH and aluminium levels can be elevated above EC directive limits for prolonged periods.

III CONCLUSIONS

Three methods were developed which reduced pH and aluminium levels following cementitious relining. These were: (a) to use a blast furnace slag (BFS) cement containing 65% BFS and 35% OPC, (b) to dose sodium bicarbonate at 50mg/l to the supply water, and (c) to reduce the contact time between the water and cement mortar.

The most practical of these to implement is the BFS cement mortar which reduces pH levels to within EC directive limits within a few days in water with an alkalinity of $35mgl^{-1}$ and above. In waters with very low alkalinities (< $10mgl^{-1}$) this cement produces pH levels between 0.5 and 1 unit lower than the pH levels observed following lining with OPC.

The sodium bicarbonate dosing is effective at reducing pH levels in very low alkalinity waters but would be more costly and difficult to implement.

Reducing contact times or increasing the flow through the main also reduces pH levels following lining. The reduction in contact time could be achieved by inducing a low flow at dead ends or linking dead ends together. These methods may be undesirable and costly to implement.

IV RESUMÉ

A series of laboratory studies and field trials were carried out in order to find potential solutions to the problem of high pH levels following cement mortar lining. These resulted in the development of a new type of cement for relining, a method of dosing sodium bicarbonate to the supply water to increase it's alkalinity and methods to reduce the contact time in the main.

CONTENTS

1. INTRODUCTION

During the past three years WRc has been investigating water quality following cement mortar relining. The first half of this work examined the effect that lining mains with ordinary Portland cement (OPC) had on water quality. The findings from that work were presented in an earlier report[1] and showed that following the application of OPC to water mains carrying low alkalinity waters, the pH level of the conveyed water could be elevated above the EC directive MAV[2] for prolonged periods. In addition to this, aluminium levels were raised above the EC directive MAC[2] for a shorter period.

As a follow up to this earlier work, WRc has been examining and developing solutions to overcome these water quality problems. This task was approached in three ways; (a) modifying the mortar, (b) dosing the supply water, (c) changing the contact time. Each of these approaches either reduces the lime leaching from the mortar or lessens its impact on water quality. These methods were tested in the laboratory in the first instance and then taken into the field for full scale tests. This report details the work carried out both in the laboratory and in the field.

2. LABORATORY WORK

2.1 MODIFYING THE MORTAR

During the early stages of the project a great deal of laboratory work was undertaken to try and find a modified mortar that would reduce the pH problems following lining. This study is given in detail in a laboratory report which is included as Appendix A. A summary of this work is outlined below.

The approaches taken in designing a modified mortar were to:

(a) Reduce the permeability of the mortar - this would result in a more dense material with less opportunity for leaching of soluble compounds. This could be achieved by using plasticisers or super plasticisers, or by adding a pozzolanic material thereby reducing the size and number of capillary pores in the mortar and reducing the amount of free lime available.

(b) Sealing the mortar surface - this would form an insoluble barrier between the conveyed water and the cement mortar thereby reducing or stopping the leaching of lime into the water. This could be achieved by use of a curing membrane or by adding chemicals to the charge up water to form an insoluble precipitate on the surface of the cement mortar.

(c) Rendering the mortar water repellant - this would reduce or inhibit the exchange of conveyed water and pore water thereby reducing the leaching rate of alkali compounds. This could be achieved by the use of waterproofing additives.

Along with its effect on water quality the mortar must be pumpable and have curing characteristics so as to allow it to be applied to the water main in the normal manner and to allow return to service of the main following an overnight curing period.

The laboratory trials consisted of testing a large range of modified mortars in short term leaching tests. The successful mortars were then subjected to a pumpability test using a flow table. Mortars that showed an improvement in contact water quality compared to OPC and were capable of being pumped were then subjected to more vigorous water quality tests. These consisted of short term tests followed by continuous flow tests in both deionised water and a low alkalinity supply water. Full experimental detail and results are given in Appendix A.

2.1.1 CONCLUSIONS FROM THE MODIFIED MORTAR TESTS

The series of experiments showed that in laboratory conditions a cement consisting of 65% blast furnace slag (BFS) and 35% ordinary Portland cement (OPC) gave the greatest reduction in the pH of the contact water compared to an OPC mortar. The reduction in pH achieved was in the order of 0.5 to 1 pH unit. This difference was maintained over each of the tests and for all conditions of contact time and flow rate examined. In addition this mortar gave excellent results during the pumpability tests.

2.2 CHEMICAL DOSING OF SUPPLY WATER

Another approach considered when trying to reduce the increase in pH following lining in low alkalinity water areas, was to dose the conveyed water so that its alkalinity was increased. The increase in alkalinity would increase the buffering capacity of the water and this would reduce the effect that the alkalis from the cement have on the pH of the water.

A series of laboratory tests were undertaken to investigate the effect of dosing sodium bicarbonate into the conveyed water to raise its alkalinity. These tests are explained in detail in an internal report which is included in Appendix B.

The tests examined the effect of dosing sodium bicarbonate at various concentrations into water that would be in contact with blast furnace slag cement. The tests were carried out on a laboratory continuous flow rig and were compared with a control using blast furnace slag cement in deionised water.

2.2.1 CONCLUSIONS FROM LABORATORY CHEMICAL DOSING TRIALS

These trials showed that dosing sodium bicarbonate into the conveyed water reduces the pH in the water compared to the control. The optimum dosage rate examined in the laboratory was $50mgl^{-1}$ (as $NaHCO_3$). This dosing rate reduced the pH by 2 units compared to the control.

The dosing of the sodium bicarbonate was stopped at 20 days after which time the pH level increased to that observed on the control test. This suggests that in the field dosing would need to be continued until the pH level on a control main dropped to the desired level.

3. FIELD WORK

The laboratory work outlined in Section 2 gave two potential solutions to the water quality problems. These are: (a) to use a blast furnace slag cement consisting of 65% BFS and35% OPC; and (b) to dose sodium bicarbonate to the supply water either temporarily or for a prolonged period.

In addition the option of increasing the flow through the main has also been considered. All these options were then tested in the field in full scale experiments.

This section details all the field work carried out to test these options and is arranged into four sections: (a) pumping and curing trials; (b) Glasgow trials (very low alkalinity water); (c) Anglesey trials (low alkalinity water); and (d) Cambois trials (moderate alkalinity water).

3.1 PUMPING AND CURING FIELD TRIALS

3.1.1 OBJECTIVES

These trials were carried out to ensure that the blast furnace slag cement developed in the laboratory was capable of being pumped through the lining contractors equipment and that the cement cured sufficiently overnight at low temperatures to allow water contact the following day.

3.1.2 METHOD

To test whether the new mortar would be pumpable or not, the BFSC was taken to two lining contractors who mixed and pumped it through their lining equipment. The lining equipment consists of a paddle mixer, a pump (either screw type or positive displacement type), 160m of 25mm hose and a spinner head to apply the mortar to the pipe wall. Of the contractors carrying out the trial one used a screw type pump the other used a triple piston positive displacement pump.

The contracters were asked to mix the mortar in the normal manner using a BFSC to sand ratio of 1:1 and a water/cement ratio of 0.35 to 0.4. The mortar was then pumped through the hoses and spinner head to line several lengths of pipe above ground. The mortar was considered to be suitable for pumping and lining if it (a) pumped through the hoses without blocking and the contractor was satisfied with the way in which it pumped and (b) if the lining produced was uniform and homogeneous.

To test whether the BFS mortar cured sufficiently at low temperatures a contractor lined several 3m lengths of 100mm diameter pipes with the BFS mortar. These pipes were then placed in a refrigerated container at 4°C. The pipes were left to cure in this atmosphere for periods of 15, 17 and 19 hours. After this period the pipes were connected up to a hydrant via a flow meter and pipes flushed at a flow of 300 l/min. This flow was assumed to represent the maximum flow experienced by a lining during return to service. After 30 minutes flushing, the linings were inspected for signs of abrasion and wear.

3.1.3 RESULTS

The pumping trials showed that the mortar pumped easily with a water/cement ratio of between 0.35 and 0.39, the optimum ratio appeared to be around 0.37. At this ratio the linings applied to the pipes were of a good uniform quality with no slumping.

The curing trials showed that after a cure of 17 hours there was some very slight signs of wear following flushing, but after 19 hours the lining appeared sufficiently cured to allow return to service.

3.1.4 CONCLUSIONS

1. The optimum water/cement ratio for pumping the mortar is about 0.37.

2. At water temperatures of 4°C and above the lining should be cured for 20 hours to ensure lining damage does not occur when returned to service.

3.2 GLASGOW FIELD TRIALS

The trials carried out at Glasgow were conducted on the same test rig originally built to test OPC linings[1]. The water supplying the area has a very low alkalinity and poor buffering capacity so it was expected that this would give the greatest change in water quality.

3.2.1 OBJECTIVES

1. To investigate the effect on water quality of lining a dead end main with blast furnace slag cement (BFSC) and compare the results with those from an OPC lining.

2. To examine the effect of dosing sodium bicarbonate into a main lined with BFSC.

3. To investigate the effect of changing the flow on a main lined with BFSC.

3.2.2 METHOD

The layout of the test rig is shown in Figure 1. Lengths A, C and D were already lined with OPC from the previous experiment. Length D, the trowelled OPC main, was removed and replaced with an unlined ductile iron pipe. Thus leaving two mains, B and D, ready for lining with BFSC. The pipes were all 100mm diameter and 52.7m long.

The rig allows normal supply water to flow through each of the lengths of main at a controlled rate. The control hut houses the flow controlling apparatus, pH meter, conductivity meter and sampling points from each main. The hut also houses a storage tank and dosing pump for sodium bicarbonate which was connected to the inlet end of main D via suitable tubing running through a duct in the ground.

The lengths of main B and D were lined with BFSC by Galliford Pipeline Services. The linings applied were about 5mm thick and had an orange peel finish. The blast furnace slag cement was supplied by Pozament Ltd.

After lining, each main was capped and allowed to cure for 18-20 hours. They were then pieced up and charged with water. A flow of 4 l/min was induced on each main.

Once the flows were stabilised sodium bicarbonate was dosed into main D to give a concentraton of $50mgl^{-1}$ of $NaHCO_3$.

The water quality at the inlet and outlet end of each main was monitored weekly for the first month and then at various intervals up to three months. Monitoring was carried out so that during one day's testing the water quality could be monitored after contact times between the water and cement mortar of 1 to 6 hours.

The dosing of the sodium bicarbonate was carried out for the first 27 days of the trial and then normal supply water passed through the pipe.

3.2.3 RESULTS

The complete set of results are tabulated in Tables 1 and 2. The results for pH, alkalinity and aluminium are shown graphically for a 1 hour contact time in Figures 2a to 4a and for a 6 hour contact time in Figures 2b to 4b.

The pH levels for the undosed main after a 1 and 6 hour contact time (Figures 2a and 2b) were initially above 11.5 but fell rapidly to values of 10.5 and 10.8 within 2 weeks. After 1 month the pH levels had fallen off to 10.1 and 10.6, the fall off with time then proceeded at a slower rate until values of 9.85 and 10.3 were reached after 6 months. Figures 3a and 3b show that these pH levels on the undosed main were coupled with very low alkalinity, typically below 20mg/l $CaCO_3$ after two weeks. These low alkalinity levels indicate that the water, despite the increased pH, was poorly buffered.

The pH levels for the dosed main after a 1 hour contact time (Figure 2a) were initially above 11 but fell to 9.6 after two weeks. During dosing the pH stayed around this level. However after day 27 when dosing was stopped the pH rose to 10 units and thereafter remained at the same level as the pH on the undosed main. Following a 6 hour contact time the pH levels (Figure 2b) were higher but followed the same trend, falling to a pH of 10 during dosing. Alkalinity results during dosing (Figures 3a and 3b) were constant, after an initial peak, at about 40mg/l due to the sodium bicarbonate dosing. After dosing was stopped the alkalinity levels fell to the same levels that were observed in the undosed main.

The aluminium levels on the undosed main after a 1 hour contact time (Figure 4a) were initially around 0.2mg/l falling to below 0.1mg/l within one week. The level at 3 months being around 0.04mg/l, the same as the supply water. Following the 6 hour contact times (Figures 4b) the aluminium levels were initially 0.38mg/l falling to 0.25mg/l at 1 month and 0.08mg/l at 3 months.

On the dosed main the aluminium levels after a 1 hour contact time (Figure 4a) were similar to the levels observed on the undosed main. Following a 6 hour contact time (Figure 4b) the levels during dosing started off at about 0.2mg/l and fell to 0.1mg/l. When dosing was stopped the aluminium levels increased to similar levels observed in the undosed main.

Tables 1 and 2 show that the pH levels in both mains are affected by the contact time between the water and the cement. As the contact time increased the pH levels rose rapidly and then levelled off towards an asymptote determined by the age of the lining. By decreasing the contact time, i.e. increasing the flow, the pH could be reduced to an acceptable limit, but the flow required would be high as the contact times need to be below 1 hour.

3.2.4 COMPARISON WITH OPC

Two years ago an experiment was carried out with ordinary Portland cement on the same test rig. The results from this experiment are outlined in an earlier report[1].

Figures 5a and 5b show pH levels after 1 hour and 6 hour contact times for OPC, BFSC and BFSC dosed with sodium bicarbonate showing that lining with BFSC produces a lower pH in the conveyed water. The BFSC lined main produces a pH between 0.25 and 0.5 units below that observed on the OPC lined main after a 1 hour contact time. Following a 6 hour contact time the reduction in pH is between 0.25 and 0.6 units.

Figure 6 gives aluminium levels after a 6 hour contact time. It shows that lining with BFSC elevates aluminium levels above the EC directive MAC[2] for a shorter period than lining with OPC.

3.2.5 DISCUSSION

The pH of the conveyed water in the undosed BFSc lined main remained above 9.5 units during the first 6 months of the trial, although this increase was lower than the increase seen after lining with OPC.

Dosing sodium bicarbonate into the supply water flowing through the BFSc lined main reduced the pH in that main to a level around the pH of the supply water. When the dosing was ceased the pH increased to a level similar to that observed on the undosed main.

After lining with BFSC, aluminium levels were above 0.2mg/l after a 6 hour contact time for the first month. This compares with aluminium levels in excess of 0.2mg/l for the first two to three months after a similar test with OPC. Dosing sodium bicarbonate to the supply water reduces these high aluminium results to around 0.2mg/l.

3.2.6 CONCLUSIONS

1. The use of blast furnace slag cement in place of OPC to line water mains, in very low alkalinity water areas, reduces the level of pH and aluminium in dead end mains.

2. Dosing sodium bicarbonate to the supply water continuously at 50mg/l reduces the pH following relining to a level near that of the supply water. The dosing also reduces the aluminium levels.

3. Increasing the flow reduces pH and aluminium levels, but the flows need to be high, as a contact time less than one hour needs to be achieved.

3.3 ANGLESEY FIELD TRIALS

These tests were carried out in an area with the same water quality as an earlier test carried out with ordinary Portland cement[1]. The water supplying this area had an alkalinity of about 35mg/l $CaCO_3$.

3.3.1 OBJECTIVES

To investigate the effect on water quality of lining a dead end main with blast furnace slag cement (BFSC) in a low alkalinity water and compare the results with those from an OPC lining.

3.3.2 METHOD

The test main was a 65m length of 100mm diameter main in Carmel in Anglesey. For the purpose of the test the length could be made into a dead end and isolated by the use of a bypass arrangement.

The main was power bored and cement mortar lined with BFS cement by direct labour services from Welsh Water. After the cement had cured for 20 hours the main was pieced up as shown in Figure 7 and return to service. The special valves shown in Figure 7 are standard gate valves with a series of holes drilled through the gates. These valves were installed to ensure plug flow through the length of main studied.

Water quality tests were carried out on days 0, 1 and 7 after return to service. The tests consisted of isolating the main with a bypass and monitoring the water quality at the inlet and dead end. The water quality at the dead end was monitored at various contact times ranging from 0.05 to 6 hours.

3.3.3 RESULTS

The complete set of results are tabulated in Table 3. The table shows results obtained after various contact times on the same day, 1 day and 7 days after return to service.

The pH levels observed during the trial were initially above the EC directive MAV[2] of 9.5 during the first two days with levels of 11.7 and 10.4 at a 1 hour contact time. By the seventh day the pH levels were well below 9.5, even after a 6 hour contact time when the level was 8.3. On each of these days there was a pH increase associated with an increase in contact time.

The alkalinity of the conveyed water remained fairly constant during the trial at between 33-37mg/l, except after a 1 hour contact time on day 0 when the level increased to 173mg/l. This high alkalinity level of 173mg/l was due to the high leaching rate of calcium salts during the first day after return to service.

Aluminium levels in the conveyed water did not increase after contact with cement, with the level remaining at 0.04mg/l throughout the trial.

During day 0 the calcium, sodium and pottasium levels all increased as the contact time increased. After day 0 there are only slight increases in calcium levels as contact time increases, but no increase in sodium or potassium levels.

3.3.4 COMPARISON WITH OPC

A similar test was carried out in the same water quality area with OPC. This work was reported in an earlier report[1], and shows that pH levels were increased above the EC directive limit for at least one month after relining.

The results obtained using BFSC show that the pH levels fall below 9.5 within the first week in this area suggesting that using BFSC instead of OPC would be beneficial in this instance.

3.3.5 CONCLUSIONS

1. The use of blast furnace slag cement in place of OPC to line water mains, in low alkalinity water areas (alkalinity = 35mg/l), reduces pH levels below 9.5 in dead end mains within the first week.

2. Increasing the flow through the main reduces the transiently high pH levels.

3.4 CAMBOIS FIELD TRIALS

These tests were carried out in Cambois, Northumbria, in an area with moderate alkalinity water (55mg/l $CaCO_3$). Similar tests were carried out earlier in an area with similar water quality using ordinary Portland cement[1].

3.4.1 OBJECTIVES

To investigate the effect on water quality of lining a dead end main with blast furnace slag cement (BFSC) in a moderate alkalinity water, and compare the results with those from an OPC lining.

3.4.2 METHOD

The test main was a 100m length of 100mm diameter main in Cambois, Northumbria. The main had no service connections on it and for the purpose of the trial could be made into a dead end.

The main was power bored and cement mortar lined with BFSC by Kilroe Pipeline Services. After the cement had cured for 20 hours the main was pieced up as shown in Figure 8 and return to service. The special valves shown in Figure 8 are standard gate valves with a series of holes drilled through the gates. These valves were installed to ensure plug flow through the length of main studied.

Water quality was monitored at the inlet end and at the dead end after various contact times ranging from 1 through to 6 hours.

3.4.3 RESULTS

Water quality tests were carried out on days 1 and 7 after return to service. By day 7 all parameters monitored were below EC directive maximum limits[2]. The complete set of results are tabulated in Table 4.

The pH levels observed on day 1 were above EC directive limit[2] of 9.5 with levels of 9.9 and 11.3 after contact times of 1 and 6 hours respectively. By day 7 these levels were very much reduced with a pH of 8.6 after a 1 hour contact time and a pH of 9.3 after a 6 hour contact time.

Alkalinity levels on day 1 increased from 55 to 104mg/l as the contact time increased from 1 to 6 hours. On day 7 the alkalinity fluctuated between 55 and 62mg/l over the range of contact times.

The aluminium levels increased very slightly after lining with the highest reading being 0.074mg/l which was well below the EC directive MAC[2] of 0.2mg/l.

The calcium, sodium and potassium levels were all increased on day 1, with the highest levels following a 6 hour contact time. By day 7 there were only slight increases in each of these parameters.

3.4.4 COMPARISON WITH OPC

A similar test was carried out on the same water quality area with OPC. This work was reported in an earlier report(1), and shows that pH levels are initially high but decrease to around 8.5 by day 7 after a 1 hour contact time.

The results obtained using BFSC show that the pH levels follow a similar trend in this area. This shows that using BFS cement in place of OPC will not cause any worse water quality problems, and has the benefit of producing lower initial pH levels.

3.4.5 CONCLUSIONS

1. The use of blast furnace slag cement in place of OPC to line water mains in moderate alkalinity water areas, has no adverse effect on water quality except transiently raised pH levels following lining.

2. Increasing the flow through the main reduces these high transient pH levels.

4. DISCUSSION

In an earlier report[1] investigating the effect on water quality after lining mains with OPC it was shown that high pH and high aluminium levels were a problem in some areas. The degree to which the quality of the water was affected depended primarily on the alkalinity or buffering capacity of the supply water and the contact time in the main.

In an effort to overcome these problems attempts have been made to: (a) reduce the amount of lime leaching into the water by altering the cement; (b) increase the alkalinity of the supply water to raise its buffering capacity; and (c) reduce contact times in the main. This report has shown that each of these methods has a beneficial affect on water quality compared to lining mains with OPC.

The modified mortar developed by WRc consists of 65% ground granulated blast furnace slag and 35% OPC. This mortar had the appropriate pumping and curing characteristics to enable it to be used as a lining material as well as having less impact on water quality compared to OPC. In very low alkalinity waters (< 10mg/l) the BFS cement produced pH levels in the region of 0.5 to 1 unit lower than those observed when using OPC over a range of contact times. In addition aluminium levels were reduced to below the EC directive MAC[2] within the first month as opposed to 2 to 3 months with OPC. In low alkalinity waters (_ 35mg/l) the BFS cement caused the pH to exceed 9.5 during the first few days, whereas the pH following lining with OPC was above 9.5 for the first month. Aluminium levels were not a problem with either cement in this area. In a moderate alkalinity water (_ 55mg/l) the BFSC produced pH levels similar to those seen with OPC, in that a high peak was seen the day after lining then the pH fell rapidly to the pH of the inlet water.

The second approach tried was to increase the alkalinity of the supply water and this was achieved by dosing sodium bicarbonate to the water at the dosing rate of 50mg/l as $NaHCO_3$. In the very low alkalinity area the dosing had the effect of increasing the alkalinity to about 40mg/l and this reduced the pH level after lining to that of the inlet water. This method appears to work very well but has the disadvantage of being costly and difficult to implement. The most cost effective way of using this method would probably be to dose locally into a main supplying the area being relined.

The third approach was to investigate the effect of contact time on the pH of the water after lining. This showed that as the contact time was reduced there was a corresponding reduction in pH. This could be used to alleviate pH problems in dead end mains where the contact time is high and could be achieved by a continuous bleed at the dead end, a regular early morning flush or joining together dead ends to form through mains. These methods may be costly and difficult to implement and therefore are considered impracticable. The contact time relationship would be more useful in predicting mains that would be likely to pose water quality problems after linings. This would rely on knowing the contact times in the distribution system. This is not always possible but a method of estimating the contact times in the distribution system is given in Appendix C.

5. CONCLUSIONS

5.1 BLAST FURNACE SLAG CEMENT

(a) This cement consists of 65% ground granulated blast furnace slag and 35% ordinary Portland cement.

(b) In very low alkalinity waters (< 10mg/l) this cement after lining produces pH levels in the conveyed water about 0.5 to 1 unit less than those observed when OPC is used.

Aluminium levels are also lower and are reduced to below the EC directive MAC within the first month as opposed to 2 to 3 months when OPC is used.

(c) In waters with alkalinities greater than 35mg/l this cement produces pH levels that fall below 9.5 within the first week after lining.

5.2 SODIUM BICARBONATE DOSING

In areas where the pH is still above 9.5 after lining the pH may be reduced by dosing the supply water with 50mg/l of sodium bicarbonate. This has the disadvantage of being expensive and difficult to implement.

5.3 CHANGING THE CONTACT TIME

Reducing the contact time or increasing the flow in the main is effective at reducing pH levels and aluminium levels where they are high. This could be accomplished by a bleed at the dead end or linking together dead ends, although these could be costly and impracticable.

6. RECOMMENDATIONS

1. In waters with an alkalinity less than 55mg/l as $CaCO_3$ the blast furnace slag cement should be used in place of OPC for relining water mains to reduce pH levels following lining.

2. In low alkalinity water areas careful consideration must be given to cement lining mains with a contact time greater than 6 hours. If mains with higher contact times have been lined and present a pH problem, this may be reduced by decreasing the contact time (e.g. increasing the flow).

3. As an alternative to decreasing contact times the method using sodium bicarbonate dosing may be used to reduce high pH levels due to cement lining.

4. Field trials should be conducted in areas which have alkalinities between 10 and 35mg/l as $CaCO_3$.

REFERENCES

1. WRc Report: Cementitious linings and water quality; Part 1, The change in conveyed water quality after lining water mains with ordinary Portland cement - D Marshallsay.

2. Council of the European Communities. Council directive relating to the quality of water intended for human consumption. Official journal of the European Communities No L229, Volume 23, August 1980, pp 11-29 (80/778/EEC).

TABLE 1 - GLASGOW BFS CEMENT TRIALS - "undosed main"

DAY	CONTACT TIME (hours)	PH units	TOTAL ALKALINITY (mg/l)	CONDUCTIVITY (uS/cm)	ALUMINIUM (mg/l)	CALCIUM (mg/l)	POTASSIUM (mg/l)	SODIUM (mg/l)
1	0.0	9.60	9.2	51.0	0.043	3.34	0.271	2.81
1	1.0	11.80	94.0	444.0	0.203	24.80	6.650	5.70
1	2.0	11.90	121.0	540.0	0.297	32.00	8.950	6.83
1	3.0	12.00	142.0	644.0	0.392	41.60	10.700	7.62
1	4.0	12.05	156.0	667.0	0.374	44.40	11.500	7.95
7	0.0	9.55	8.0	50.0	0.041	3.64	0.329	2.95
7	0.5	10.50	15.4	69.1	0.105	4.92	0.555	3.04
7	1.0	10.65	19.8	71.8	0.106	5.43	0.576	3.03
7	2.0	10.85	20.7	96.5	0.174	6.63	0.706	3.07
7	4.0	11.15	30.8	132.6	0.266	9.56	1.150	3.38
7	5.0	11.25	43.0	149.0	0.297	10.30	1.250	3.50
7	6.0	11.30	46.0	164.5	0.386	11.90	1.670	3.70
7	7.0	11.35	46.0	182.6	0.420	13.30	1.810	3.85
13	0.0	9.50	7.7	47.7	0.040	3.24	0.291	3.00
13	0.5	10.35	12.5	61.8	0.094	4.51	0.421	3.06
13	1.0	10.45	12.8	62.7	0.095	4.66	0.441	3.08
13	2.0	10.55	17.0	74.2	0.120	5.61	0.519	3.10
13	3.0	10.75	19.3	83.2	0.153	6.13	0.584	3.08
13	4.0	10.90	23.3	93.9	0.201	7.23	6.510	3.14
13	5.0	10.90	24.3	103.1	0.243	7.82	0.767	3.25
13	6.0	10.95	25.8	108.4	0.252	8.24	0.797	3.24
13	7.0	11.00	28.4	116.6	0.301	8.94	0.914	3.33
22	0.0	9.70	9.0	53.5	0.040	4.22	0.393	3.03
22	0.5	10.30	15.1	67.8	0.113	5.34	0.453	3.01
22	1.0	10.35	15.9	70.8	0.099	5.46	0.378	3.01
22	2.0	10.45	16.5	75.7	0.130	5.71	0.442	2.98
22	3.0	10.50	18.2	81.0	0.169	6.24	0.494	3.03
22	4.0	10.60	18.6	86.9	0.159	6.53	0.580	3.21
22	5.0	10.65	21.6	94.0	0.190	7.02	0.569	3.16
22	6.0	10.70	21.9	97.6	0.239	7.54	0.664	3.37
27	0.0	9.30	7.8	47.6	0.040	3.00	0.315	2.95
27	0.5	10.05	10.9	57.6	0.088	4.16	0.378	3.11
27	1.0	10.15	11.5	60.8	0.080	4.70	0.413	3.04
27	2.0	10.30	13.0	65.8	0.087	4.57	0.432	3.07
27	3.0	10.40	15.9	71.8	0.104	5.13	0.476	3.02
28	0.0	9.60	8.7	48.7	0.054	3.41	0.450	3.04
28	1.5	10.15	12.6	60.1	0.083	4.97	0.481	3.11
28	3.0	10.40	15.1	69.3	0.129	5.10	0.545	3.14
28	4.0	10.50	18.7	81.9	0.145	6.09	0.509	3.08
28	6.0	10.60	20.8	92.1	0.188	7.01	0.549	3.09
49	0.0	9.60	8.8	51.3	0.043	3.24	0.347	2.95
49	1.5	10.00	11.2	57.1	0.075	3.92	0.348	2.98
49	3.0	10.30	14.6	67.0	0.140	5.10	0.421	3.14
49	4.0	10.40	15.8	75.2	0.164	5.67	0.391	2.98
49	5.0	10.45	18.0	78.5	0.184	5.87	0.418	2.90
49	6.0	10.50	18.9	82.2	0.209	6.06	0.410	2.95

TABLE 1 (cont)

DAY	CONTACT TIME (hours)	PH units	TOTAL ALKALINITY (mg/l)	CONDUCTIVITY (uS/cm)	ALUMINIUM (mg/l)	CALCIUM (mg/l)	POTASSIUM (mg/l)	SODIUM (mg/l)
90	0.0	9.40	7.7	52.7	0.040	3.24	0.231	2.88
90	0.5	9.90	9.9	58.0	0.040	3.47	0.305	2.82
90	1.0	9.95	10.8	56.3	0.040	3.80	0.210	2.81
90	2.0	10.05	11.7	60.6	0.044	4.35	0.176	2.91
90	3.0	10.20	12.5	63.7				
90	4.0	10.25	14.9	68.8	0.052	5.52	0.281	2.98
90	5.0	10.30	15.9	71.5	0.073	5.44	0.303	2.84
90	6.0	10.35	15.8	75.7	0.084	5.85	0.284	2.96
180	0.0	9.70	5.5	50.8	0.055	5.03	0.360	2.90
180	0.5	9.80	9.0	53.7	0.070	5.43	0.330	2.85
180	1.5	9.85	8.5	53.7	0.049	4.80	0.390	2.91
180	6.0	10.30	11.6	60.9	0.094	6.40	0.340	2.83

TABLE 2 - GLASGOW BFS CEMENT TRIALS - "dosed main"

DAY	CONTACT TIME (hours)	PH	TOTAL ALKALINITY (mg/l)	CONDUCTIVITY (uS/cm)	ALUMINIUM (mg/l)	CALCIUM (mg/l)	POTASSIUM (mg/l)	SODIUM (mg/l)
1	0.0	9.60	9.2	51.0	0.043	3.34	0.271	2.81
1	1.0	11.10	65.4	210.0	0.151	9.97	3.210	14.90
1	2.0	11.35	85.0	244.0	0.213	12.50	4.280	15.60
1	3.0	11.50	89.0	305.0	0.195	14.80	5.100	16.30
1	4.0	11.70	112.0	356.0	0.231	19.40	7.050	17.10
7	0.0	9.55	8.0	50.0	0.041	3.64	0.329	2.95
7	0.5	9.80	38.2	104.7	0.105	4.10	0.625	14.00
7	1.0	9.95	39.1	107.0	0.103	4.31	0.577	14.00
7	2.0	10.00	41.3	110.1	0.108	4.32	0.606	14.00
7	4.0	10.40	47.1	122.3	0.163	5.30	0.810	14.40
7	5.0	10.45	45.4	131.3	0.150	5.15	0.812	14.40
7	6.0	10.55	71.0	137.2	0.195	6.99	1.160	14.90
7	7.0	10.50	55.0	135.6	0.149	5.82	0.888	14.60
13	0.0	9.50	7.7	47.7	0.040	3.24	0.291	3.00
13	0.5	9.55	38.0	103.6	0.067	3.68	0.392	14.60
13	1.0	9.55	38.9	104.1	0.072	4.72	0.521	14.80
13	2.0	9.80	39.6	104.2	0.046	3.92	0.374	14.90
13	3.0	9.90	40.2	110.3	0.110	4.71	0.486	14.80
13	4.0	9.90	40.8	111.0	0.083	4.13	0.455	15.00
13	5.0	10.00	41.6	114.7	0.107	4.62	0.607	15.20
13	6.0	10.05	42.0	116.5	0.109	4.67	0.629	15.40
13	7.0	10.20	43.6	125.5	0.159	5.49	0.762	15.10
22	0.0	9.70	9.0	53.5	0.040	4.22	0.393	3.03
22	0.5	9.65	36.8	106.2	0.098	4.60	0.471	14.10
22	1.0	9.70	38.2	105.5	0.067	4.45	0.359	14.20
22	2.0	9.80	39.5	112.0	0.109	4.88	0.460	14.30
22	3.0	9.85	41.1	113.0	0.113	4.97	0.457	14.50
22	4.0	10.00	42.1	118.0	0.134	5.36	0.534	14.60
22	5.0	10.00	42.7	118.5	0.143	6.05	0.579	14.90
22	6.0	10.00	42.6	118.0	0.173	5.74	0.620	14.40
27	0.0	9.30	7.8	47.6	0.040	3.00	0.315	2.95
27	0.5	9.40	39.8	107.4	0.063	3.61	0.383	15.40
27	1.0	9.55	41.1	108.8	0.056	3.93	0.412	15.70
27	2.0	9.65	42.4	112.3	0.078	4.26	0.469	15.90
27	3.0	9.70	43.8	115.2	0.127	4.77	0.508	16.10
28	0.0	9.60	8.7	48.7	0.054	3.41	0.450	3.04
28	1.0	10.10	12.4	60.1	0.069	4.25	0.411	3.01
28	3.0	10.35	14.5	64.3	0.086	4.77	0.443	3.02
28	4.0	10.40	16.8	76.6	0.137	5.59	0.496	3.28
28	6.0	10.55	19.8	86.3	0.216	6.71	0.621	3.30
49	0.0	9.60	8.8	51.3	0.043	3.24	0.347	2.95
49	1.5	10.00	11.7	57.6	0.079	4.01	0.359	3.03
49	3.0	10.25	13.8	65.8	0.112	5.53	0.386	2.98
49	4.0	10.35	14.6	70.7	0.151	5.69	0.393	2.91
49	5.0	10.40	18.2	77.4	0.181	5.69	0.406	2.97
49	6.0	10.40	19.3	74.5	0.199	5.56	0.437	2.96

TABLE 2 (cont)

DAY	CONTACT TIME (hours)	PH units	TOTAL ALKALINITY (mg/l)	CONDUCTIVITY (uS/cm)	ALUMINIUM (mg/l)	CALCIUM (mg/l)	POTASSIUM (mg/l)	SODIUM (mg/l)
90	0.0	9.40	7.7	52.7	0.040	3.24	0.231	2.88
90	0.5	9.80	8.7	54.2	0.040	3.12	0.246	2.83
90	1.0	9.95	10.6	56.2	0.040	4.00	0.199	2.83
90	2.0	9.95	10.7	58.0	0.040	3.98	0.136	2.84
90	3.0	10.10	12.9	63.8				
180	0.0	9.70	5.5	50.8	0.550	5.03	0.360	2.90
180	0.5	9.80	9.0	56.6	0.055	5.23	0.310	2.83
180	1.5	9.85	8.3	50.8	0.061	4.91	0.400	2.94
180	6.0	10.35		63.2	0.104	6.64	0.300	2.82

Table 3 - Results from Anglesey BFS cement trials

TIME days	CONTACT TIME hours	pH	TOTAL ALKALINITY mg/l CaCO3	CONDUCTIVITY 5S/cm	ALUMINIUM mg/l	CALCIUM mg/l	SODIUM mg/l	POTASSIUM mg/l
0	0	7.7	33	317	0.04	29.1	13.0	3.46
0	0.05	10.3*	35	326	0.04	30.7	12.9	4.81
0	0.15	11.4*	33	456	0.04	48.2	13.5	6.90
0	1.0	11.7*	173	845	0.04	84.6	16.0	17.5
1	0	7.7	33	317	0.04	29.1	13.0	3.46
1	0.12	9.8*	39	317	0.04	29.0	13.2	3.48
1	1.0	10.4*	43	326	0.04	32.0	13.2	4.33
7	0	7.4	37	299	0.04	24.7	11.8	3.21
7	0.5	7.5	37	299	0.04	25.1	12.1	3.33
7	1	7.6	28	299	0.04	24.8	11.8	3.38
7	1.5	7.7	37	300	0.04	24.8	11.8	3.47
7	3	8.0	37	299	0.04	25.5	12.3	3.66
7	4	8.2	37	300	0.04	23.9	11.7	3.66
7	6	8.3	35	299	0.04	23.2	11.7	3.86

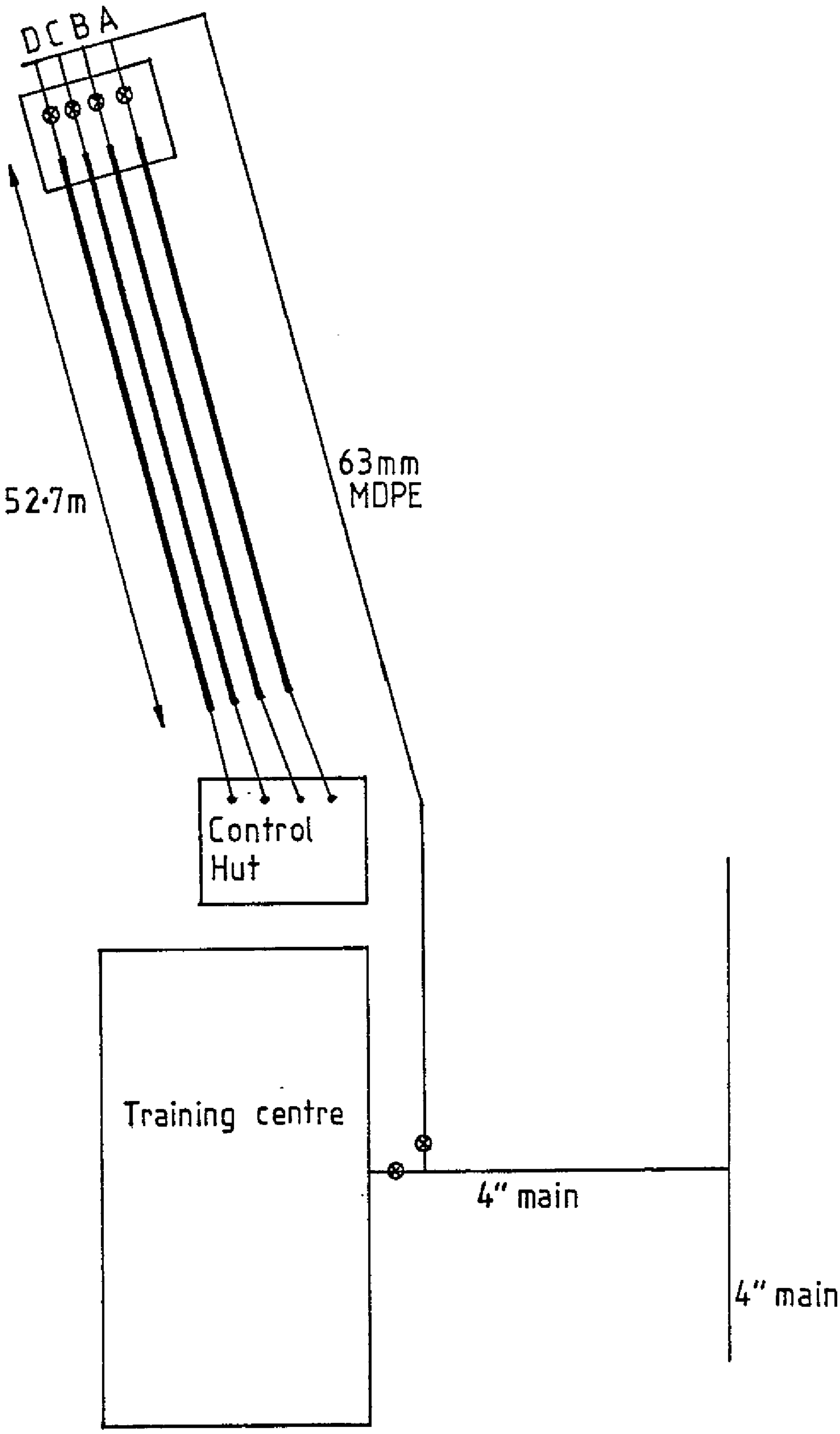
* Levels in excess of the EC directive(2) maximum limits

Table 4 - Results from Cambois BFS cement trials

TIME days	CONTACT TIME hours	pH	TOTAL ALKALINITY mg/l CaCO3	ALUMINIUM mg/l	CALCIUM mg/l	SODIUM mg/l	POTASSIUM mg/l
1	0	8.6	54.0	0.04	28	6.40	1.0
1	1	9.9*	55.0	0.043	32.2	7.05	1.92
1	2	10.2*	55.3	0.047	32.6	7.21	2.33
1	3	10.4*	61.7	0.046	38.7	7.50	3.06
1	4	10.9*	61.7	0.056	39.6	7.72	3.59
1	5	11.2*	65.9	0.063	40.3	7.88	4.08
1	6	11.3*	104	0.056	41.4	8.17	4.73
7	0	8.6	54	0.04	28	6.40	1.0
7	1	8.6	63.5	0.04	29.3	6.56	1.16
7	2	8.8	61.4	0.061	28.8	6.61	1.26
7	3	9.0	61.4	0.061	28.3	6.70	1.37
7	4	9.1	55.1	0.074	28.1	7.22	1.43
7	5	9.3	57.5	0.060	28.0	6.99	1.62
7	6	9.3	56.5	0.069	28.5	7.34	1.74

* Levels in excess of EC directive MAV[2]

FIGURE 1 LAYOUT OF TEST RIG



KEY

A - Factory lined pipe

B - DI. not in use

C - C.M.Lined
orange peel

D - C.M.Lined
trowelled

FIGURE 2a

pH vs Time (1 hour contact time)

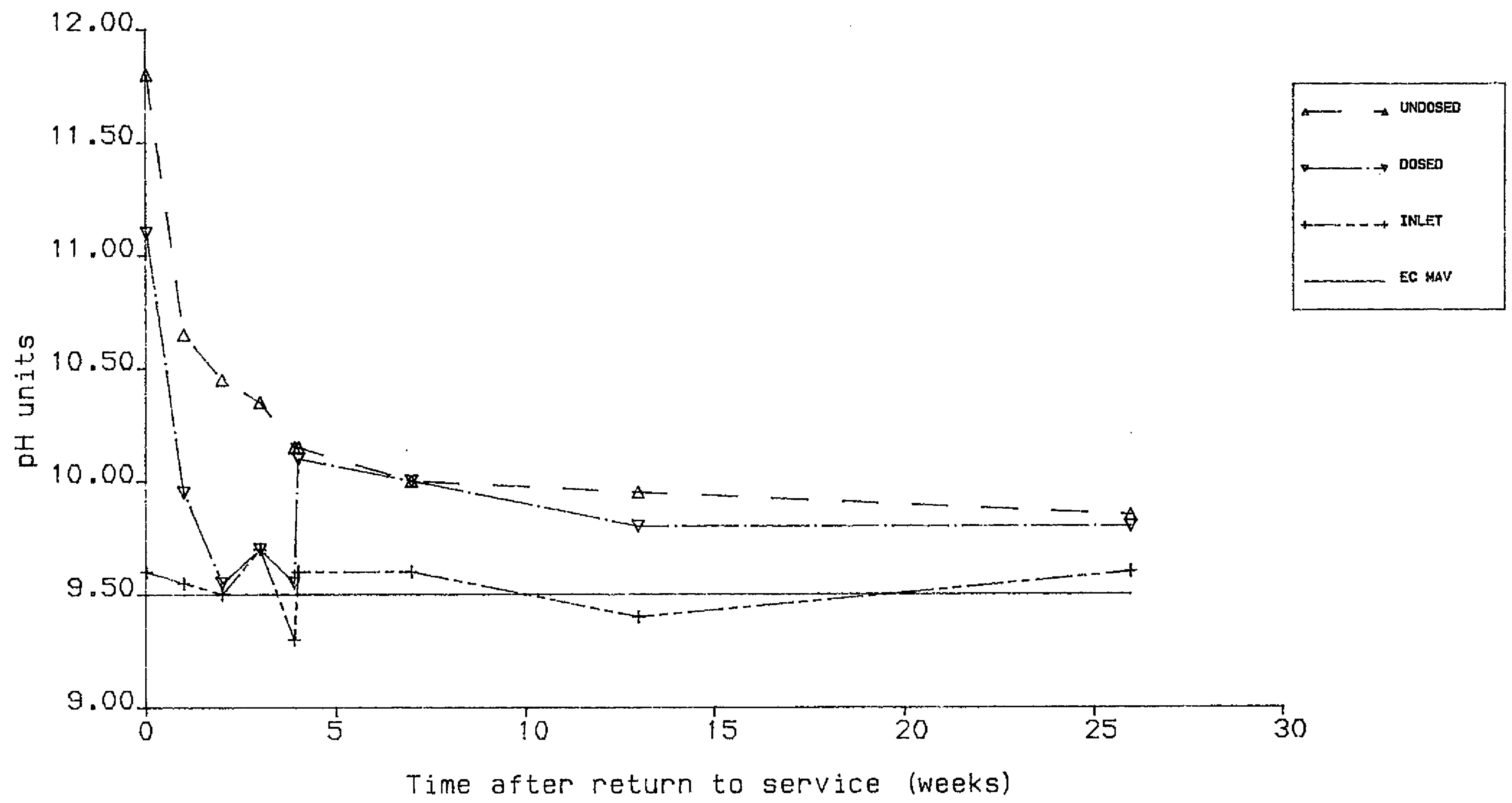


FIGURE 2b

pH vs Time (6 hour contact time)

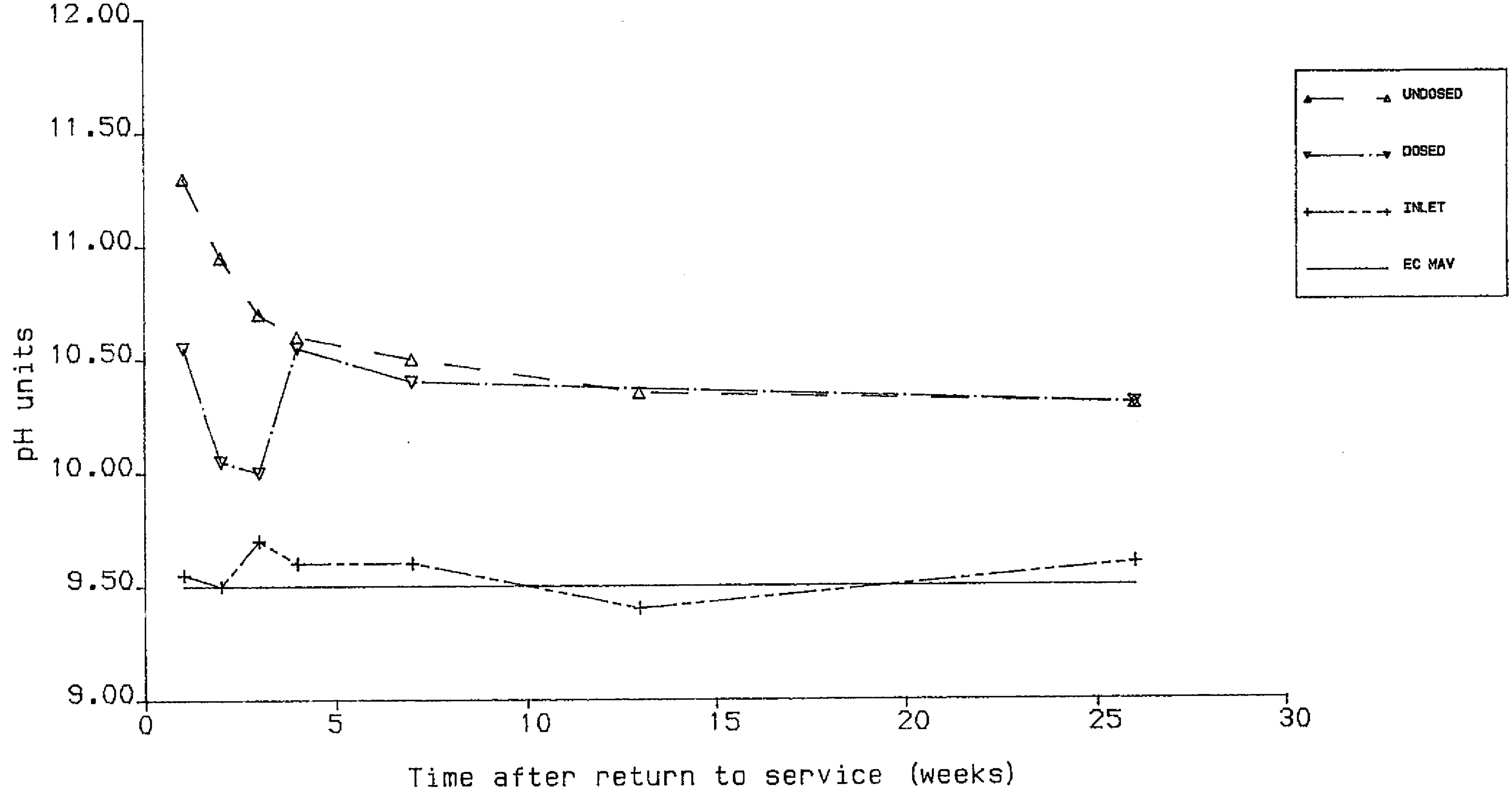


FIGURE 3a

Total Alkalinity vs Time (1 hour contact time)

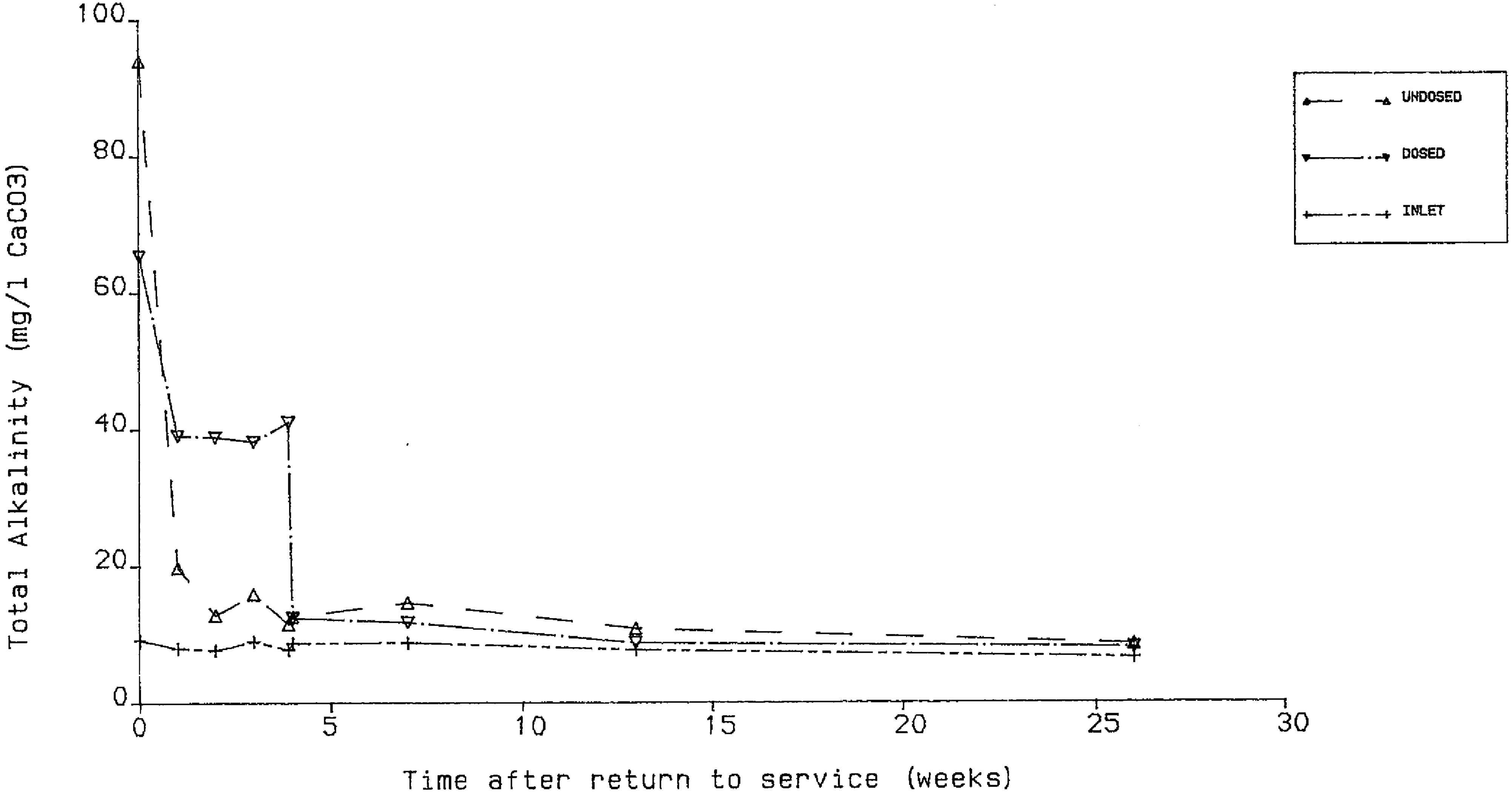


FIGURE 3b

Total Alkalinity vs Time (6 hour contact time)

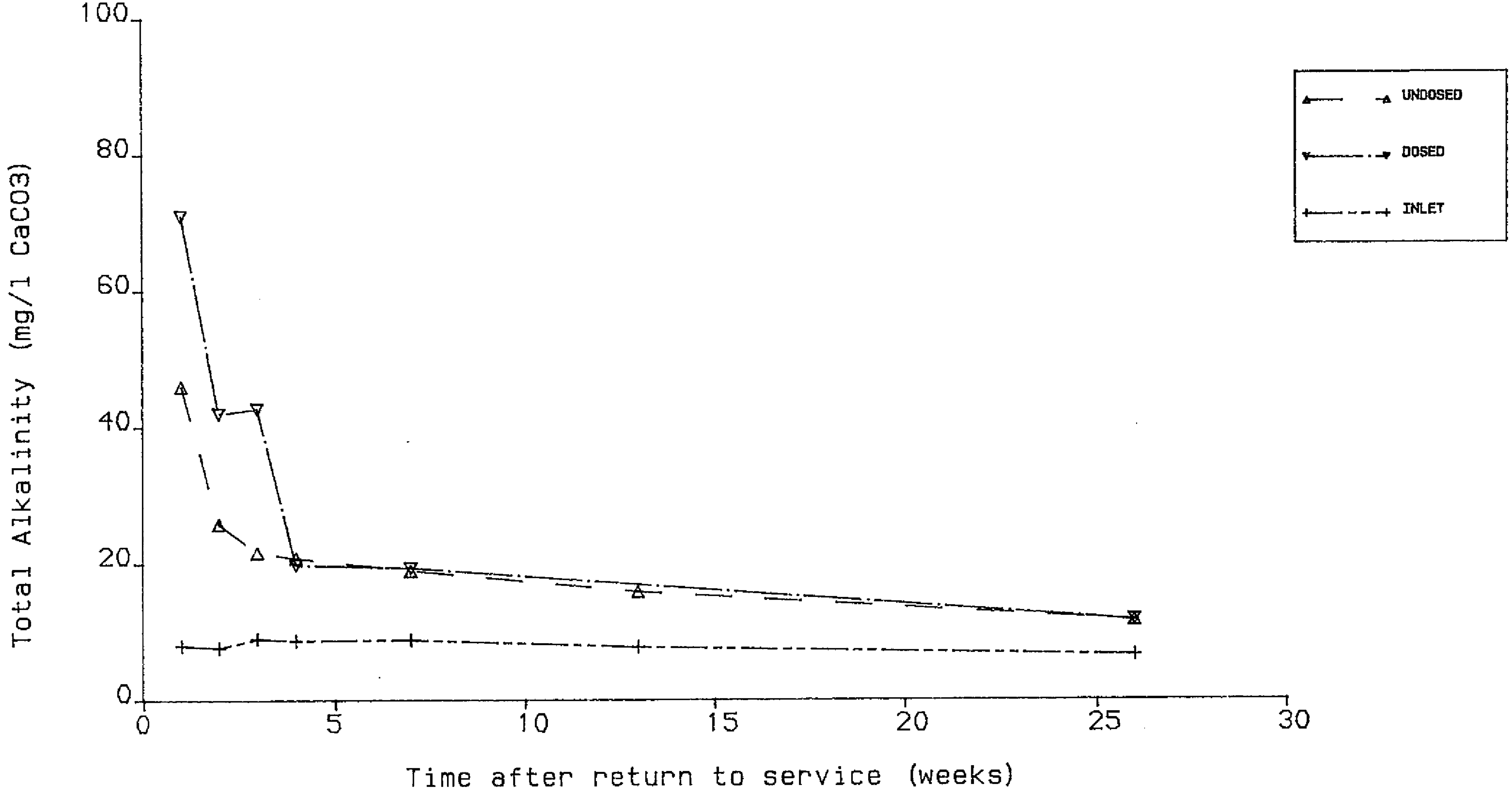


FIGURE 4a

Aluminium vs Time (1 hour contact time)

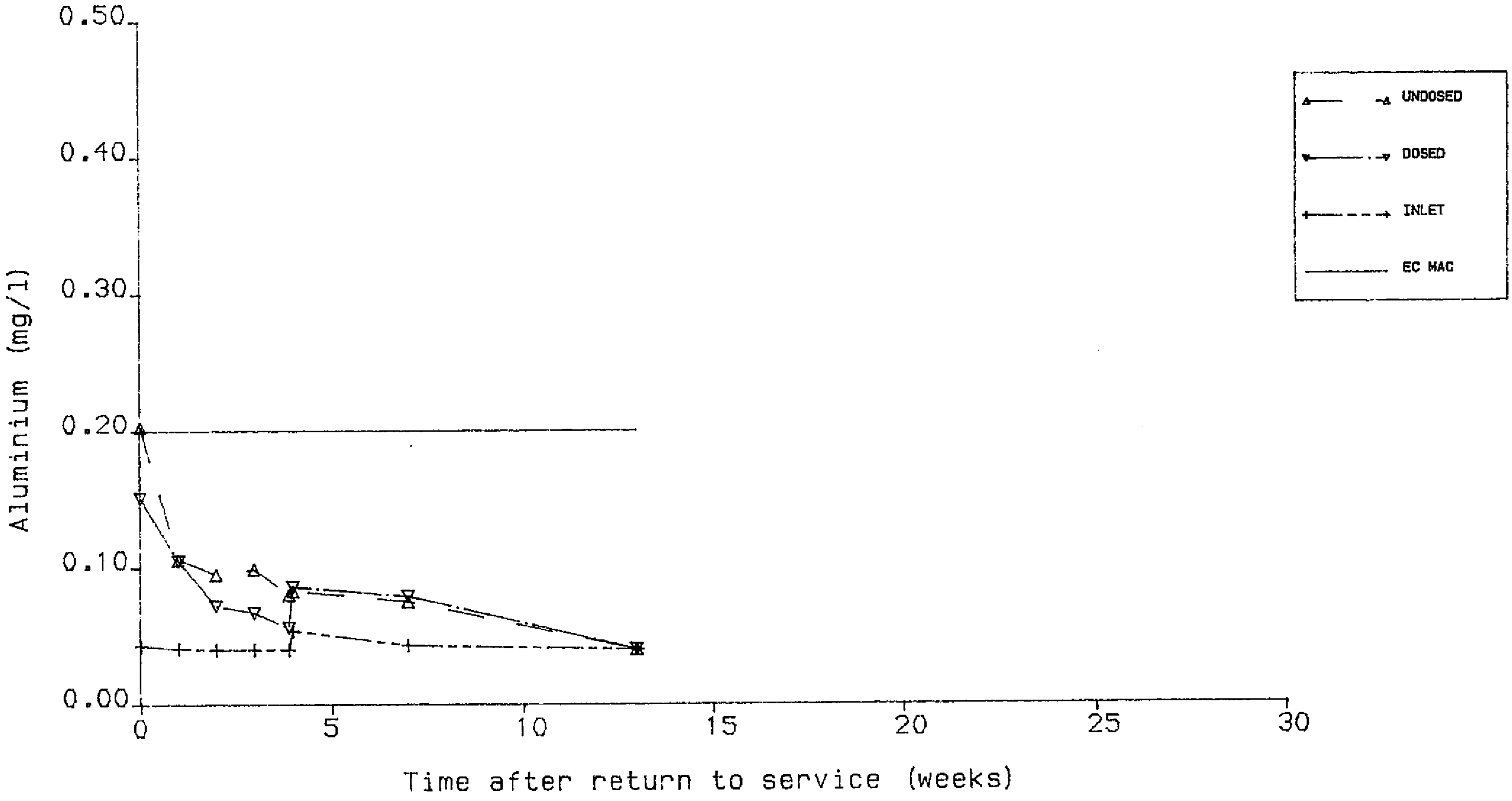


FIGURE 4b

Aluminium vs Time (6 hour contact time)

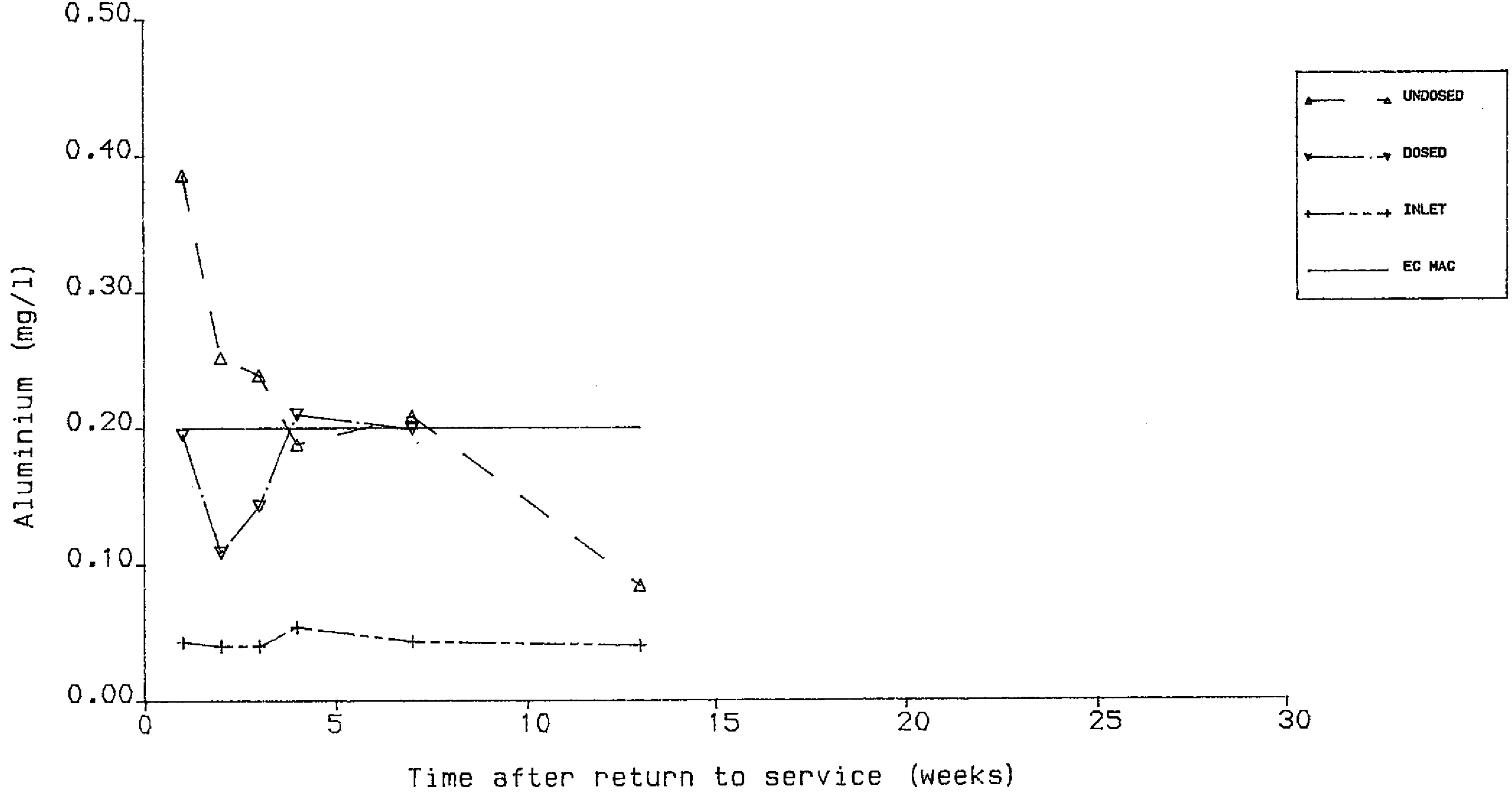


FIGURE 5a

pH vs Time (1 hour contact time)

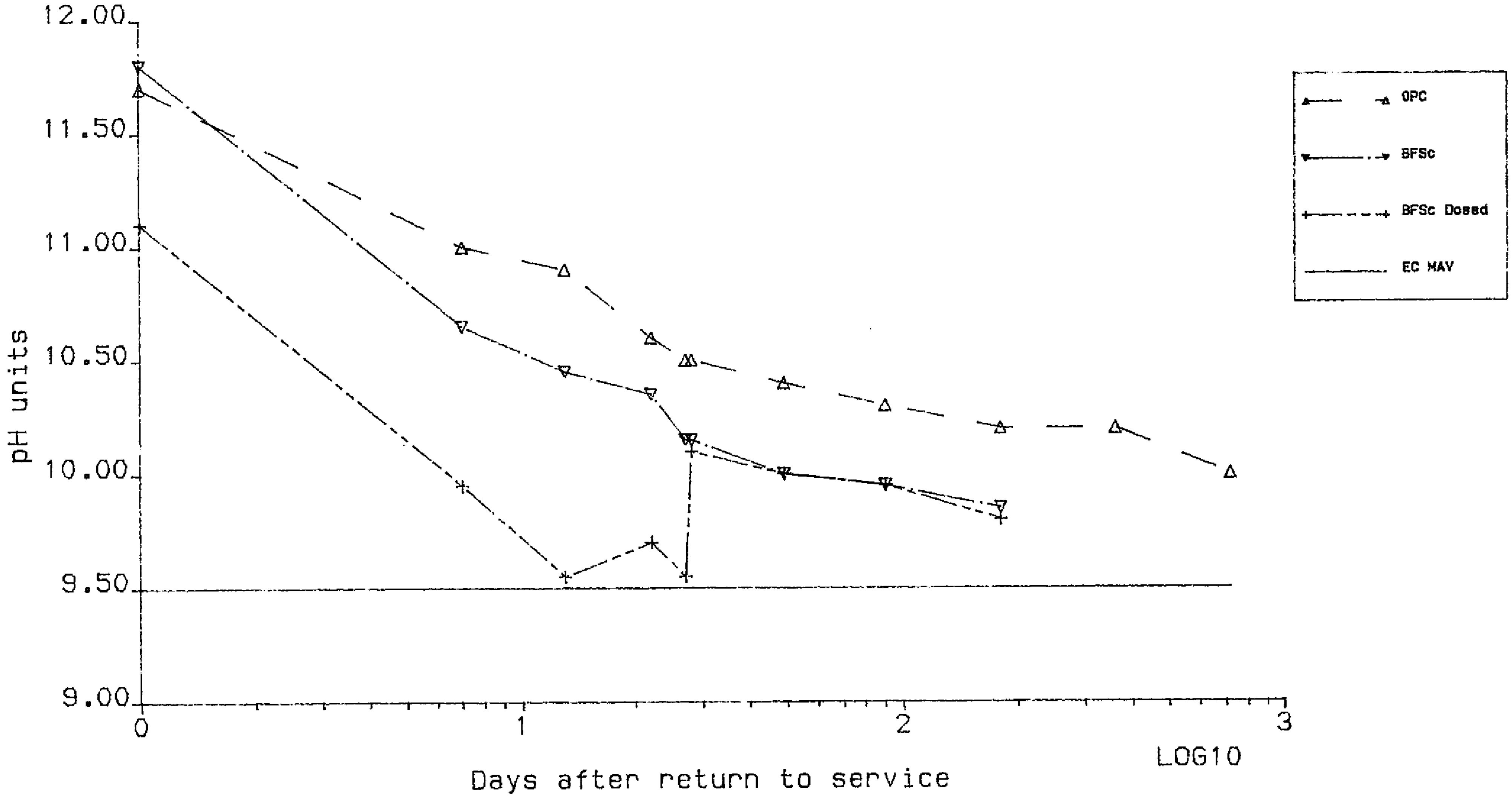


FIGURE 5b

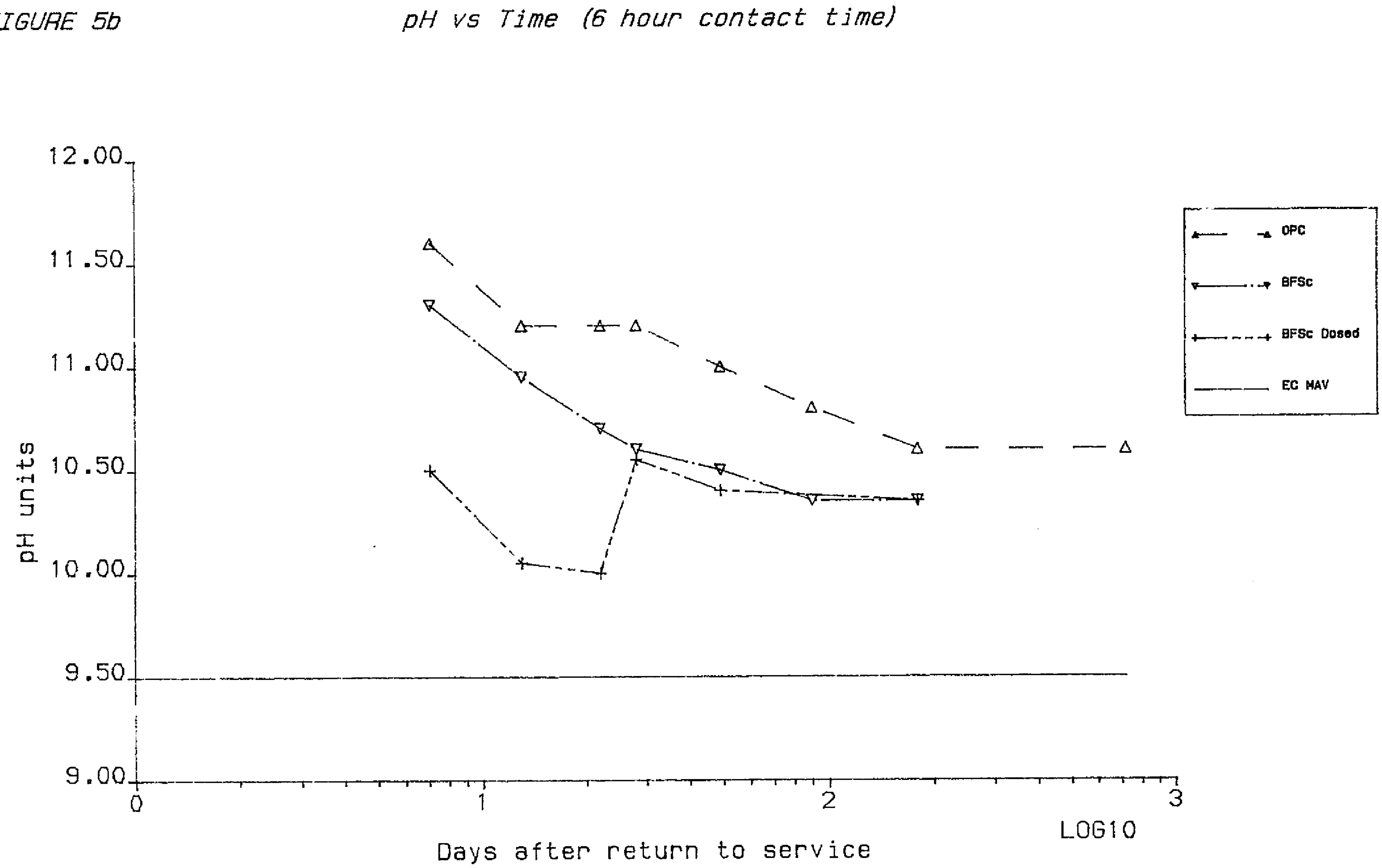

pH vs Time (6 hour contact time)
12.00
11.50
11.00
10.50
10.00
9.50
9.00
pH units
0
1
2
3
LOG10
Days after return to service
OPC
BFSc
BFSc Dosed
EC MAV

FIGURE 6

Aluminium vs Time (6 hour contact time)

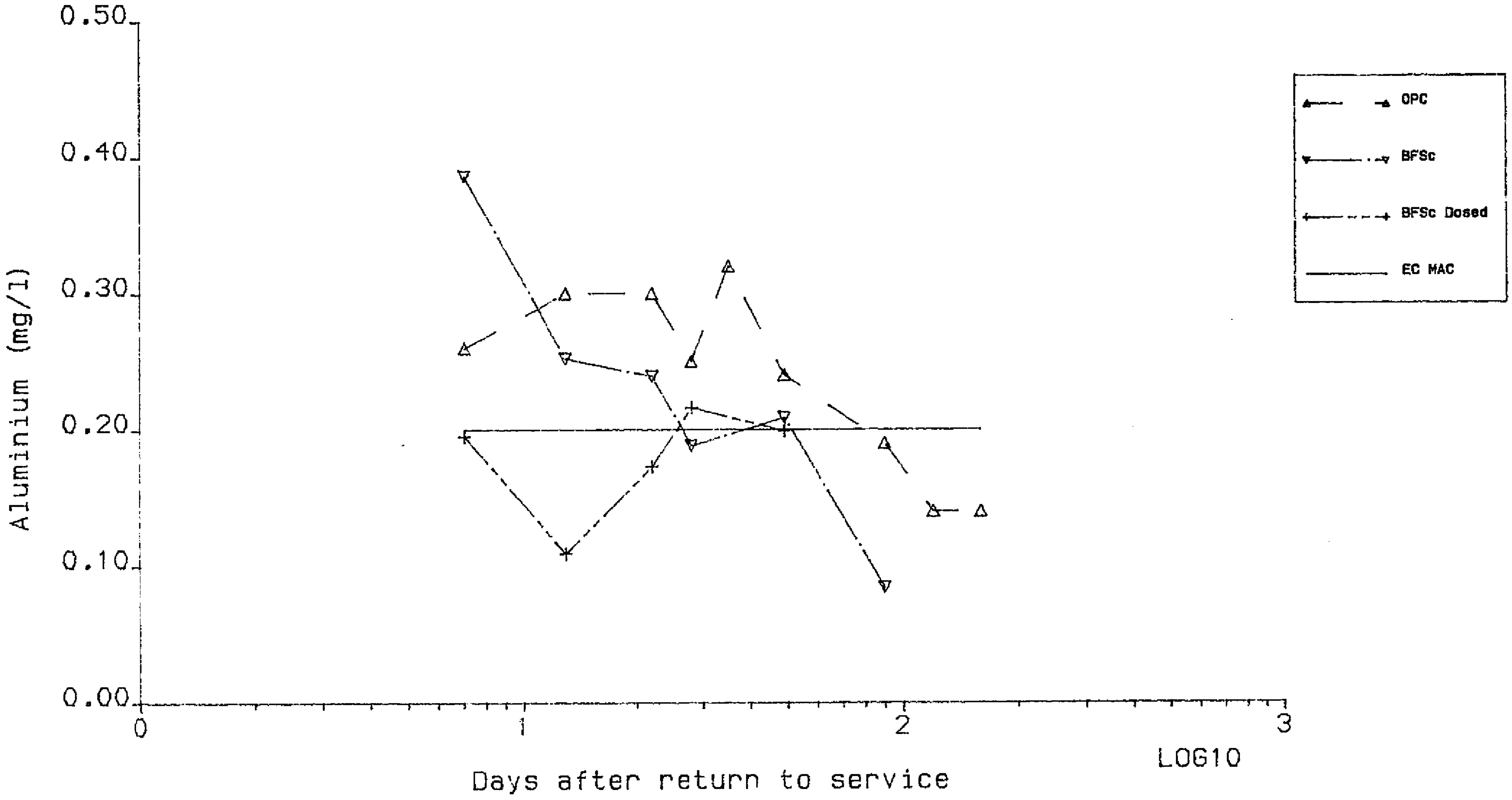
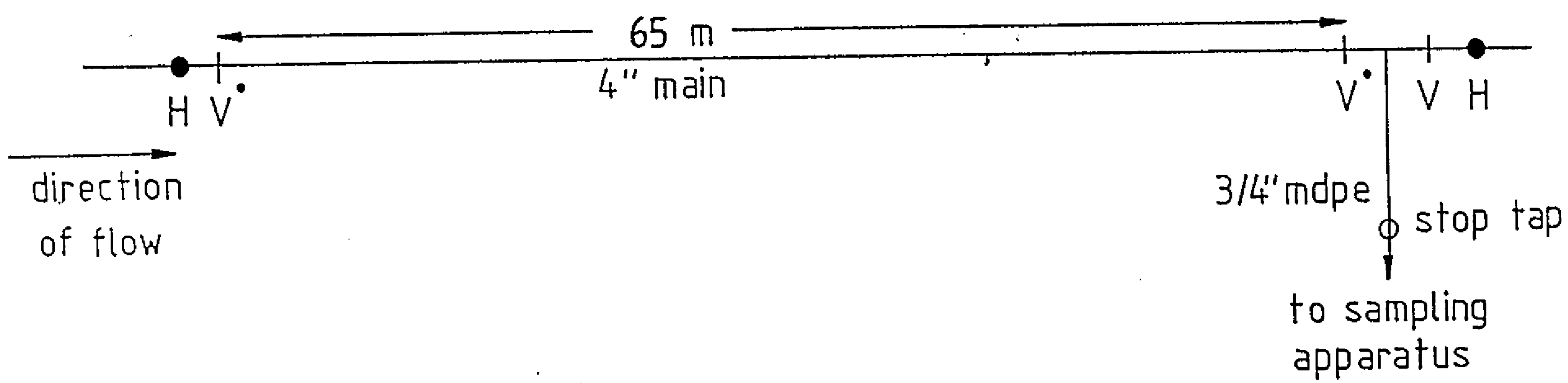


FIGURE 7   LAYOUT OF TEST MAIN



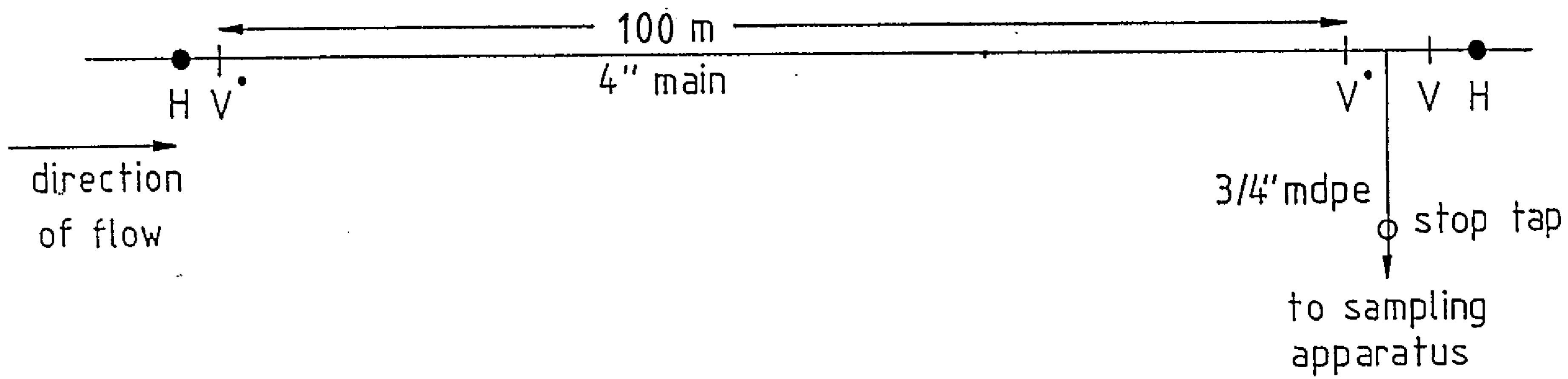
KEY

H - hydrant

V - standard valve

V˙ - special valve

FIGURE 8 LAYOUT OF TEST MAIN



KEY

H - hydrant

V - standard valve

V• - special valve

APPENDIX A

AUTHORS: E P White, J Wheeler, T Liennard

MARCH 1987

AN EVALUATION OF THE EFFECT OF POTENTIAL CEMENT MORTAR LININGS FOR WATER MAINS ON THE pH OF THE CONVEYED WATER

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SUMMARY

I OBJECT

a) To examine the changes in potable water quality after contact with potential in-situ cement mortar lining materials.

b) To ensure that the mortars assessed meet specific flow and pumpability requirements.

II REASON

Cement mortar renovation of water mains using ordinary Portland cement (OPC) is known to increase the pH of certain qualities of conveyed water to above the European Community Council Directive maximum of 9.5. A potential solution to the problem is to use alternative mortar compositions containing less soluble alkaline compounds or to chemically treat the conveyed water to make it less aggressive to cement. Prior to any field trials, laboratory evaluations were required to identify those techniques which are most promising.

III CONCLUSIONS

a) Reductions in pH compared to a normal ordinary Portland cement mortar, of >0.5 have been achieved by using a 65% replacement of the OPC with Blast Furnace Slag (BFS).

b) The lower pH for the BFS mortar was maintained over the whole range of contact times examined.

c) Some mortar compositions are unsuitable as they do not meet the flow requirements of the application technique. This is true of high alumina cement mortars which, although they produce the greatest reduction in pH are thixotropic, and thus could not be applied by current techniques.

d) The experimental techniques used to evaluate the mortars, showed the same order of pH reduction in deionised water and a normally distributed soft water.

e) Comparison of the pH with the calcium concentration of the contact waters shows a strong relationship, which closely parallels that produced when calcium hydroxide is titrated into the water.

f) Dosing the contact water with bicarbonate as sodium bicarbonate for both OPC and BFS mortars resulted in measured pH's well below the EEC maximum admissable value of 9.5. On cessation of dosing the pH returned to the same value as the control.

IV RECOMMENDATIONS

Prior to the use of mortars containing any admixtures of pozzolanic materials the following areas should be examined.

a) The effect of the mortars on water quality, with relevant approval from the DoE CCM.

b) Full scale pumping trials to ensure spray application is practical.

c) The corrosion protection afforded to the iron pipes.

d) The durability of the mortars to ensure a viable economic performance.

e) The low temperature cure characteristics of the mortars.

V RESUME

A range of mortar compositions have been tested to assess their flow characteristics to ensure any proposed materials are potentially pumpable.

The effect of a range of pumpable mortars on the pH of the contact water has been assessed by a variety of experimental techniques. The more promising mix designs have been tested in a continuous flow rig in both deionised water and a typical soft water. Further trials to examine the effects of treatment of the contact water have been performed.

A pH reduction of at least 0.5 compared to OPC has been achieved with a 65% blast furnace slag cement mortar, which was consistent in both short and long term leaching trials and in deionised and distributed soft waters over a wide range of water contact times.

Analysis of the contact water showed the calcium concentration from the BFS cement to be approximately half that from the OPC mortar for equivalent mortar ages and conditions.

Similar trials have been performed incorporating chemical dosing of the contact water. For bicarbonate dosing the pH was reduced to below the EEC mav as long as the dosing was maintained. When dosing ceased the pH returned to the control value.

CONTENTS

1. INTRODUCTION

The recently adopted European Community Council Directive relating to the quality of water intended for human consumption (EC 80/778/EEC)[1] gives a maximum admissible value (mav) for hydrogen ion concentrations (pH) of 9.5. Following renovation of water mains using in-situ cement mortar lining, pH values in excess of the mav have been recorded. These values have been particularly high in mains conveying low flows of soft waters. Indeed pH values as high as 12.5 have been recorded. Thus to try and alleviate the problem of high pH, WRc has investigated modifications to the mortar mix design and chemical dosing of the conveyed water

Initial short term trials on mortars indicated that limited reductions in the contact water pH were possible. However, before more extensive field trials were performed it was important to ensure the mortar designs tested were of equivalent pumpability, and to compare their performance under conditions similar to those encountered in the field.

This report therefore gives details of flow table tests performed on a variety of mortars, and a range of tests, including continuous flow tests to determine the effect of the mortars on the pH of the contact water. Trials were performed in both deionised water, and in a normally distributed soft water.

The results of chemical dosing of the water are additionally reported.

2. EFFECT OF MORTARS ON CONVEYED WATER

The techniques employed for the renovation of water mains using cement mortar lining are presented in 'In-Situ Cement Mortar Lining - Operational Guidelines'[2]. This describes in detail the cleaning of deteriorated water mains, relining with cement mortar and recommissioning. Currently these three aspects are completed within approximately 30 hours, with the mortar allowed to cure for approximately 16 hours overnight. Thus the mortar is not fully cured when the main is returned to service.

When a soft, poorly buffered water comes into contact with the partially cured mortar, the soluble alkaline components of the mortar pass rapidly into solution in the conveyed water. As the water is poorly buffered, only a small dissolution of alkalis is required to raise the pH substantially. The initial peak in pH is followed by a gradual reduction to a stable value which relates to the dissolution of calcium compounds from the mortar.

Four approaches were adopted to try and reduce the increase in pH of the contact water:

i) Reduce the permeability of the mortar.

ii) Seal the mortar surface.

iii) Render the mortar water repellant.

iv) Dosing the conveyed water to make it less aggressive.

2.1 REDUCING THE PERMEABILITY OF THE MORTAR

This results in a more dense material with less opportunity for leaching of soluble compounds from within the body of the mortar. Two methods have been used:

a) reducing the water content of the mortar, by using plasticisers or superplasticisers to maintain the workability. These materials distribute the water more evenly throughout the mix thus ensuring few large pores when fully cured.

b) reducing the size and number of capilliary pores in the mortar by introducing a pozzolanic admixture. The pozzolanic admixtures are very fine and can thus fill pores in the mortar. Additionally over a period of time they react with the free calcium hydroxide to produce relatively insoluble calcium alumino-silicates.

2.2 SEALING THE MORTAR SURFACE

An insoluble barrier can potentially be formed between the conveyed water and the soluble components in the mortar. Two methods have been tried.

a) spraying a curing membrane onto the fresh mortar to provide a physical barrier.

b) dosing the charge-up water with relatively high concentrations of chemicals intended to react with the alkaline compounds to precipitate an insoluble surface layer.

2.3 RENDERING THE MORTAR WATER REPELLANT

By introducing additives to the mortar mix the exchange of conveyed water and pore water can be inhibited thus reducing the rate of release of alkaline compounds.

2.4 DOSING THE CONVEYED WATER

Increasing the buffering capacity of the water should result in a smaller pH rise for a given rate of dissolution of the alkaline compounds.

Details of each of the materials used, with the concentrations and mortar mix designs are presented in Appendix A. A list of the manufacturers and their addresses is given in Appendix B.

3. INITIAL SHORT TERM LEACHING

3.1 PROCEDURE

Initial short term tests were performed on a series of mortars to determine the scale of any potential benefit, and the viability of each approach to reducing the pH increase of the contact water. For each material five blocks were manufactured by the standard procedure given in Appendix C, and following a 24 hr room temperature cure were immersed in deionised water. Simultaneously an identical set of ordinary Portland cement (OPC) blocks was made with a 0.4 water:cement ratio to act as a control.

After immersion in the deionised water for six minutes the pH was measured and the contact water renewed. This procedure was repeated up to fifty times. The average difference between the pH of the control and the modified mortar was calculated to determine the resultant potential benefit.

3.2 RESULTS

The mix designs subjected to this initial short term testing are identified in Table 1, and the average pH reductions achieved compared to an OPC control are given in Table 2.

From this series of simple tests it was apparent that small reductions in the pH of the contact water could be achieved, but for the majority of the mixes used there was little or no benefit.

4. FLOW TABLE TESTS

Flow table tests were performed on selected mortars (see Table 1) to determine the water/cement ratio which gives flow characteristics similar to that of an OPC mortar of 0.4 water/cement ratio. This was to ensure that the mortars tested for leaching could be spray applied to the pipes using existing equipment and technology.

4.1 EXPERIMENTAL

The tests were performed on a flow table as specified in BS4551, section 12. The procedure used was based on that specified in BS4551[3] but modified to enable comparison of more fluid mortars.

Mortar flow as defined in BS4551 is measured from the percentage increase in the average diameter of the spread mortar over the original diameter after the table has been operated 25 times in 15 seconds. However, as this caused many of the more fluid mortars to flow off the table, the spread was measured after the flow table was operated 13 times in 8 seconds. Thus the rate of energy input to the mortar was maintained, but for a shorter period. The procedures used for mixing the mortar, and for the flow table tests are presented in Appendix C.

4.2 RESULTS

Figure 1 shows the flow table values obtained for both an OPC mortar using the BS4551 procedures of 25 table operations in 15 seconds, and the modified procedure of 13 table operations in 8 seconds. It can be seen that the modified procedure enables evaluation of mortars with a higher water/cement ratio, i.e. more fluid mixes.

The flow results from the various mortar mixes are presented in Figure 2 where the modified procedure was used. The band marked between 200% and 210% is the flow considered to be acceptable for spray lining of water mains. Thus suitable water/cement ratios for each mix design can be determined, and are presented in Table 3.

For a given flow, PFA or plasticised mortars require lower water/cement ratios than OPC mortars, conversely BFS mortar requires a slightly higher water/cement ratio.

Addition of silica fume to the mortar to tie up the free lime, and reduce the porosity results in a thixotropic mix, which has unpredictable pumping characteristics. HAC mortars exhibited the same phenomenon, and additionally suffered from bleeding, resulting in a weak material when cured. BFS cement mortars, with a plasticiser added to reduce the water/cement ratio suffered from "shear rate blockage", i.e. when left to stand the mortar flows freely whereas when worked it becomes very stiff.

4.3 MATERIALS SELECTED FOR FURTHER EXAMINATION

From the results presented in Figure 2 it can be seen that only a few of the mortars can achieve the flow required for application. These were selected for leaching trials, together with HAC mortar because despite the problems of false set (thixotropy) it contains few soluble alkaline compounds and therefore may not significantly elevate the pH of the contact water.

5. LEACHING

Various mortar mix designs which met the above flow criteria were selected for further leaching trials (see Table 1). Three leaching trial tests were developed and run on the various mortars, and included a short term rinsing test, a 'daily pot test' and continuous flow tests in both deionised water and a normally distributed soft water. In each test the pH of the water after being in contact with the mortars was recorded, and limited chemical analyses were performed.

5.1 SHORT TERM RINSES

5.1.1 TESTING

Short term rinsing tests were performed on each of the selected mortars as they provide a quick assessment of the scale of any likely benefit measured in terms of pH reduction. The procedure used is given in Appendix C and is based on that used previously. The geometry of the test cell however was modified to produce better repeatability of results by reducing concentration gradients (see Figure 3). For each mortar studied, simultaneous measurements were made on control blocks produced from a standard Cement and Admixture Association OPC mortar at a water/cement ratio of 0.4.

The test measures the pH of water which has been in contact with the mortar blocks for six minutes. The water is renewed and the pH again measured after six minutes. This process is repeated fifty times for both the mortar under investigation, and the control. The test therefore monitors the initial period of the mortar's life.

5.1.2 RESULTS

A plot of pH against rinse number is presented in Figure 4 for the short term rinse tests in deionised water, and Figure 5 in distributed soft water. Figures 6 and 7 show the difference in pH resulting from the modified mortars and the OPC control in deionised and distributed soft waters respectively. Mean pH reductions relative to the control are presented in Table 2, for each mortar together with their standard deviations.

5.2 DAILY POT TESTS

5.2.1 TESTING

Daily pot tests were used to enable simple comparison of the effects of the mortars on water quality over a longer time period. The method used was principally the same as for the short term leaching trials, except the pH was measured, and the water changed once every 24 hours. Periodically through the tests water samples were taken for chemical analysis.

5.2.2 RESULTS

Changes in pH with time for the daily pot tests are presented in Figures 8 and 9 for the trials performed in deionised and distributed soft waters respectively.

Table 4 gives the water quality analyses from daily pot tests on some of the mortars evaluated. The contact water quality was also monitored for the daily pot tests on selected mortars in a normally distributed soft water, and the results are presented in Table 5.

5.3 CONTINUOUS FLOW TESTS

5.3.1 TESTING

The continuous flow rig shown in Figure 10 was designed to model conditions existing in a 100mm diameter distribution main. Two mortars and an OPC control can be evaluated simultaneously in three parallel cells which hold mortar blocks suspended in the test water. The ratio of surface area of the mortar to the volume of water in the cell is designed to be the same as the surface area to volume ratio in a 100mm pipe. Temperature of the test cells was maintained at 10°C which represents an average temperature of underground mains.

Water from a continuously overflowing constant head device is fed via needle valve flow meters to the bottom of each test cell which contain the mortar blocks. This displaces water from the top of the sealed cell into a small measurement container where the pH is continuously monitored. Each of the cells is stirred to prevent the formation of high concentration gradients around the mortar blocks.

Air interfaces with the test water in the system are minimised to prevent absorption of atmospheric carbon dioxide.

5.3.2 EXPERIMENTS

The two most promising mix designs from the short term tests were selected and mortar blocks were made and allowed to cure for 24 hours. The blocks were installed in the test cells and the flow set to 15ml/minute to each cell. This gives a residence time in the cell of approximately 1½ hours, which is comparable to a flow of 4 l/minute through 50m of 100mm diameter pipe. The pH of the effluent water from each cell was continuously measured and recorded. At periodic intervals samples of the effluent water were collected for chemical analysis.

The rig was run for a minimum of twenty eight days using both deionised water, and a typical soft water.

Experiments were also performed with a typical soft water using a range of flow rates and stagnations, representing a wide range of contact times. The conditions selected for the test were comparable to those used on the pipe rig installed at Strathclyde Regional Councils premises at Balmore Road, to enable direct comparison of the results.

5.3.3 MATERIALS INVESTIGATED

A sand to cement plus pozzolan ratio of 1:1 was used for each mortar. Water/cement ratios were those found to give a flow equivalent to an OPC mortar at 0.4 water/cement. For each mortar a standard OPC from the Cement Admixtures Association (CAA) was used, and the sand was dry bagged Buckland FG50.

The following mix designs were investigated:

MORTAR	CEMENTITIOUS COMPONENT	SAND	WATER/CEMENT RATIO
Control	100% OPC	FG50	0.4
BFS	65% BFS 35% OPC	FG50	0.42
PFA1	40% PFA 10% Silica Fume 50% OPC	FG50	0.4
PFA2	70% PFA 10% Silica Fume 20% OPC	FG50	0.38

Mix design PFA1 was evaluated in the distributed soft water and design PFA2 in deionised water.

The composition of PFA2 theoretically ensures that all the lime in the OPC reacts with the silica within approximately seven days, thereby potentially reducing the calcium hydroxide available for leaching.

5.3.4 RESULTS

i) DEIONISED WATER

Continuous flow leaching trials were performed in deionised water on PFA2 and BFS mortars, as well as an OPC control. The pH trace against time is presented in Figure 11 for the first forty days of operation. The difference between the pH of the OPC contact water and the BFS, and PFA2 contact waters is shown in Figure 12.

At intervals during the tests water samples were taken for chemical analysis and the results are presented in Table 6. Figure 13a shows the change in the calcium content of the contact water against time, and it can be seen that the calcium concentration resulting from the BFS mortar is approximately half that from the OPC mortar.

ii) TYPICAL SOFT WATER

Changes of pH with time are shown in Figure 14 for a typical soft water in contact with the three mortars. A typical analysis of the water before contact is given in Appendix D. Figure 15 presents the difference between pH of the control and the BFS and PFA1 contact waters. Samples of the effluent water were taken for analysis at intervals throughout the tests, and the results are presented in Table 7. Calcium concentrations for each sample are plotted in Figure 13b, and it is evident that the calcium concentration of the water in contact with BFS mortar is approximately half that for OPC.

Following forty days exposure, the effects of various water flow rates and stagnation times were assessed, and water samples were taken for analysis. The results are plotted in Figure 16 as pH against water contact time, with the chemical analyses of the contact water presented in Table 7. Figure 17 is a plot of the calcium concentration against contact time.

6. CHEMICAL DOSING OF CONTACT WATER

6.1 EXPERIMENTAL

The apparatus used for the chemical dosing experiments operated on the same principle as for the continuous flow tests. The inlet water to the test cells was dosed with a range of concentrations of various chemicals, and the pH of the effluent water was continuously monitored over a period of twenty eight days. For each series of experiments an undosed control was also run.

OPC mortars were tested with phosphate, silicate and several concentrations of bicarbonate dosing. Both OPC and 65% Blast Furnace Slag (BFS) mortars were tested with different concentrations of bicarbonate dosing over various time periods. Table 9 shows the concentrations and dosing periods examined for OPC and BFS mortars.

6.2 RESULTS OF DOSING

Dosing the OPC mortars with silicates (at 15mg/l as SiO_2) and phosphates (at 2.2mg/l as P) did not cause any significant reduction in the pH of the effluent contact water. However, dosing with bicarbonate (at 100mg/l as HCO_3) reduced the pH to below the EEC mav within four days (see Figure 18). For each of the bicarbonate concentrations examined the pH of the effluent water remained below the EEC mav, at around pH9. However, as soon as the dosing ceased, the pH very rapidly returned to around the value of the control sample which had received deionised water for the duration of the test (see Figure 19). This indicates that the dosing does not result in the precipitation of a relatively insoluble layer of carbonate on the surface of the mortar.

Bicarbonate dosing trials on BFS mortars showed similar trends, with the pH of the contact water reduced to pH9 during dosing, but with the pH recovering to the control BFS reading on cessation of dosing (see Figure 20). Examination of the calcium concentrations of the contact water against age (Figure 21) shows a decreasing amount of Ca leached from the control mortars with time. The Ca concentrations for the dosed waters are significantly lower, and relatively constant. Following cessation of dosing on the BFS mortars it can be seen that the Ca concentration rises to above the Ca of the BFS control, thus reflecting the observed rise in pH.

7. DISCUSSION OF RESULTS

7.1 SHORT TERM LEACHING

The results from the short term leaching trials in deionised water (Figure 4) show the pH of the water after a six minute contact time to progressively decrease with the number of rinses performed. When normalised to the OPC control (Figure 6) it can be seen that in order of increasing benefit the mortars are PFA, PFA plus plasticiser, BFS and HAC.

The trials performed in a soft distributed water showed the same general trends of reducing pH (Figure 5), but the pH values recorded were higher. This was due to the initial pH of the distributed water being higher. When normalised to the OPC control, the reduction in pH by using PFA and BFS are of the same order as in deionised water (Figure 7).

7.2 DAILY POT TESTS

Daily pot tests on the modified mortars show the same trends as the short term leaching tests, although the pH values recorded are much higher due to the 24 hours contact time. Again the results from the distributed soft waters are higher than from the deionised water, although the reductions compared to the OPC control are of the same order.

Examination of the water quality analyses from daily pot tests in distributed soft water (Table 5) shows the measured pH to be related to the calcium content. The calcium in the water in contact with the BFS mortar is significantly lower than the OPC control or the PFA contact water. The concentrations of each of the elements analysed decrease progressively with time, showing that less material is being leached from the mortars.

Water quality analysis of daily pot tests on HAC mortar show very high aluminium levels more than 30 times the level on the OPC control even after 14 days. Because of this and the potential application problems associated with high alumina cement, this mortar was not investigated further.

7.3 CONTINUOUS FLOW TESTS

In both the deionised and soft waters the initial pH of the contact water was about 12.0 (Figures 2 and 5). These high levels reflect the leaching of the highly soluble alkali components, reflected in the high concentrations of potassium seen in the contact waters (Tables 6 and 7). For each of the mortars studied the pH decayed rapidly over the first week of operation, with the OPC mortar levelling out at around 10.75, the PFA mortar at 10.55 and the BFS mortar at 10.3. The difference in pH for each of the mortars compared to an OPC control is presented in Figures 12 and 15 for deionised and distributed soft waters respectively. In both cases the PFA mortars show an increased pH for the first ten days which probably relates to the higher levels of soluble alkalis present in PFA (see Appendix E). After approximately ten days exposure, the PFA mortars show a reduction in pH. Of the PFA mortars evaluated, PFA2, which was specifically designed to tie up all the free calcium hydroxide, shows the greater reduction in pH.

The BFS mortars show an immediate benefit which increased during the experiment. After 40 days in both deionised and soft waters the reduction compared to OPC mortar is between 0.5 and 0.6 pH units.

Various flow and stagnation tests were performed in the distributed soft water after 40 days exposure and the pH monitored for each of the mortars. The results plotted in Figure 16 are presented as a function of the contact time of the water. It can be seen that at high flow rates, i.e. contact times of less than 1½ hours, the pH of the water is very sensitive to contact time, whereas after 1½ hours, the changes are much slower. Additionally, the difference in pH between the PFA mortar, the BFS mortar and the OPC control remain relatively constant over the whole range of contact times.

Chemical analysis of the water taken at various times through the experiments, showed high initial concentrations of dissolved chemicals which reduced with time. The calcium ion concentrations are plotted in Figure 13a for the mortars in deionised water, and in Figure 13b for the soft water. For most of the tests the calcium leached from the BFS mortar was significantly lower than the OPC mortars. Concentrations from the PFA mortars were generally between the OPC and BFS levels.

Similar trends are seen for the data on contact time (Figure 17) with the BFS mortar resulting in calcium levels approximately half those from OPC. These measurements were made using water which has an initial calcium ion concentration of approximately 3.5 mg/l. Thus the release from the BFS mortar can be seen to be very low.

There appears to be a strong correlation between the pH of the water and its calcium concentration. Figure 22 shows a plot of pH of the contact water against the calcium concentrations for all the long term, flow and stagnation tests in the distributed soft water. This figure also shows the results from titration of calcium hydroxide into the same water. Slightly higher pH values have been measured than are predicted from the titration curve but this is probably due to the effect of additional soluble alkali compounds leached from the cement mortars.

7.4 CHEMICAL DOSING

It was anticipated that dosing the conveyed water with phosphates would cause a reaction with the surface calcium hydroxide to precipitate a layer of relatively insoluble calcium phosphate. Thus an initial reduction in pH was anticipated which would continue when dosing ceased. The dosing with silicates was expected to allow a reaction with the calcium hydroxide forming calcium silicates in the surface pores which would provide a physical barrier to the interchange of pore and conveyed waters. However, it is evident from figure 18 that limited reductions in pH occur during dosing, and that this benefit is not continued when dosing ceases. Elemental analysis of sections of the blocks following dosing showed a slight increase in phosphorous at the surface of the phosphorous dosed blocks, but this precipitation over 28 days was not enough to provide a barrier.

Bicarbonate dosing proved effective at all concentrations examined, but only while dosing continued. As soon as dosing ceased the pH returned to the same, or a slightly higher value than the control, confirming that no significant precipitation of calcium carbonate had occurred. This return to a higher pH is reflected by the rise in Ca concentration in the contact water.

7.5 GENERAL

The series of experiments has shown that in laboratory conditions a 65% blast furnace slag cement gives the greatest reduction in pH of the contact water compared to an OPC mortar. This difference is maintained for each of the tests and for all conditions of contact time and flow rate examined. The material, however, cures more slowly than OPC at low temperatures and therefore may require temperature/time limitations, or additional heating during cure.

For areas where the benefit from using BFS is not sufficient, chemical dosing can be utilised either on OPC, or in conjunction with BFS cement mortars to overcome the initial high pH peak.

8. REFERENCES

1. European Community Council Directive of 15 July 1980 relating to the quality of water intended for human consumption (80/778/EEC).

2. WRc Water Mains Rehabilitation Manual 1986 Source Document No 2. 'In-Situ Cement Mortar Lining - Operational Guidelines'.

3. BS4551 (1980) British Standard Methods of Testing Mortars, Screeds and Plasters.

Table 1 - Mortar mix designs subjected to each test

MORTAR MIX	INIT. SHORT TERM LEACHING	FLOW TABLE TESTS	DEIONISED WATER			DISTRIBUTED SOFT WATER		
			SHORT TERM	DAILY POT	CONT. FLOW	SHORT TERM	DAILY POT	CONT. FLOW
OPC Control	/	/	/	/	/	/	/	/
20% Si Fume + Plasticiser	/	/						
40% PFA	/	/	/					
40% PFA + Plasticiser	/	/	/	/				
OPC + Silicate Spray	/							
OPC + Plasticiser	/	/						
OPC + Superplasticiser	/							
OPC + Silicate	/							
65% BFS		/	/	/	/	/	/	/
HAC		/	/	/				
65% BFS + Si Fume		/		/				
65% BFS + Plasticiser		/		/				
65% BFS + Superplasticiser		/		/				
OPC + Waterproofer		/		/				
OPC + Waterproofing Agent		/		/				
70% PFA + 10% Si Fume		/		/	/			
40% PFA + 10% Si Fume		/				/	/	/

TABLE 2

a) AVERAGE PH REDUCTION COMPARED TO OPC CONTROL FOR SIMPLE LEACHING TRIALS

MORTAR	pH REDUCTION	
	MEAN	STANDARD DEVIATION
20% Si Fume + Plasticiser	-0.58	0.13
40% PFA	-0.47	0.10
40% PFA + Plasticiser	-0.41	0.09
OPC + Silicate Spray	-0.33	0.12
OPC + Plasticiser	-0.19	0.11
OPC + Superplasticiser	-0.15	0.35

b) PH REDUCTIONS FOR SHORT TERM RINSING TESTS

MORTAR	DEIONISED WATER pH reduction over cntrl mortar		DISTRIBUTED SOFT WATER ph reduction over cntrl mortar	
	MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION
40% PFA replacement	0.05	0.13	0.12	0.06
40% PFA replacement plus plasticiser	0.06	0.17	-	-
High Alumina Cement	0.70	0.30	-	-
65% BFS replacement	0.45	0.13	0.24	0.06

TABLE 3 MIX DESIGNS OF MORTARS EVALUATED

MORTAR	PUMPABLE WATER : CEMENT
OPC Control	0.4
HAC Mortar	Thixatropic
BFS Mortar	0.42
PFA Mortar	0.38
PFA + Plasticiser	0.27
Silica Fume Mortar	Thixatropic
OPC + Plasticiser	0.33
PFA + Silica Fume	Thixatropic
Silica Fume + Plasticiser + Workability Aid	Thixatropic
BFS + Si Fume	0.62
OPC + Waterproofing Agent	0.40
OPC + Waterproofer	0.26
BFS + Plasticiser	0.34
BFS + Superplasticiser	0.34

TABLE 4 WATER QUALITY ANALYSIS OF DAILY POT TESTS IN DEIONISED WATER

MORTAR	DAY NO	Concentration mg/l				
		Al	Fe	Si	K	Ca
HAC	1 7 14	1190.0 41.50 24.40	2.476 0.243 0.062	0.820 0.478 1.131	7.758 0.499 0.191	242.305 79.985 37.718
CONTROL	1 7 14	1.729 0.969 0.707	0.215 0.000 0.000	2.731 6.606 8.093	361.761 16.737 10.194	268.929 64.716 32.984
PFA + SIKAMENT	1 7 14	1.357 1.090 1.172	0.069 0.000 0.005	4.946 5.732 5.339	320.309 26.693 13.519	135.374 45.745 24.210

TABLE 5 WATER QUALITY ANALYSIS OF DAILY POT TESTS IN DISTRIBUTED SOFT WATER

MORTAR	DAY NO	Al	Fe	Si	K	Ca
PFA	4 11 18 25	0.711 1.054 0.859 0.756	0.104 0.178 0.091 0.090	5.934 5.565 3.987 3.537	21.165 16.359 11.807 9.252	65.364 39.701 30.554 27.250
CONTROL	4 11 18 25	0.617 0.795 0.765	0.087 0.130 0.110	6.218 6.509 4.928	19.654 13.902 8.685	79.647 56.706 40.591
BFS	4 11 18 25	0.745 0.809 0.695 0.604	0.140 0.326 0.102 0.096	6.464 5.723 4.769 4.232	6.759 3.829 2.530 1.679	35.452 28.232 21.638 20.679

TABLE 6 WATER ANALYSIS FROM CONTINUOUS FLOW RIG USING DEIONISED WATER

MORTAR	DAY	Ca mg/l	Al mg/l	Fe mg/l	Si mg/l	K mg/l
OPC	2 8 20 28	38.2 10.5 5.1 4.2	0.29 0.26 0.60 0.16	0.001 0.008 0.013 0.154	2.20 1.44 0.74 0.75	4.90 0.91 0.29 0.59
PFA2	2 8 20 28	34.9 9.4 3.2 2.2	0.24 0.98 0.69 0.83	0.000 0.005 0.013 0.045	0.73 0.39 0.26 0.22	3.67 0.28 0.19 0.12
BFS	2 8 20 28	21.5 4.80 2.19 1.26	0.39 0.22 0.46 0.11	0.000 0.002 0.005 0.005	2.15 1.20 0.68 0.42	4.46 0.64 0.19 0.10

TABLE 7 WATER ANALYSIS FROM CONTINUOUS FLOW RIG USING A TYPICAL SOFT WATER

MORTAR	DAY	Ca mg/l	Al mg/l	Fe mg/l	Si mg/l	K mg/l
OPC	1 7 14 23 29	37.3 14.88 18.44 8.89 12.30	0.09 0.29 0.48 0.20 0.26	0.07 0.11 0.07 0.12 0.09	1.93 10.85 2.49 1.01 10.41	9.20 1.94 4.11 0.99 1.40
PFA1	1 7 14 23 29	28.75 11.93 7.61 7.70 9.71	0.15 0.21 0.15 0.17 0.20	0.07 0.08 0.08 0.09 0.09	2.11 1.36 0.86 0.88 1.10	14.14 1.71 0.93 1.25 1.50
BFS	1 7 14 23 29	17.43 9.31 8.91 6.10 6.86	0.24 0.28 0.34 0.22 0.24	0.09 0.08 0.07 0.10 0.08	2.12 1.64 1.73 1.06 1.19	5.60 1.11 0.79 0.73 0.64

TABLE 8 WATER QUALITY ANALYSIS FOR VARIOUS CONTACT TIMES FOLLOWING FORTY DAYS EXPOSURE IN A TYPICAL SOFT WATER

MORTAR	CONTACT TIME Hrs Mins	Ca mg/l	Al mg/l	Fe mg/l	Si mg/l	K mg/l	Na mg/l	pH mg/l
OPC	0.09	4.08	0.04	0.07	0.39	0.32	2.27	9.92
	0.18	4.42	0.05	0.07	0.42	0.28	2.68	10.17
	0.30	5.01	0.06	0.08	0.49	0.32	2.81	9.94
	0.45	6.06	0.12	0.09	0.59	0.46	2.80	10.16
	3.00	10.11	0.21	0.07	1.06	0.92	2.41	11.07
	7.30	12.08	0.27	0.06	1.59	1.06	2.81	11.09
	13.30	17.21	0.45	0.04	2.38	1.81	2.39	11.44
PFA1	0.09	4.55	0.07	0.08	0.38	0.29	2.28	9.87
	0.18	4.20	0.06	0.11	0.40	0.32	2.28	10.12
	0.30	4.68	0.09	0.16	0.46	0.45	2.80	10.20
	0.45	5.21	0.11	0.13	0.51	0.49	2.77	10.37
	3.00	9.27	0.19	0.09	0.85	0.99	2.85	10.92
	7.30	9.64	0.21	0.12	1.20	1.21	2.38	11.00
	13.30	13.33	0.44	0.07	1.83	2.22	2.53	11.37
BFS	0.90	3.76	0.04	0.07	0.39	0.29	2.25	9.61
	0.18	3.79	0.05	0.07	0.40	0.25	2.27	9.77
	0.30	4.10	0.06	0.08	0.46	0.28	2.28	9.65
	0.45	4.69	0.12	0.08	0.56	0.34	2.64	9.90
	3.00	5.96	0.18	0.07	0.92	0.52	2.36	10.40
	7.30	7.23	0.21	0.07	1.19	0.38	2.88	10.43
	13.30	8.67	0.38	0.06	1.87	0.71	2.39	10.77

TABLE 9 CONCENTRATION AND DURATION OF CHEMICAL DOSING

MORTAR	CONCENTRATION AS HCO^3		
	100 mg/l	250 mg/l	500 mg/l
OPC	1 day	14 days	14 days
OPC	5 days		28 days
OPC	9 days		
OPC	28 days		
65% BFS	9 days	16 days	16 days

OPC	28 days	15 mg/l as S_iO_2
OPC	28 days	2.2 mg/l as P

APPENDIX A

MATERIALS USED, AND MORTAR MIX DESIGNS

For each mortar the ratio of cemenations comparent to sand was 1:1 by weight.

Sand	Buckland FG50 dry bagged sand
Ordinary Portland Cement	(OPC)
Blast Furnace Slag	(BFS)
Pulverised Fuel Ash	(PFA)
Silica Fume	(Si Fume) Sika FS3
High Alumina Cement	(HAC)
Plasticiser	Sikament
Superplasticiser	Complast M1 (melamine formaldehyde)
Waterproofing Agent	Caltite
Waterproofer	Sikacem 810
Sodium Bicarbonate	$NaHCO_3$
Sodium Silicate	Crystal 79
Sodium Phosphate	Kalipol

Mortar	Water:Cement
OPC Control	0.4
HAC	Thixotropic
65% BFS + 35% OPC	0.42
40% PFA + 60% OPC	0.38
40% PFA + 60% OPC + Plasticiser	0.27
OPC + Plasticiser	0.33
40% PFA + 10% Si Fume + 50% OPC	Thixotropic
BFS + Plasticiser	0.34
65% BFS + 10% Si Fume + 25% OPC	0.65
OPC + Waterproofer	0.40
OPC + Waterproofing Agent + Plasticiser	0.40
70% PFA + 10% Si Fume + 20% OPC	0.40

Dosing	mg/l as anion
Sodium Silicate Crystal 79	15
Sodium Phosphate Kalipol	2.2
Sodium Bicarbonate	100, 250, 500

APPENDIX B

MANUFACTURERS NAMES AND ADDRESSES

OPC	Cement Admixtures Association 2A High Street Hythe Southampton SO4 6YW Tel: (0703) 842765
BFS	Frodingham Cement Co Ltd Brigg Road Scunthorpe South Humberside DN16 1AW Tel: (0724) 872931
PFA	Ash Marketing - CEGB Sudbury House 15 Newgate Street London EC1A 7AU Tel: (01 634) 6662
Si Fume Silca FS3	Sika Ltd Watchmead Welwyn Garden City Herts AL7 1BQ Tel: (07073) 29241-4

HAC		Lafarge Aluminous Cement Co Ltd Fordu Works 730 London Road West Thurrock Grays Essex RM16 1NJ Tel: (0708) 863333
Plasticiser	Sikament	Sika Limited Watchmead Welwyn Garden City Herts AL7 1BQ Tel: (07073) 29241-4
Superplasticiser	Conplast M1	Fosroc Ltd Construction Chemicals Division Vimy Road Leighton Buzzard Beds LU7 7EW Tel: (0525) 375646
Waterproofing Agent	Caltite	Cementaids Europe Ltd 51A George Street Richmond Surrey TW9 1HT Tel: (01 948) 4622

Waterproofer	Sikacem 810	Sika Ltd Watchmead Welwyn Garden City Herts AL7 1BQ Tel: (07073) 29241-4
Sodium Bicarbonate		BDH Chemicals Ferris & Co Kenn Road Hillside Road St Georges Bristol BS5 7PE Tel: (0272) 551601
Sodium Silicate	Crystal 79	Joseph Crosfield & Sons Ltd Warrington Cheshire
Sodium Phosphate	Kalipol	Albright & Wilson Ltd Oldbury Warley
Sand	Buckland FG50	Buckland Minerals Ltd Reigate Heath Reigate Tel: (073 72) 40151

APPENDIX C

MORTAR MIXING PROCEDURE, FLOW TABLE PROCEDURE AND MANUFACTURE OF MORTAR BLOCKS

i) MIXING PROCEDURE

The individual components for the mortars were stored at a constant temperature of 10°C. After weighing out the correct amounts, the components were mixed in a Hobart mixer first dry, then following addition of the gauging water for:

1 minute at a slow speed
2 minutes at a fast speed
2 minutes at a slow speed

ii) FLOW TABLE TESTS

The flow table and mould were stored at 10°C. The flow table was assembled, and the mould placed at the centre of the table.

The mould was filled with the mortar according to BS4551 (1980) and the mould lifted away vertically. The flow table was then operated thirteen times in eight seconds, and the average diameter of the mortar measured on four diameters at equal intervals. The resultant flow was expressed as a percentage of the internal base diameter of the mould.

iii) MANUFACTURE OF MORTAR BLOCKS

The moulds were coated with a thin layer of release oil, and the mortar as prepared in (i) tamped in to remove any entrapped air.

The exposed surface of the mortar blocks was smoothed, and sealed during curing by covering with a piece of cling film.

After 24 hours cure the blocks were removed from the moulds and immediately placed in the leaching cells.

iv) SHORT TERM LEACHING TESTS

For each mix design, a set of five mortar blocks was made using the procedure detailed in (iii).

The blocks, each 25mm x 25mm x 100mm were suspended in 1405ml of stirred water to model the surface area to volume ratio of a four inch main. The pH of the water was measured after 6 minutes, and the water discarded. The blocks were immersed in fresh water and the pH measured after 6 minutes. This process was repeated fifty times. Simultaneous measurements were made on an OPC control mortar for direct comparison.

APPENDIX D

TYPICAL ANALYSES OF THE NORMALLY DISTRIBUTED SOFT WATER USED IN LEACHING TRIALS

Mean pH	8.87
Mean Ca	3.61
Mean Al	0.029 mg/l
Mean Na	3.51 mg/l
Mean K	0.36 mg/l
Mean Mg	0.755 mg/l
Mean Fe	0.024 mg/l
Mean Si	0.303 mg/l
Total Alkalinity ($CaCO_3$)	9 mg/l
Conductivity	38 mg cm^{-1}

APPENDIX E

TYPICAL CHEMICAL ANALYSIS OF CEMENTS AND ADDITIVES USED

	OPC	PFA	BFS	BUCKLAND FG50 SAND
SiO_2	21.1	51.4	35 - 38.5	99.5
Al_2O_3	5.1	27.3	9.5 - 13.0	0.15
Fe_2O_3	2.9	10.4	0.5 - 3.0	0.10
CaO	64.5	2.1	39.0 - 43.0	0.07
MgO	2.7	1.5	7.0 - 8.5	
S			1.0 - 1.4	
S_2			1.0 - 1.4	
SO_3	2.5	0.7	0 - 0.2	
MnO			0.5 - 0.8	
TiO_2		1.0	0.5 - 0.8	
Na_2O	0.3	1.0	0.2 - 0.4	0.02
K_2O	0.7	3.5	0.5 - 0.7	0.08
C			0.05 - 0.15	
Free Lime	1.5		0.01 - 0.07	

jec/jnw/51
23/07/87

FIGURE 1 COMPARISON OF FLOW TABLE PROCEDURES FOR OPC MORTARS

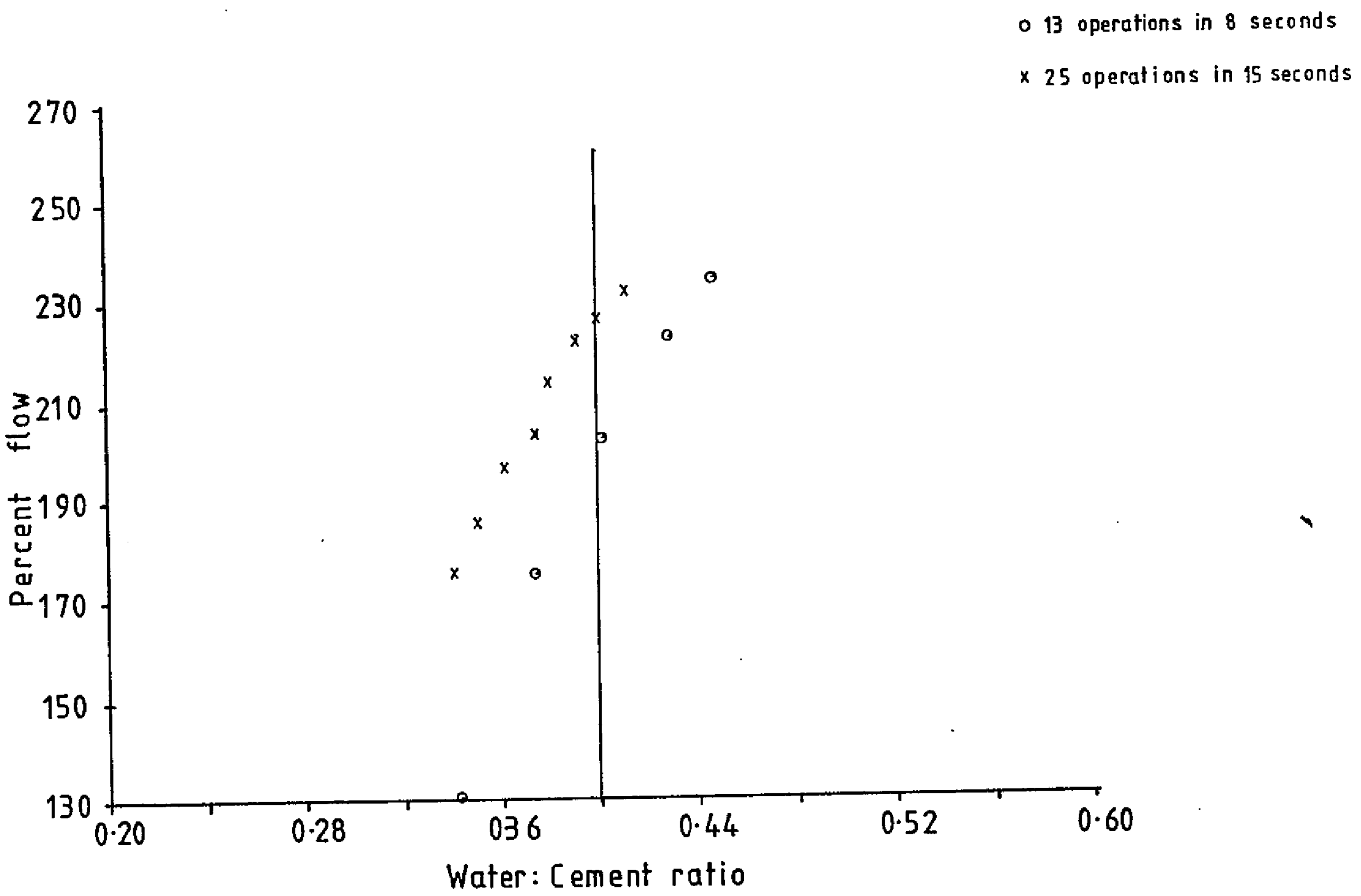


FIGURE 2 FLOW OF MORTAR MIXES AGAINST WATER : CEMENT RATIO

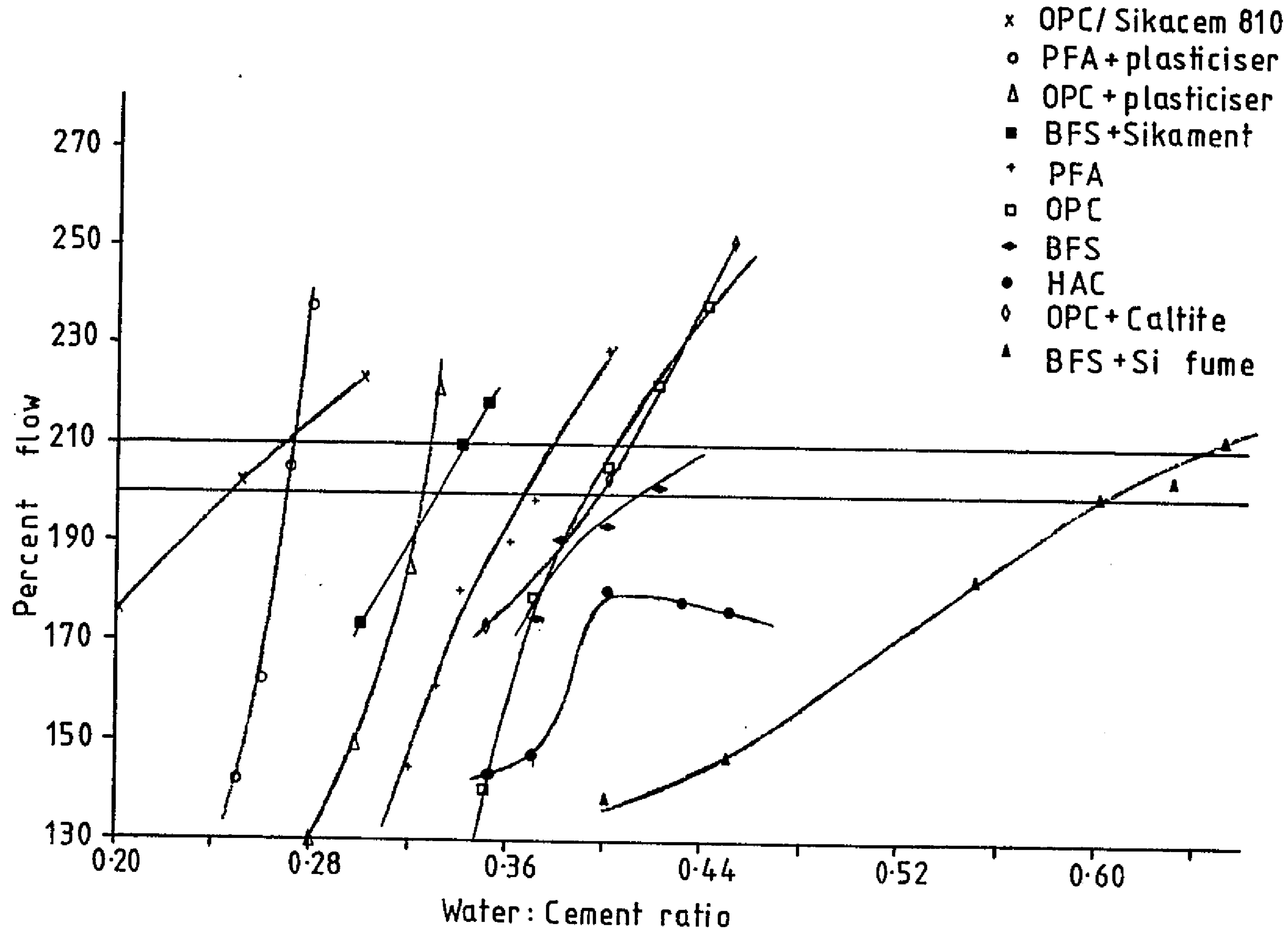


FIGURE 3 EQUIPMENT FOR LEACHING EXPERIMENTS

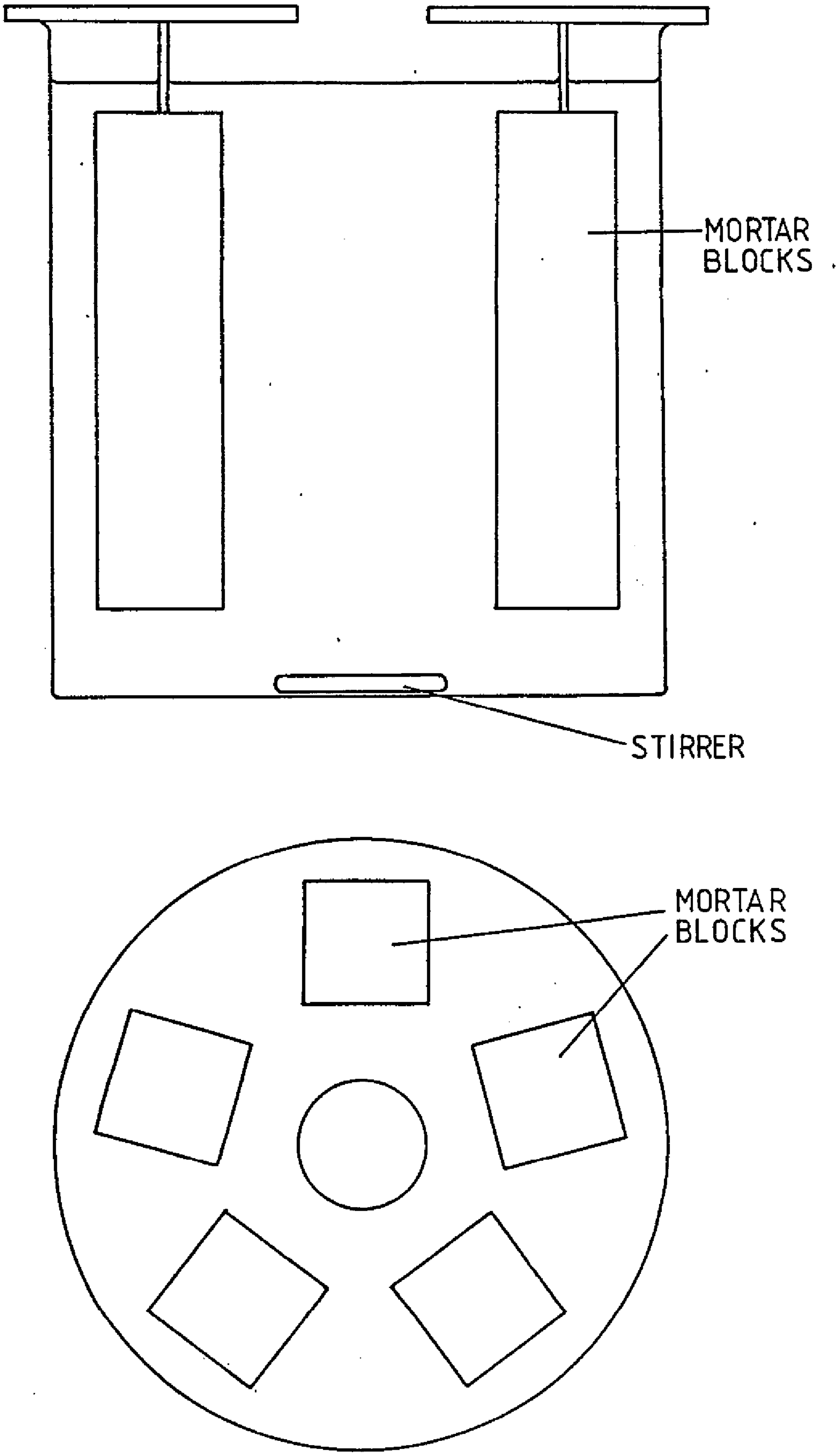


FIGURE 4 —MAXIMUM PH WITHIN EACH RINSE IN DEIONISED WATER

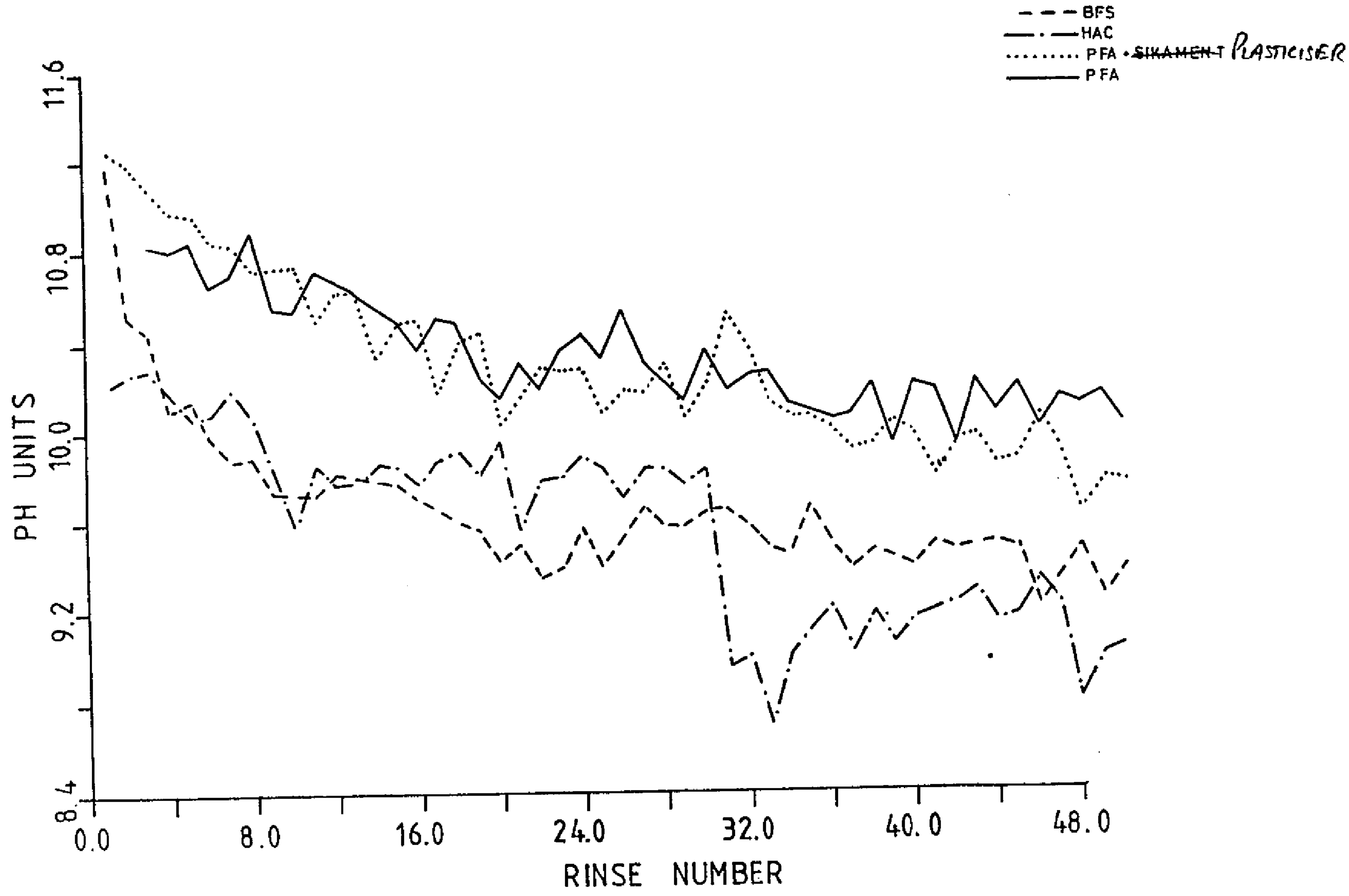


FIGURE 5 – MAXIMUM PH WITHIN EACH RINSE — DISTRIBUTED SOFT WATER

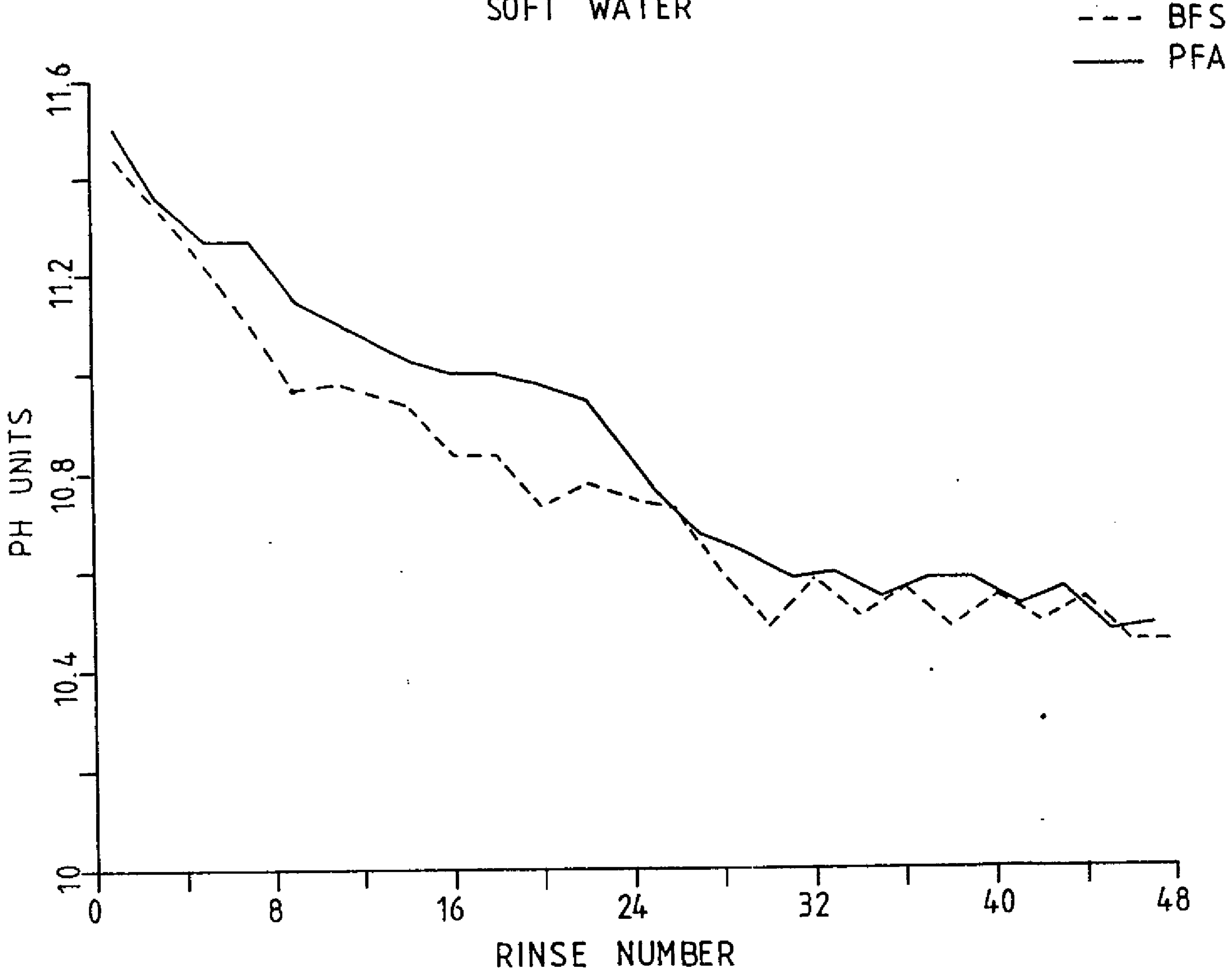


FIGURE 6 — COMPARISON BETWEEN MAXIMUM PH FOR EACH MORTAR AND ITS CONTROL

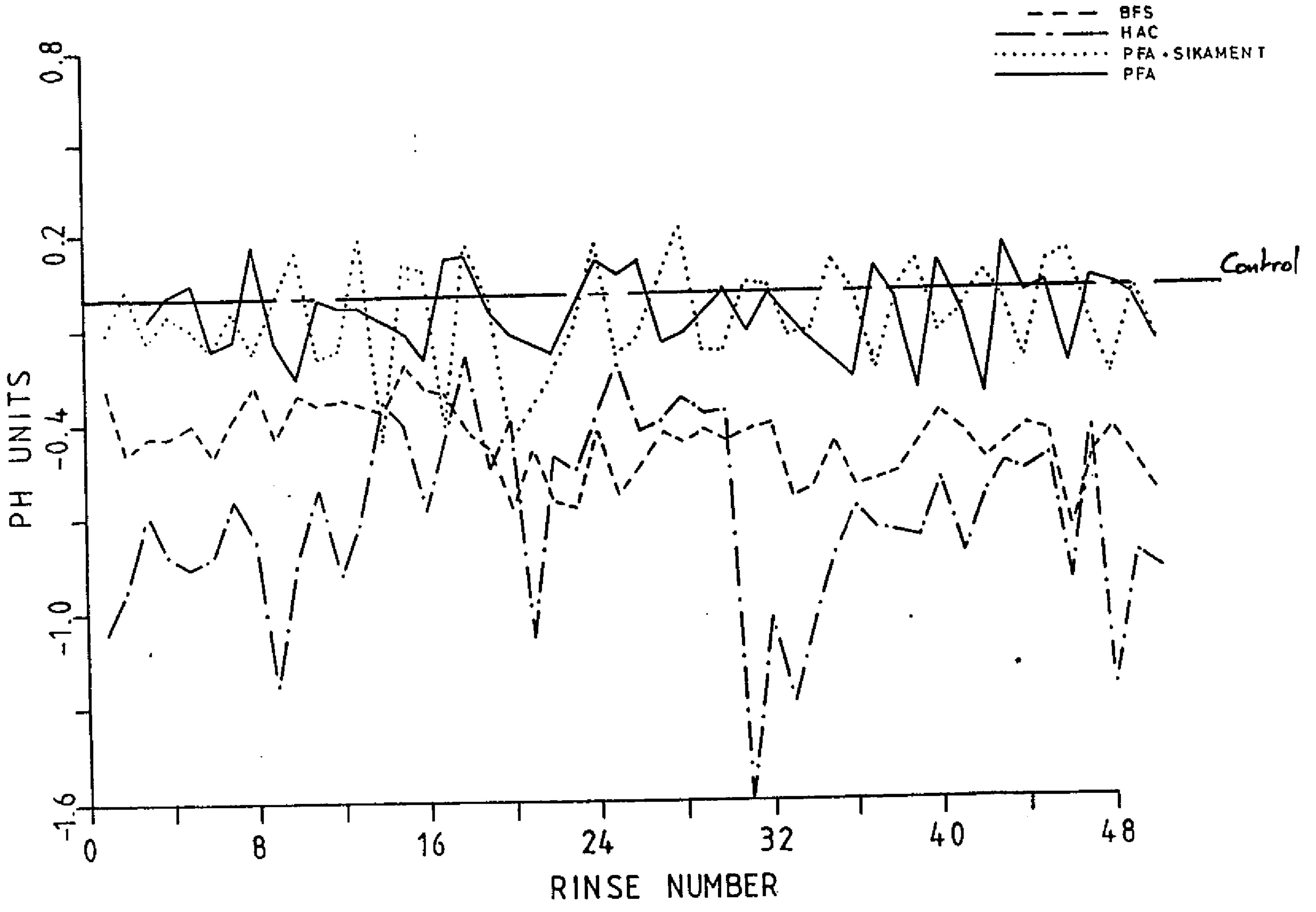


FIGURE 7 COMPARISON BETWEEN MAXIMUM PH OF EACH MORTAR AND ITS CONTROL DISTRIBUTED SOFT WATER

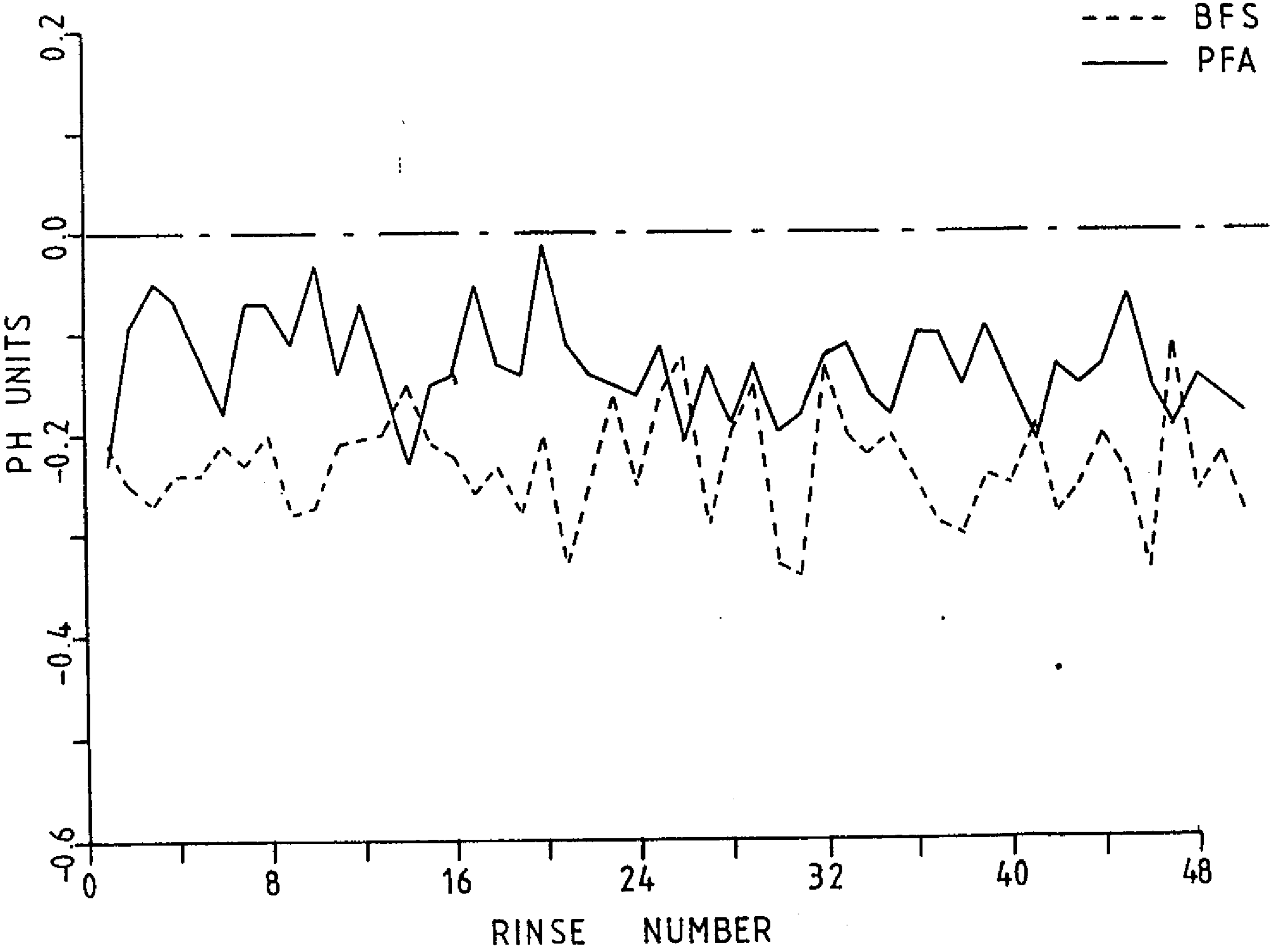


FIGURE 8a DAILY POT TESTS IN DEIONISED WATER

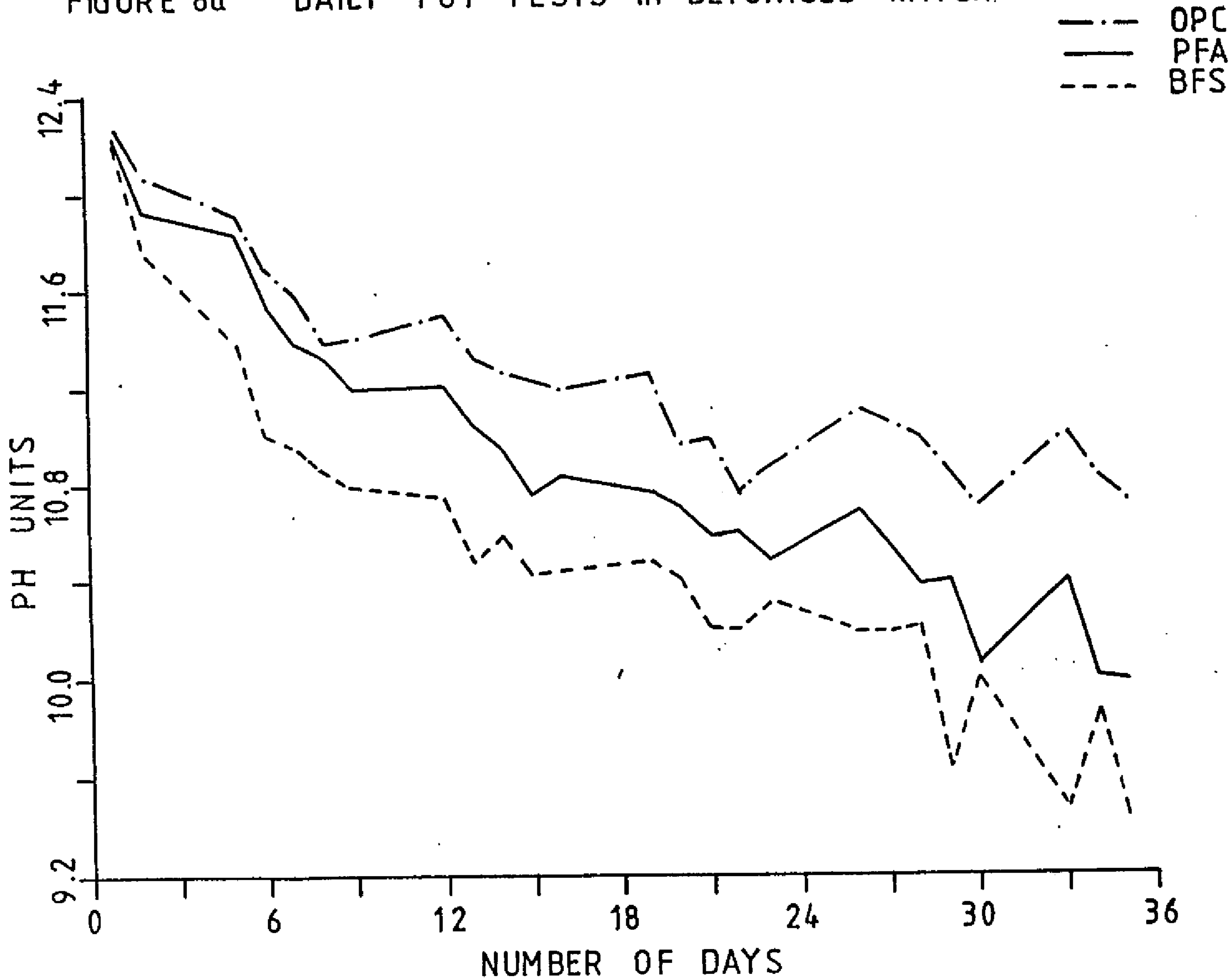


FIGURE 8b DAILY POT TESTS IN DEIONISED WATER

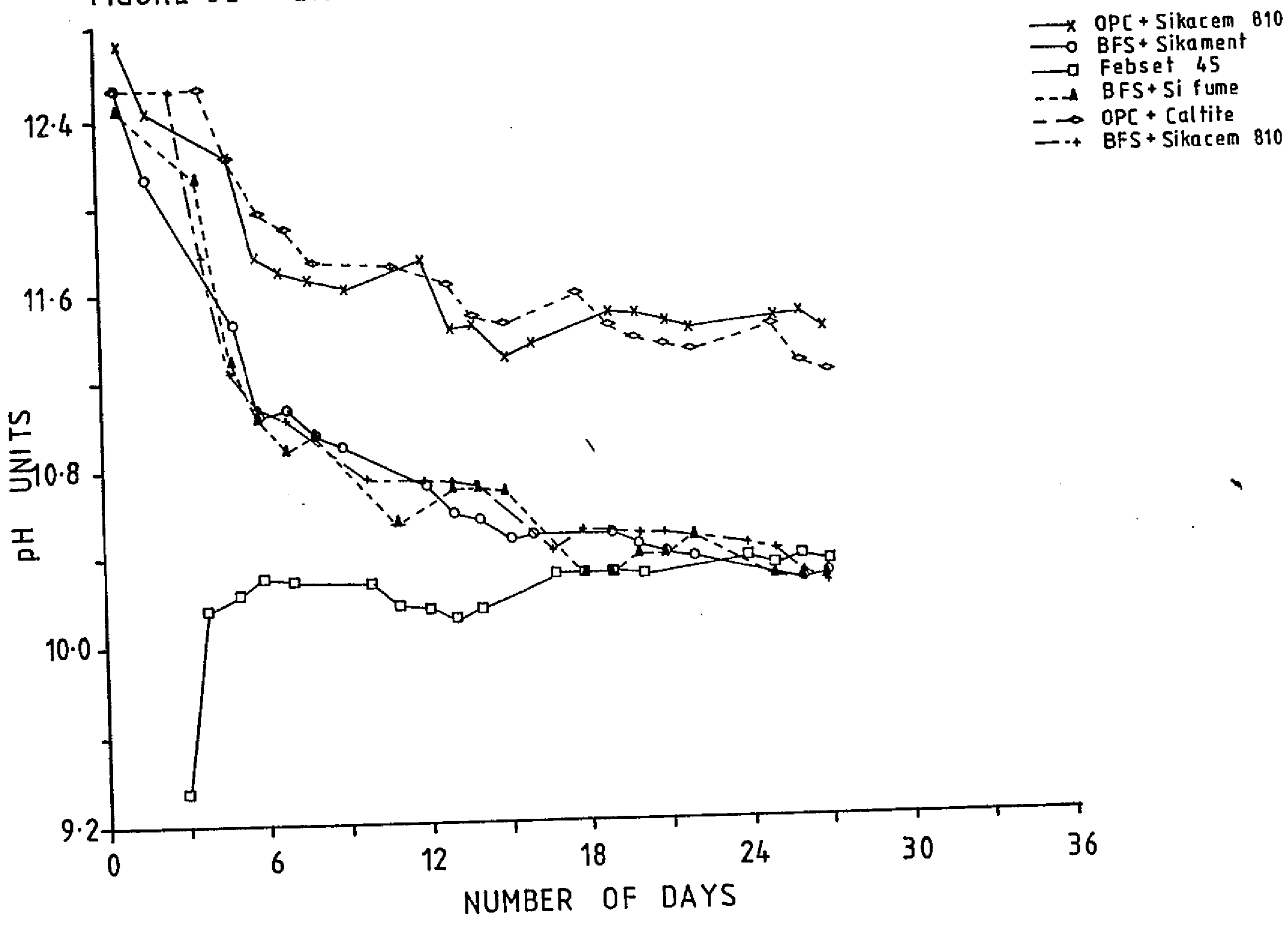


FIGURE 9 DAILY POT TESTS IN NORMALLY DISTRIBUTED SOFT WATER

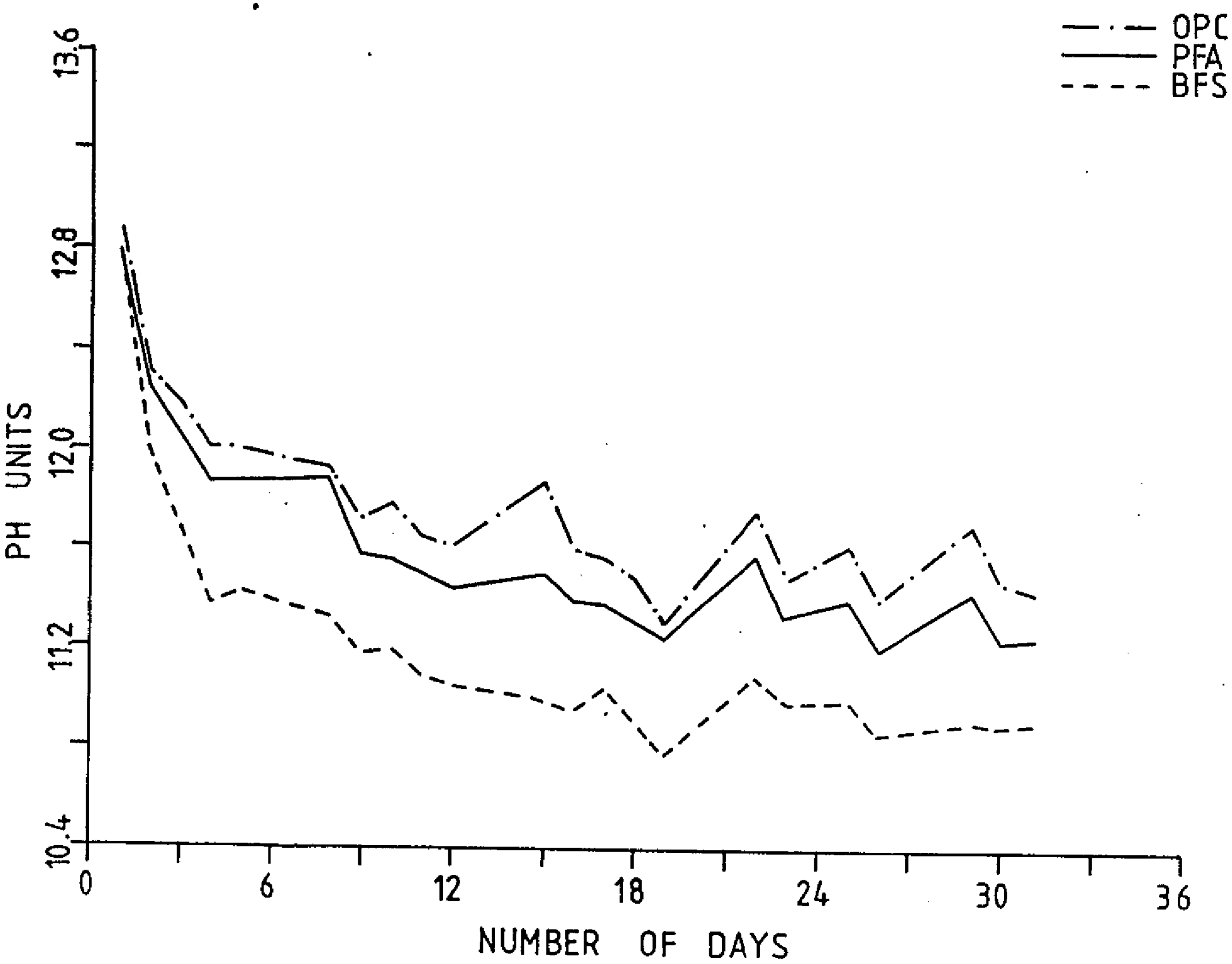


FIGURE 10 SCHEMATIC DIAGRAM OF CONSTANT FLOW LEACHING RIG

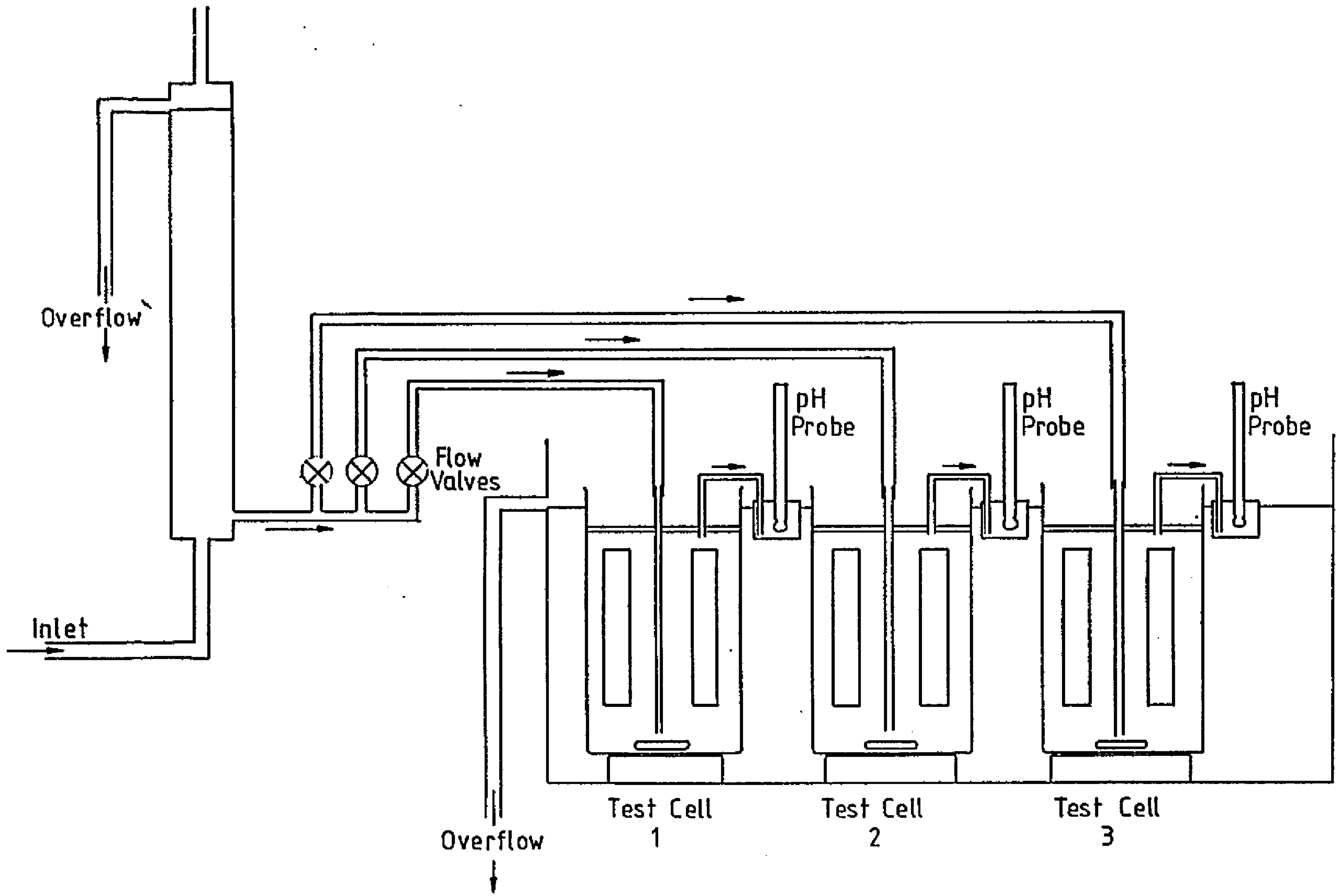


FIGURE 11 CONTACT WATER pH FOR MORTARS IN DEIONISED WATER

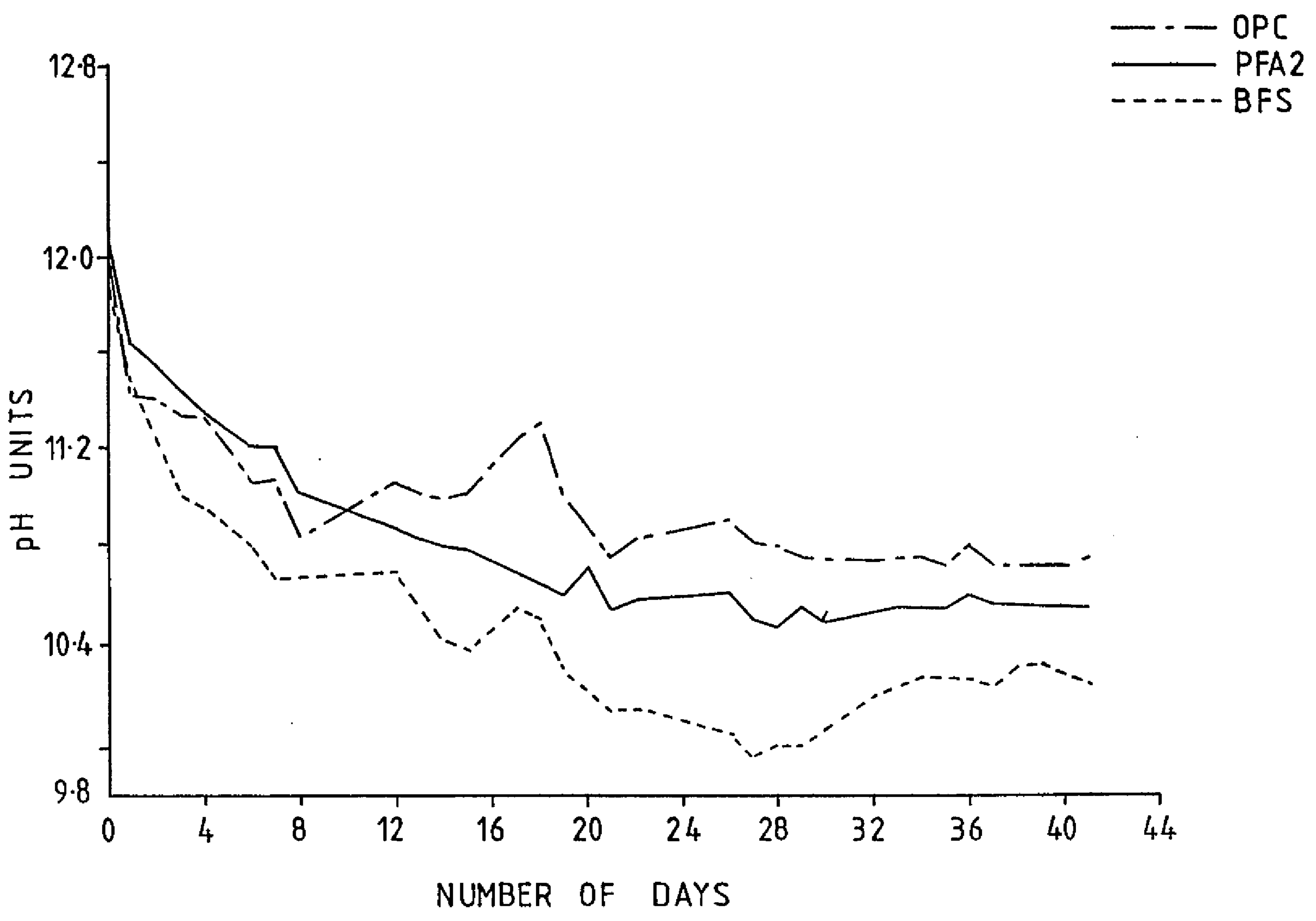


FIGURE 12 pH OF CONTACT WATER MINUS CONTROL pH FOR MORTARS IN DEIONISED WATER

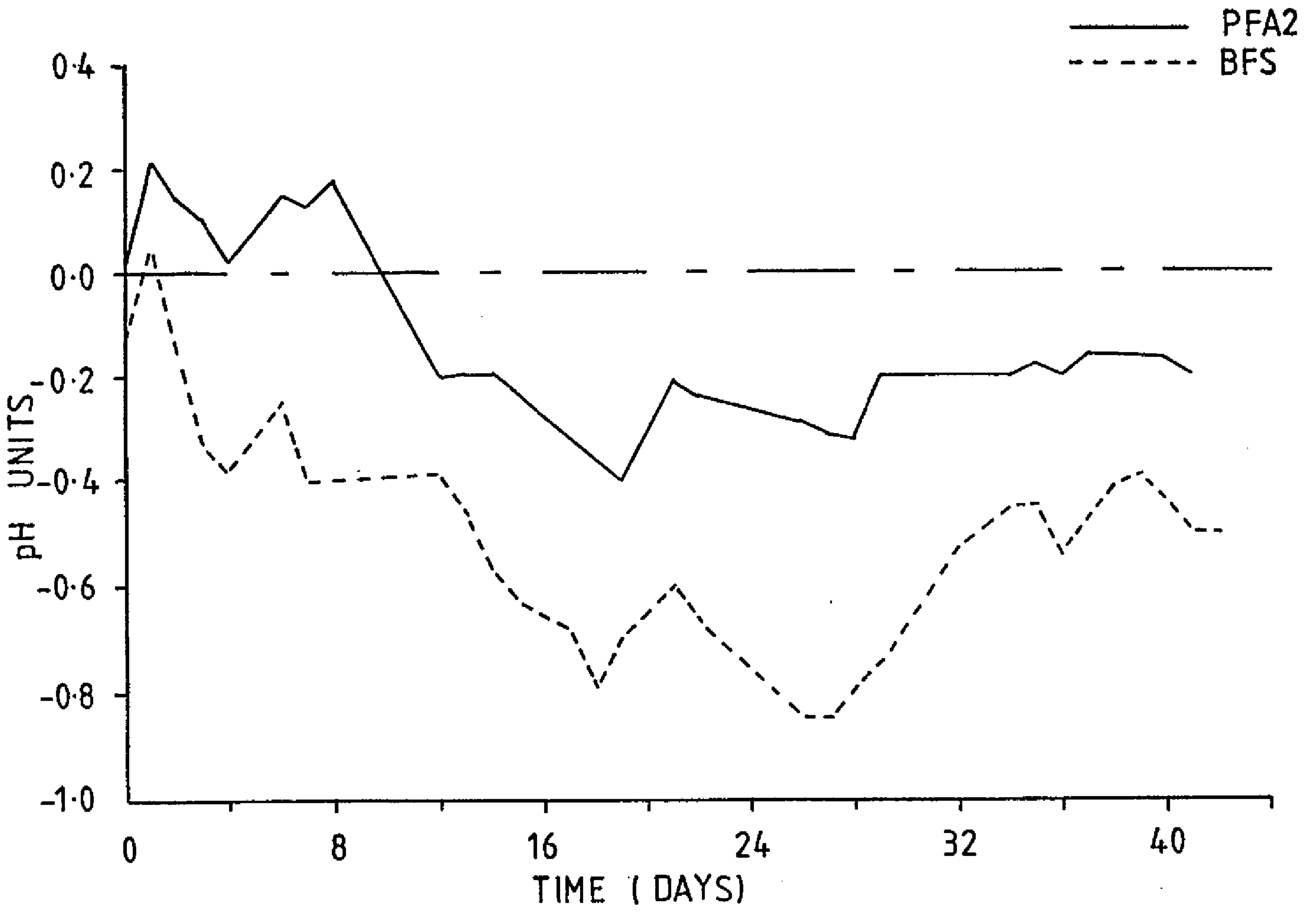
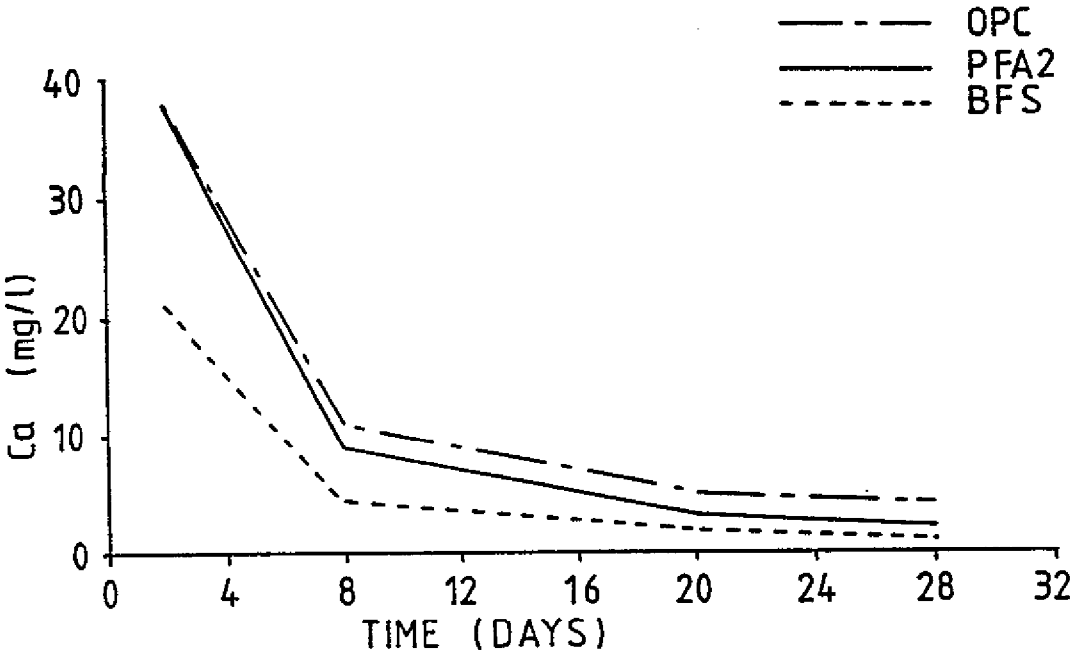


FIGURE 13 CALCIUM CONCENTRATION OF CONTACT WATER AGAINST TIME

a) Deionised water



b) Typical soft water

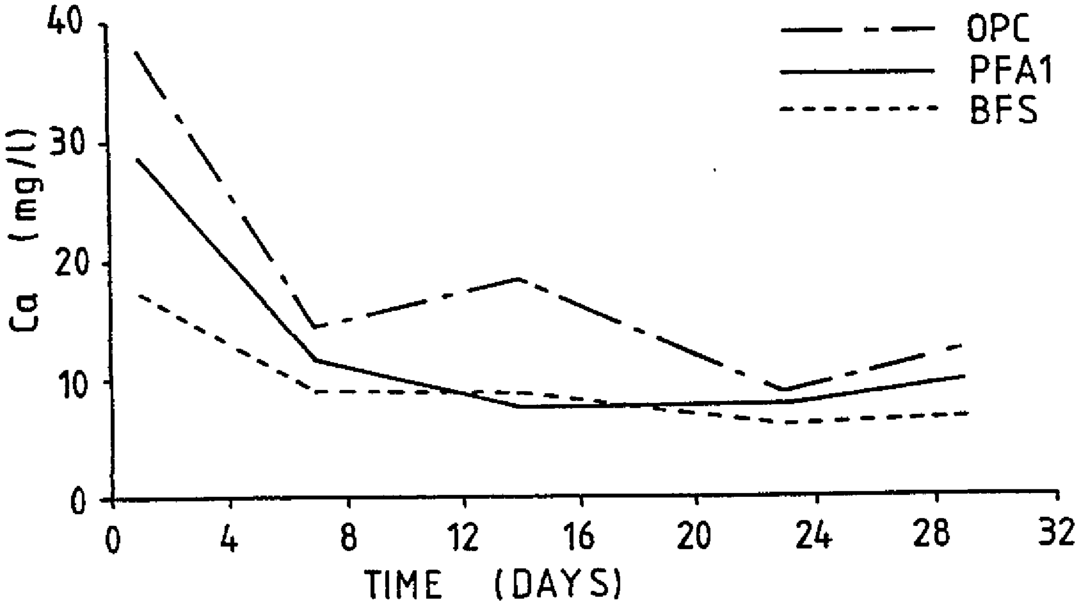


FIGURE 14 CONTACT WATER pH FOR MORTARS IN A TYPICAL SOFT WATER

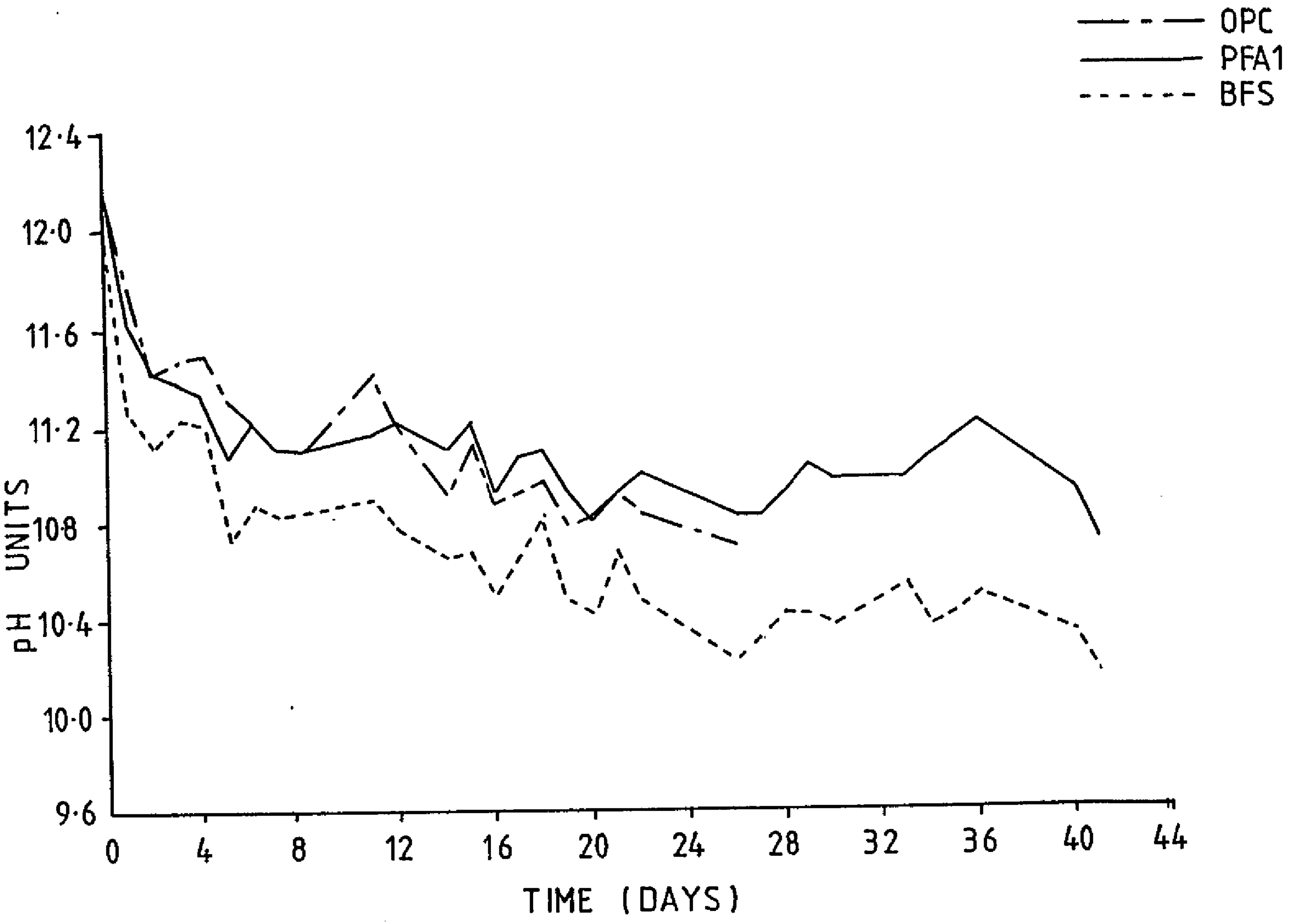


FIGURE 15 pH OF CONTACT MINUS CONTROL pH FOR MORTARS IN A TYPICAL SOFT WATER

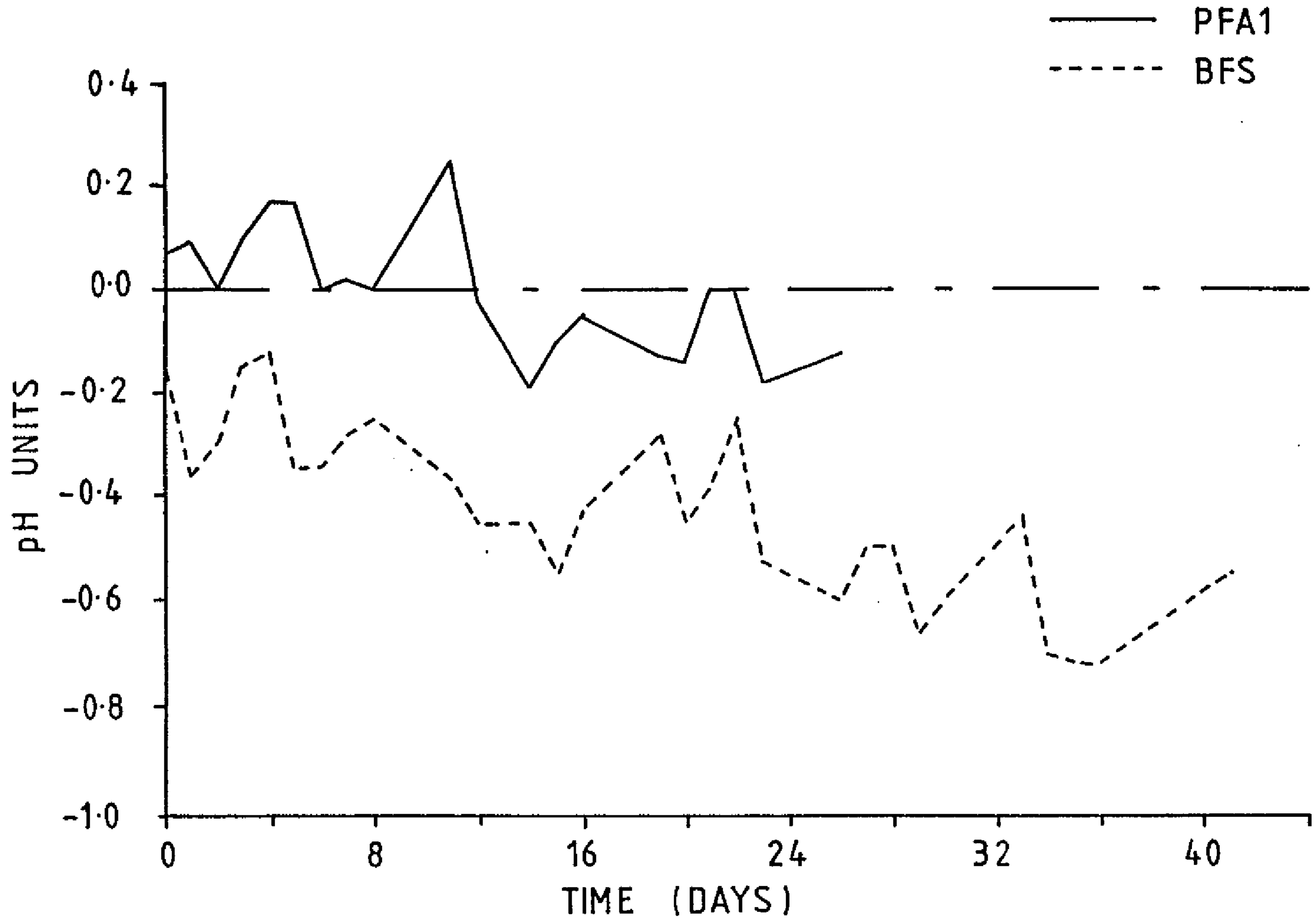


FIGURE 16 pH AGAINST CONTACT TIME FOR MORTARS IN A TYPICAL SOFT WATER AFTER 40 DAYS

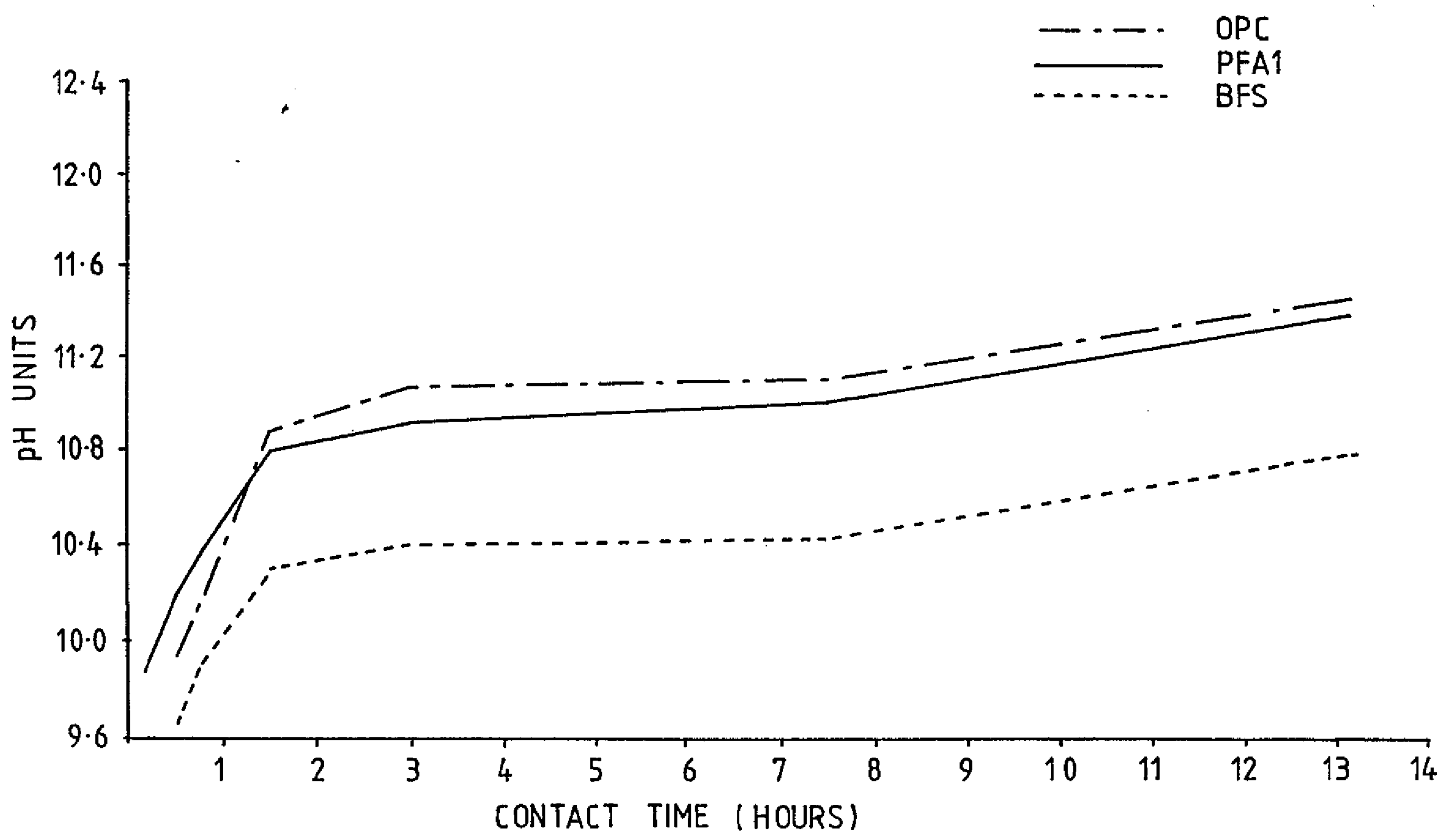


FIGURE 17 CALCIUM CONCENTRATION OF WATER AGAINST CONTACT TIME FOR MORTARS IN A TYPICAL SOFT WATER AFTER 40 DAYS

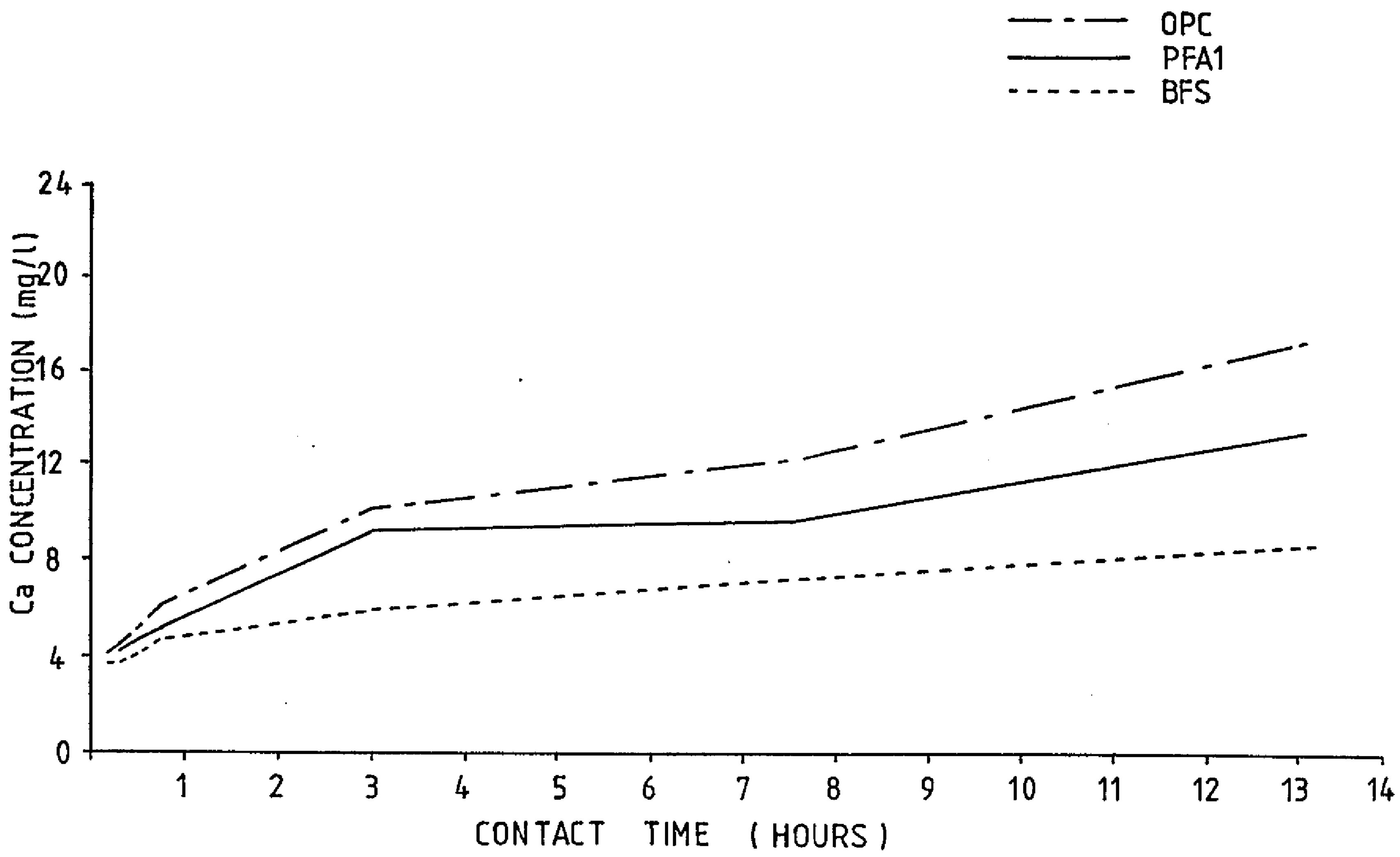


FIGURE 18 CHEMICAL DOSING OF CONTACT WATER FOR OPC MORTAR

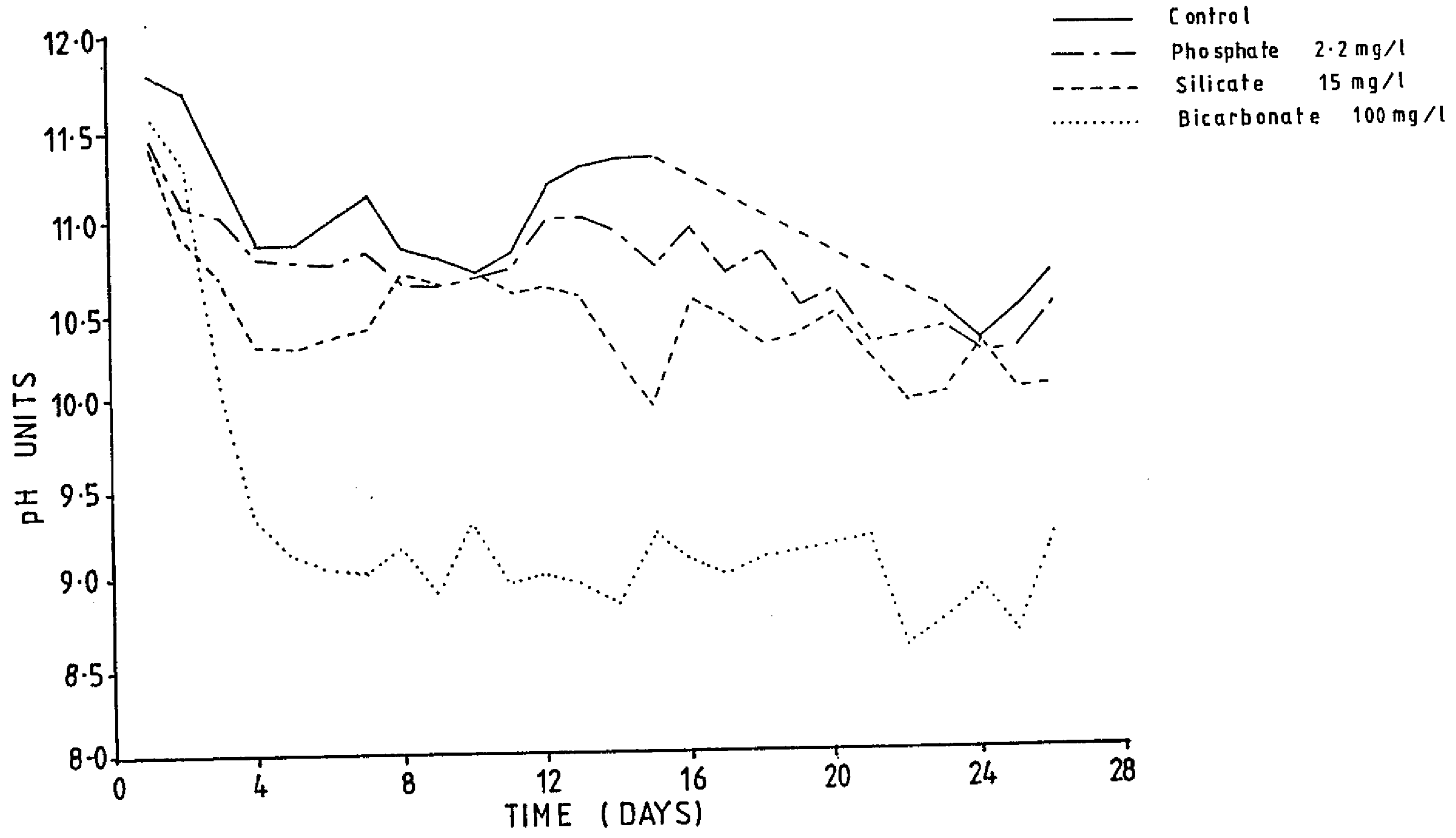


FIGURE 19 BICARBONATE DOSING OF CONTACT WATER FOR OPC MORTARS

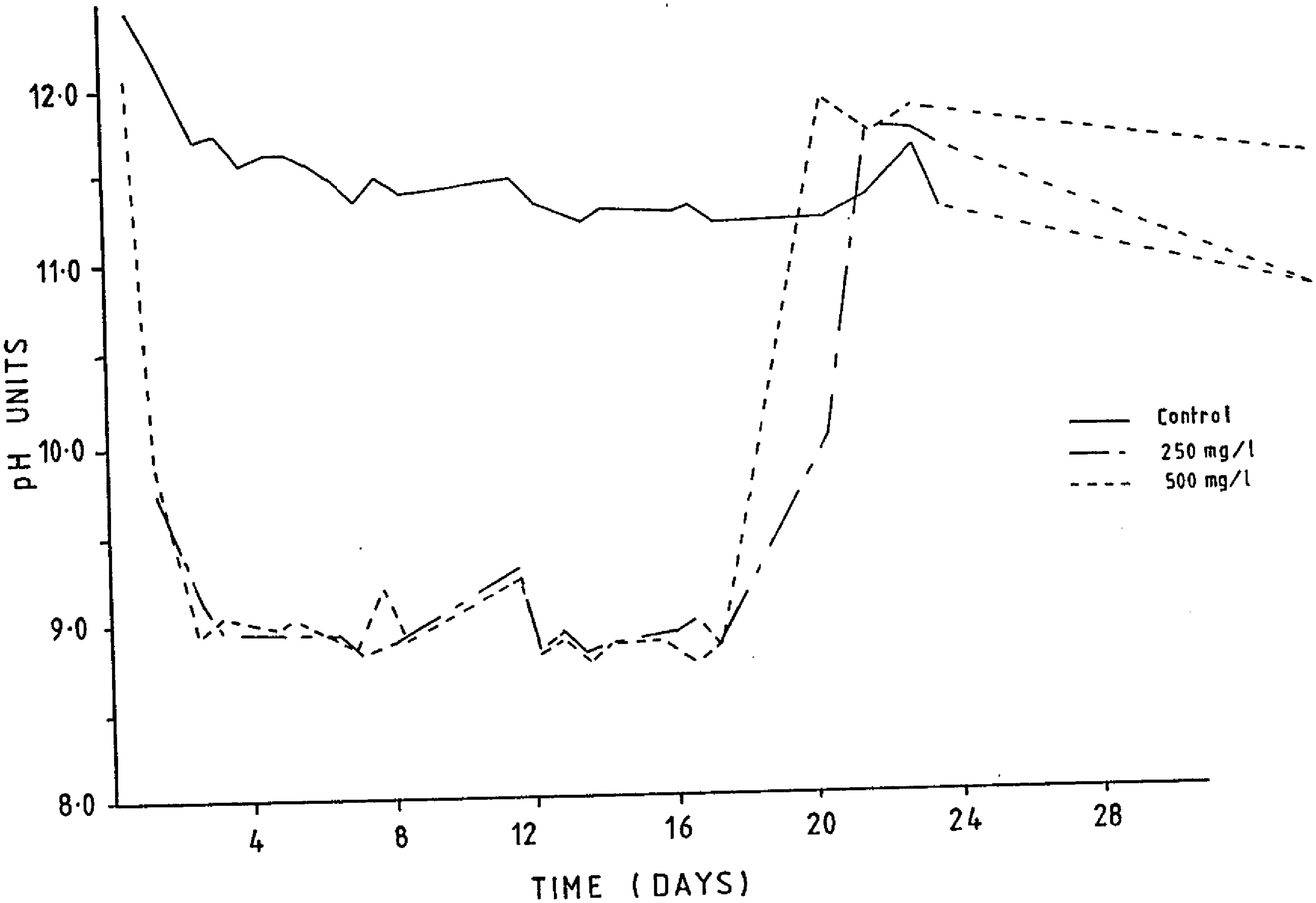


FIGURE 20 BICARBONATE DOSING OF CONTACT WATER FOR BFS MORTARS

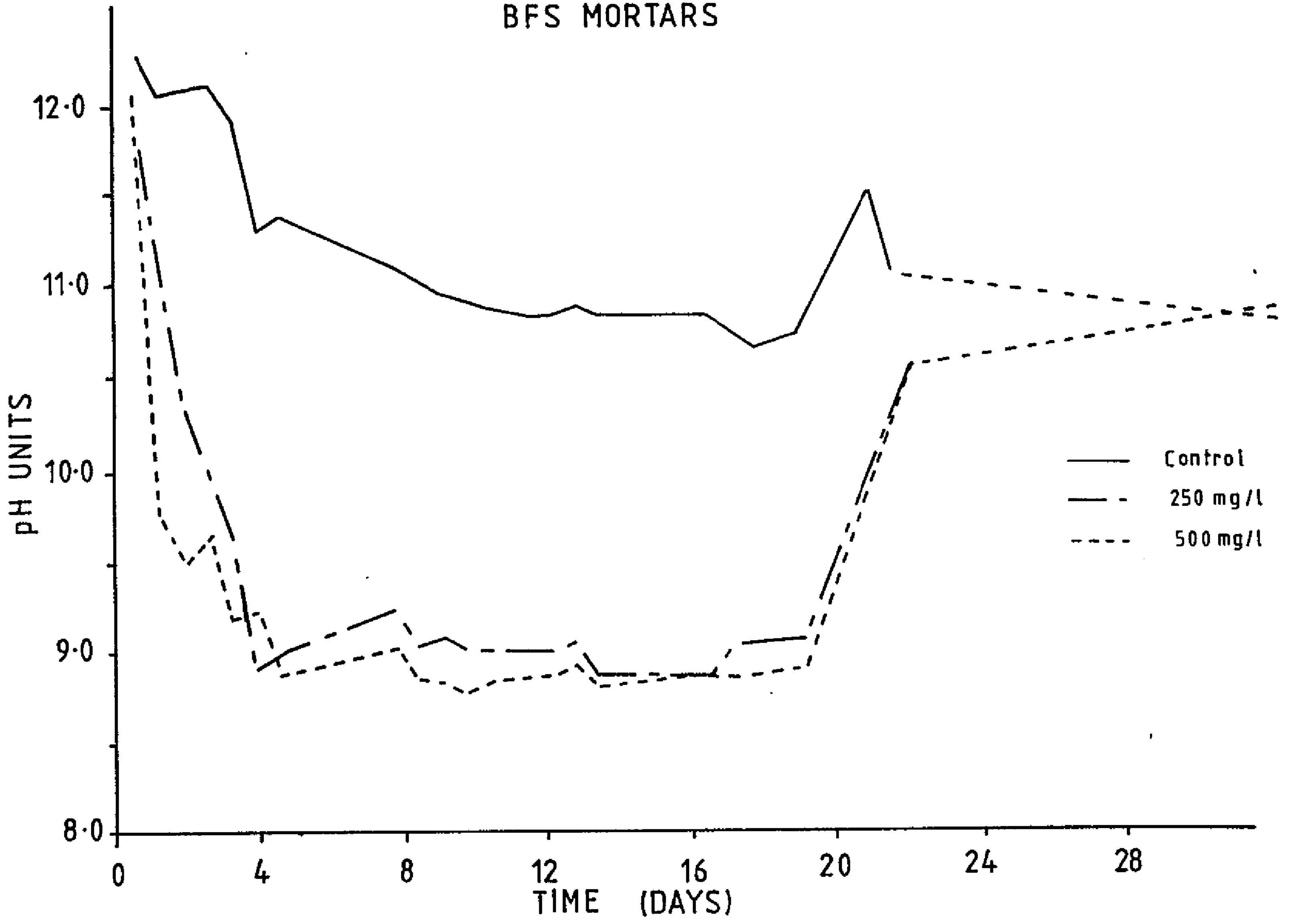
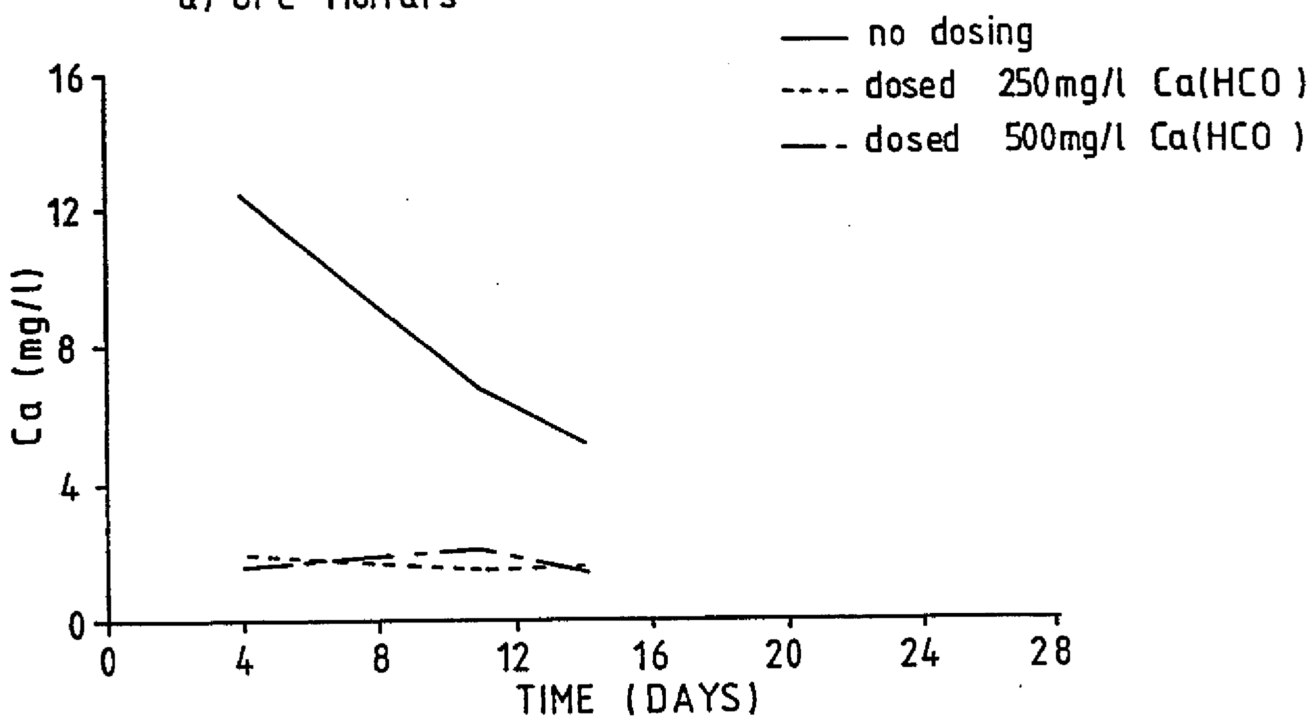


FIGURE 21 CALCIUM CONCENTRATION OF CONTACT WATER AGAINST TIME

a) OPC Mortars



b) BFS Mortars

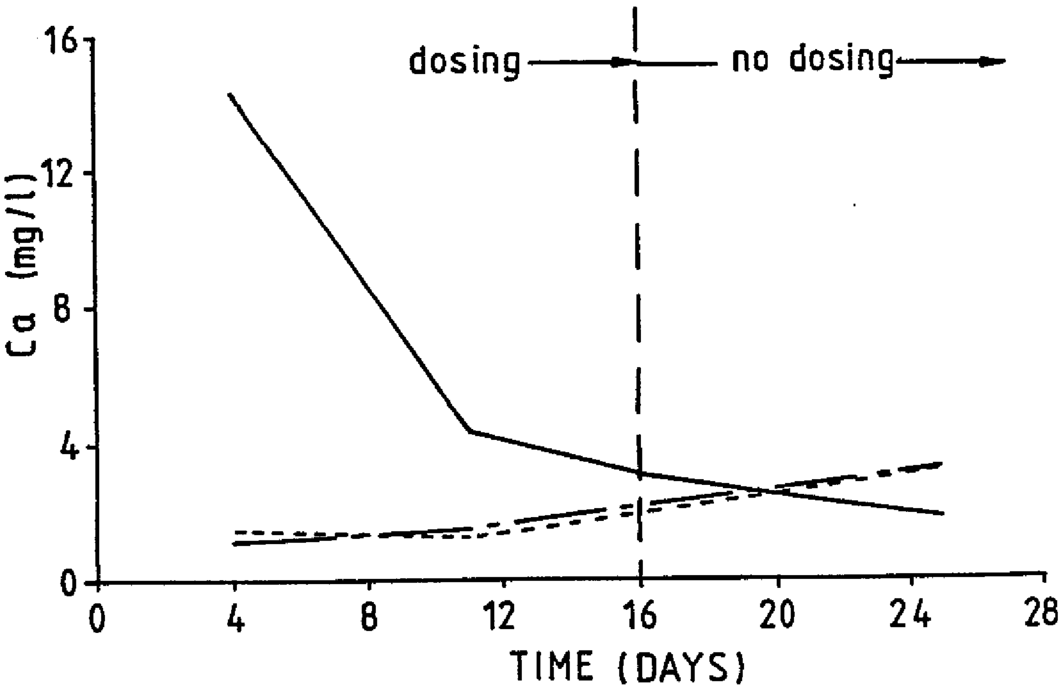
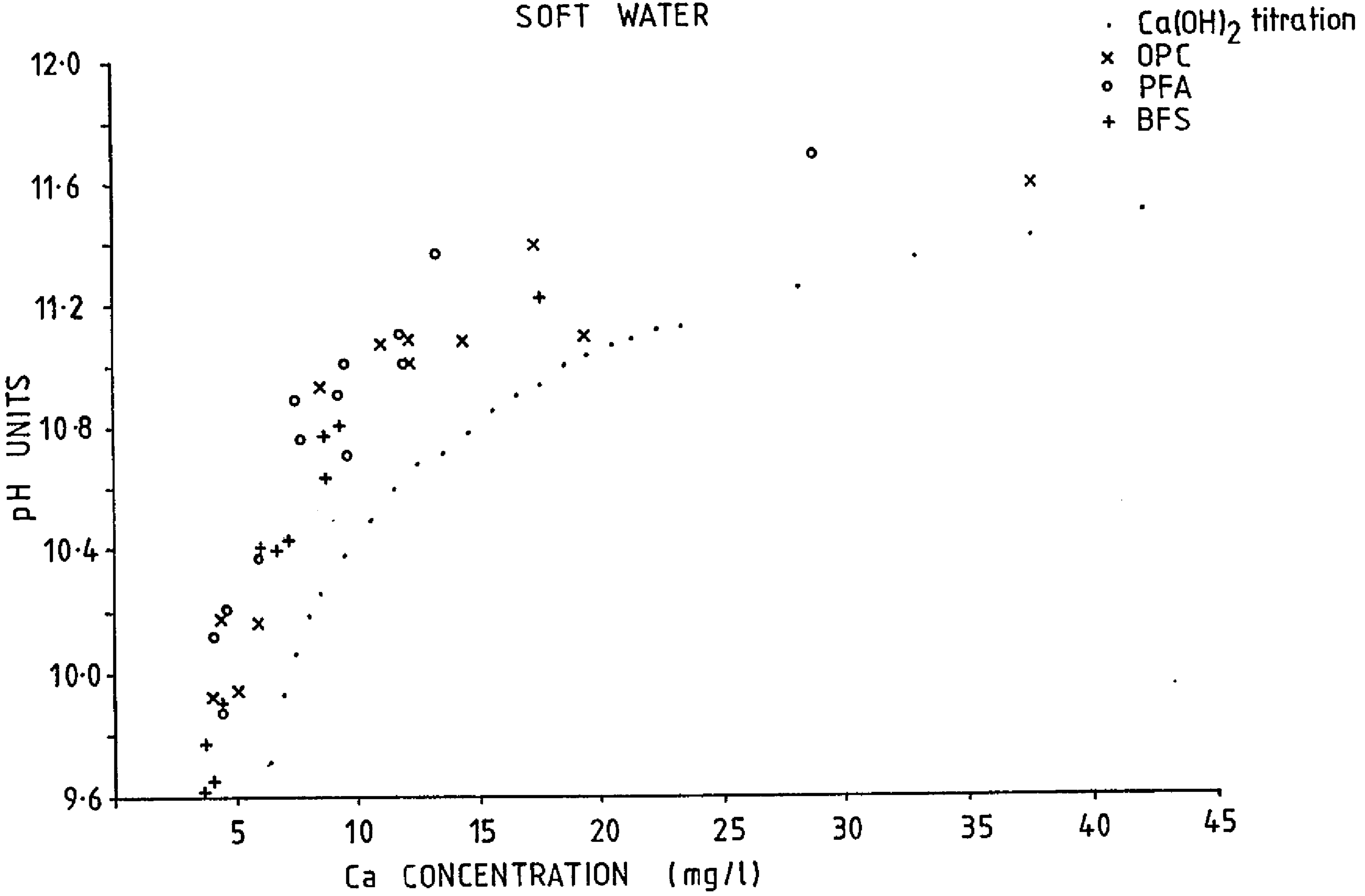


FIGURE 22 pH AGAINST CALCIUM CONCENTRATION IN A TYPICAL SOFT WATER



APPENDIX B

AUTHOR: S Mason

July 1987

INTERNAL REPORT

CONFIDENTIAL

**EVALUATING THE EFFECT OF
DOSING SODIUM BICARBONATE
AFTER CEMENT MORTAR LINING,
BY CONTINUOUS FLOW TESTS**

DRAFT 2

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EVALUATING THE EFFECT OF DOSING SODIUM BICARBONATE AFTER CEMENT MORTAR LINING, BY CONTINUOUS FLOW TESTS

SUMMARY

i) OBJECT

To evaluate the effect of dosing various concentrations of sodium bicarbonate ($NaHCO_3$) into the conveyed water after cement mortar lining with a combination of Ordinary Portland Cement and Blast Furnace Slag.

ii) REASON

Work previously carried out by WRc has shown that the use of Blast Furnace Slag as an admixture to Ordinary Portland Cement reduces the pH in soft waters following relining. To examine the possible further reduction of pH by chemically dosing the conveyed water, a continuous flow test was run for twenty two days at various concentrations of dosing.

iii) CONCLUSIONS

i) The addition of $NaHCO_3$ to the conveyed water does reduce the measured pH in the that water.

ii) For the dosed water, the reduction in pH over the initial days is rapid, with the moderately high concentration of dosing lowering the pH by 2 units within 4 days.

iii) Higher concentrations of dosing reduced the pH more rapidly and kept the pH significantly lower in comparison to weaker solutions.

iv) After 20 days, the pH value of the 50 mg/l dosed cell had reduced to 8, 2 pH units lower than the deionised water cell.

v) When the chemical dosing was stopped the pH value returned to a level similar to that recorded by the permanently undosed samples.

iv) RECOMMENDATIONS

Prior to the use of chemical dosing using $NaHCO_3$ on mains that have been relined with Blast Furnace Slag the following areas should be examined:

a) The effect of dosing on representative soft waters.

b) Chemical analysis of waters effected by leaching and dosing.

c) Information on the long term levels of pH, especially after dosing is stopped.

v) RESUME

By use of flow tests on cement mortar blocks, the effect of sodium bicarbonate ($NaHCO_3$) dosed into the conveyed water was examined. This was carried out in a continuous flow rig which models a 50m length of 100mm diameter water main flowing at 4 l/min. The equipment is capable of running three parallel cells at various dosing levels, with the contact water passing the immersed cement blocks being continually monitored for pH.

EVALUATING THE EFFECT OF DOSING SODIUM BICARBONATE AFTER CEMENT MORTAR LINING, BY CONTINUOUS FLOW TESTS

1. INTRODUCTION

After renovating water mains in predominantly soft water areas using cement mortar lining, high values of pH were evident in the potable water. This was mainly due to the leaching of alkalis from the cement by the soft water. To overcome this problem, a series of cement alternatives and additives were examined by WRc (Ref 1). These tests resulted in the recommendation of the use of a combination of Ordinary Portland Cement (OPC) with Blast Furnace Slag (BFS) as the cementitious ingredient of the mortar. Evaluation of this new cement indicated a pH reduction in both deionised and soft waters of some 0.5 to 0.6 pH units.

This report details the use of both Blast Furnace Slag and chemical dosing when relining, and their combined effect on the pH of the potable water.

The evaluation of the chemical dosing was carried out using a continuous flow rig designed for testing mortars in an environment which models a typical 100mm distribution main.

Similar mortars were tested using deionised water dosed with varying amounts of sodium bicarbonate or with no chemicals added.

2. CONTINUOUS FLOW RIG

The continuous flow rig shown in Figure 1 was designed to model conditions existing in a 100mm diameter distribution main. Separate mortars can be evaluated simultaneously in three parallel cells, which hold mortar blocks suspended in the test water. The ratio of surface area of the mortar to the volume of water in the cell is designed to be the same as the surface area to volume ratio in a 100mm pipe. Temperature of the test cells was maintained at 10^{o}C which represents an average temperature of underground mains.

Water from three separate head tanks, two of which are dosed, is fed via needle valve flow meters to the bottom of each test cell which contain the mortar blocks. This displaces water from the top of the sealed cell into a small measuring container where the pH is continuously monitored. Each of the cells is stirred to prevent the formation of high concentration gradients around the mortar blocks.

Air interfaces with test water in the system are minimised to prevent absorption of atmospheric carbon dioxide.

3. MATERIALS

3.1 Cement Mortar

A series of 15 similar cement mortar blocks were cast, five for each cell. The design mix is shown in Table 1.

3.2 Dosing Chemicals

Dosing of cells 2 and 3 involved the addition of known amounts of chemicals into the respective head tanks. The dosing agent used was Sodium Hydrogen Carbonate $NaHCO_3$ (sodium bicarbonate).

Quantities of $NaHCO_3$ powder were added to the deionised water within the head tanks in amounts of 50 mg/l and 30 mg/l respectively for cells 2 and 3.

No dosing was added to the deionised water feeding cell 1.

4. EXPERIMENTS

The design mix blocks were air cured for 18 hours at 20°C. These cement mortar blocks were then installed into the test cells (five per cell) and the flow set to 14 ml/minute to each cell. This gives a residence time in the cell of approximately 1.5 hours, which is comparable to a flow of 4 l/minute through 50m of 100mm diameter pipe. The pH of the effluent water from each cell was continuously measured and recorded.

The rig was run for twenty two days with the dosed water flowing through the two cells. At the end of this period the dosing was stopped and the rig left running with similar deionised water from a common tank feeding all three cells.

5. RESULTS

5.1 Dosing

Continuous flow leaching trials were performed in deionised water and deionised water dosed with $NaHCO_3$ at 50 mg/l and 30 mg/l. The pH of the contact water against time is presented in Figure 2 for the first twenty two days of operation.

5.2 After Dosing

After twenty two days of continuous flow, the dosing feeds to cells 2 and 3 were removed and replaced with deionised only inputs. All three cells now had a common water supply. This effect upon the pH of the contact water is presented in Figure 3.

6. DISCUSSION

6.1 The Effect of $NaHCO_3$ Dosing

For all three cells the initial pH value of the contact water was about 12.0 (Figure 2) before the $NaHCO_3$ dosing had little chance to effect the values. As results were plotted for the first few days it is evident that the dosing has some effect and the pH of the treated water reduced more rapidly than the deionised only water.

For a nominal pH value of 10.5 units the contact water in cell 2 (50 mg/l) had reduced beyond this figure within 3 days. The 30 mg/l dosed cell took 5 days to reduce to 10.5 but the untreated deionised water of cell 1 took some 14 days. This number of days compares exactly to the pH reduction periods described by a previous WRc report (ref 1).

Steady reductions were recorded in the contact water pH for all cells for the first three weeks. The pH values after 22 days being 10.0, 8.0 and 9.2 for cells 1 to 3 respectively.

6.2 After Dosing

The effect of the removal of chemicals from the contact water is presented in Figure 3. The pH in the two dosed cells rose over a period of 10 days up to a level slightly higher than that of the unchanged cell 1. This rise levelled off leaving cell 2 now recording the highest pH at 10.6, some 2.6 units above its minimum level when dosed.

The abrupt rise in the unchanged deionised only contact water is probably due to the plumbing of cells 2 and 3 into the same supply and causing aeration of the water. It is difficult to explain why the pH remains at this higher level after the flow had settled. Though comparison with the results obtained in the previous WRc report (Ref 1, Figure 2) indicates that a similar 0.4 units rise in the pH of deionised water also occurred after 27 days. This may possibly be due to the deterioration of the pH probes accuracy caused by their immersion in a low conductivity water over an extended period.

REFERENCES

1. WHITE E P, WHEELER J (1986). Evaluating the lime leached from potential cement mortar linings for water mains by continuous flow tests. Draft 2, WRc report.

Figure 1 Schematic Diagram of Constant Flow Leaching Rig

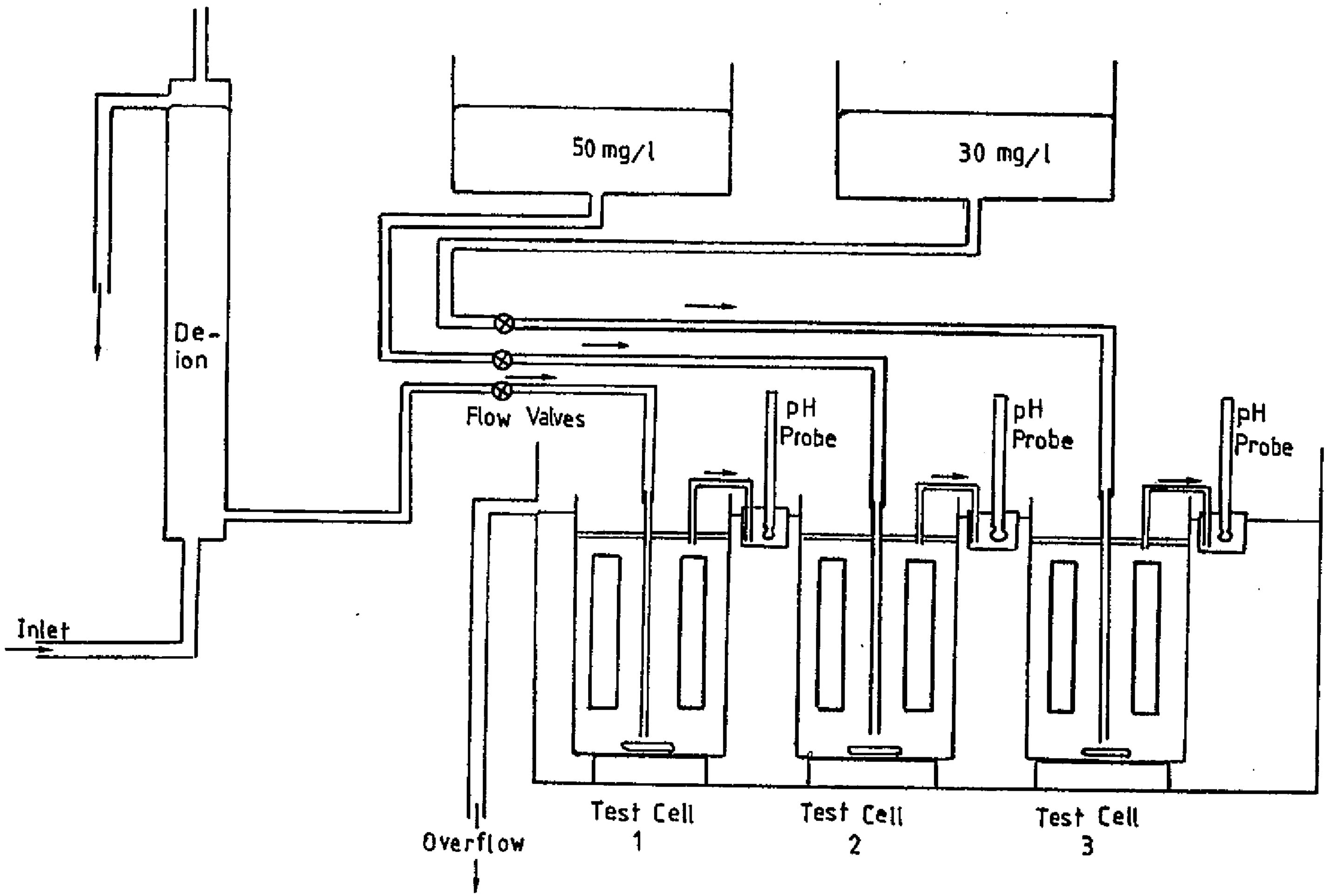


FIGURE 2 CONTACT WATER pH, WHILST NaHCO3 DOSING

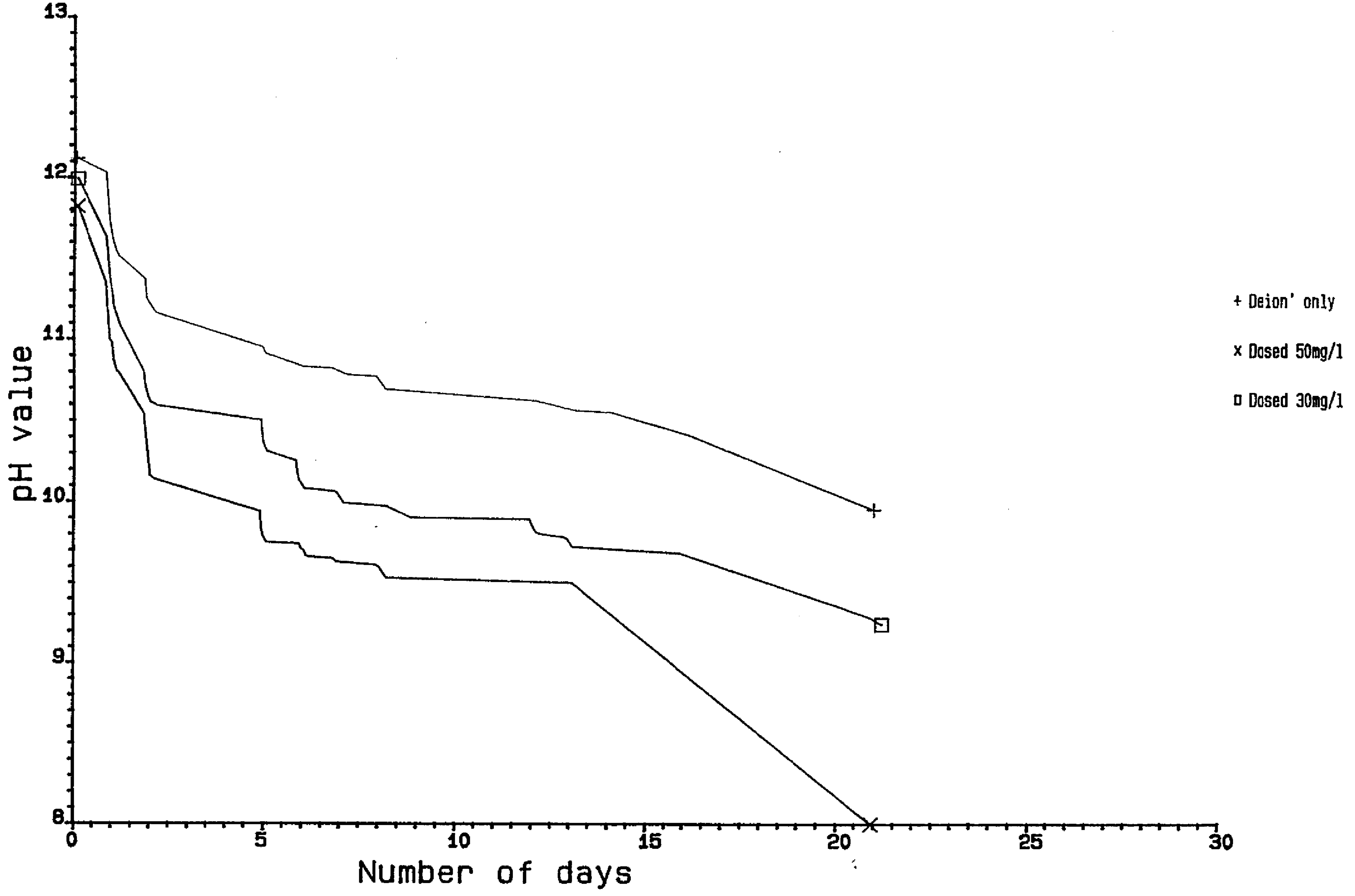
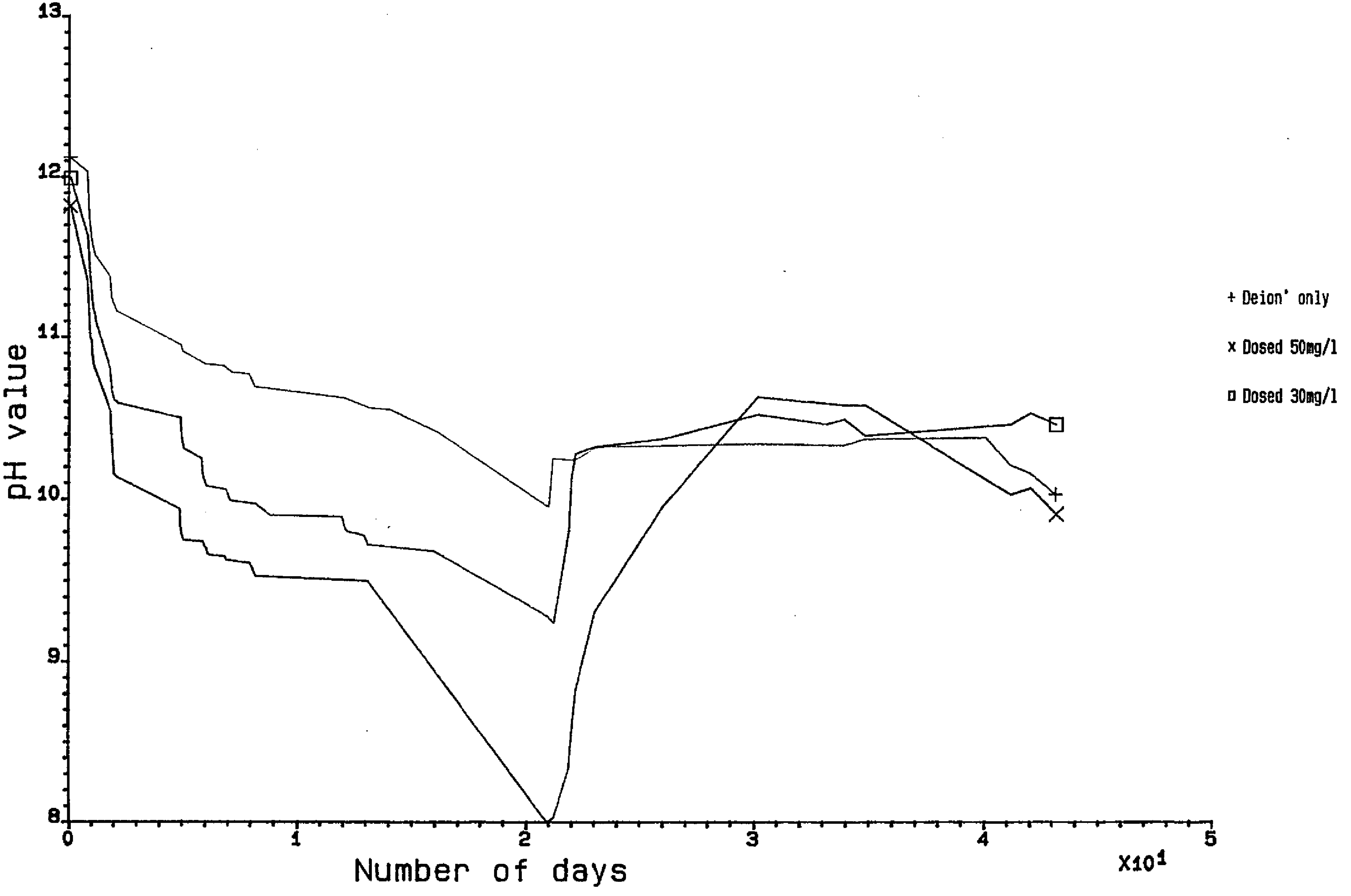


FIGURE 3 CONTACT WATER pH BEFORE & AFTER DOSING



APPENDIX C

ESTIMATING CONTACT TIMES INSIMPLE DISTRIBUTION SYSTEMS

The increase in pH after cement mortar lining small diameter mains is related to the contact time between the conveyed water and cement mortar. Therefore it is necessary to be able to estimate the contact times in urban networks so that mains which may potentially give rise to water quality problems can be identified.

CONTACT TIMES

For a main of length L and diameter D with a flow of Q induced at the dead end the contact time along the main is given by:-

$$T_c = \frac{\pi D^2 L}{4Q} = K \frac{KD^2 L}{Q} \quad \text{where } K = \frac{\Pi}{4}$$

For most mains the flow is not induced at the dead end but at numerous services along its length. If we simplify this slightly so that N services are spaced at equal distances l along the main AB and an average flow q is flowing through each service; the contact time along length AB is given by:-

$$T_c = KD^2 L \sum_{n=1}^{N} \frac{1}{qn}$$

If a flow Q is induced at the dead end then the contact time is given by:-

$$T_c = KD^2 L \sum_{n=1}^{N} \frac{1}{(qn)+Q}$$

This equation can be incorporated into a computer program which can then be used to estimate contact times in a network.

EXAMPLE

To illustrate the use of the program a simple network has been drawn in Figure A. The inlet to the system in at node P_1, and each of the other nodes is given an identifying number. The number of properties along each main are also shown on the diagram.

The object is to estimate the contact time from node P_1 to each of the other nodes so that mains with long contact times can be identified.

Assume:- average consumption per person = 130 l/h/day
- average of 3 person/property
@ average flow per property = 390 l/day = 0.27 l/min
- internal diameter of main after relining = 90mm.

Using the program the following table can be drawn up.

MAIN	LENGTH (m)	NO. OF PROPERTIES	FLOW ALONG THE LENGTH (l/min)	FLOW AT END OF LENGTH (l/min)	CONTACT ALONG LENGTH (hours)
P11 - P12	100	20	5.4	0	7.06
P8 - P11	100	20	5.4	5.4	1.34
P9 - P10	100	25	6.75	0	5.99
P8 - P9	100	10	2.7	6.75	1.30
P4 - P8	100	15	4.05	20.25	0.43
P5 - P7	100	20	5.4	0	7.06
P5 - P6	100	20	5.4	0	7.06
P4 - P5	200	50	13.5	10.8	1.26
P2 - P4	100	15	4.05	48.6	0.19
P2 - P3	100	25	0.75	0	5.99
P1 - P2	100	20	5.4	59.4	0.17

Using the table the contact times from the inlet P_1 to the other nodes can be calculated by summation:-

Contact time in hours from P_1 to P_2 = 0.17

P_3 = 6.16

P_4 = 0.36

P_5 = 1.62

P_6 = 8.68

P_7 = 8.68

P_8 = 0.79

P_9 = 2.09

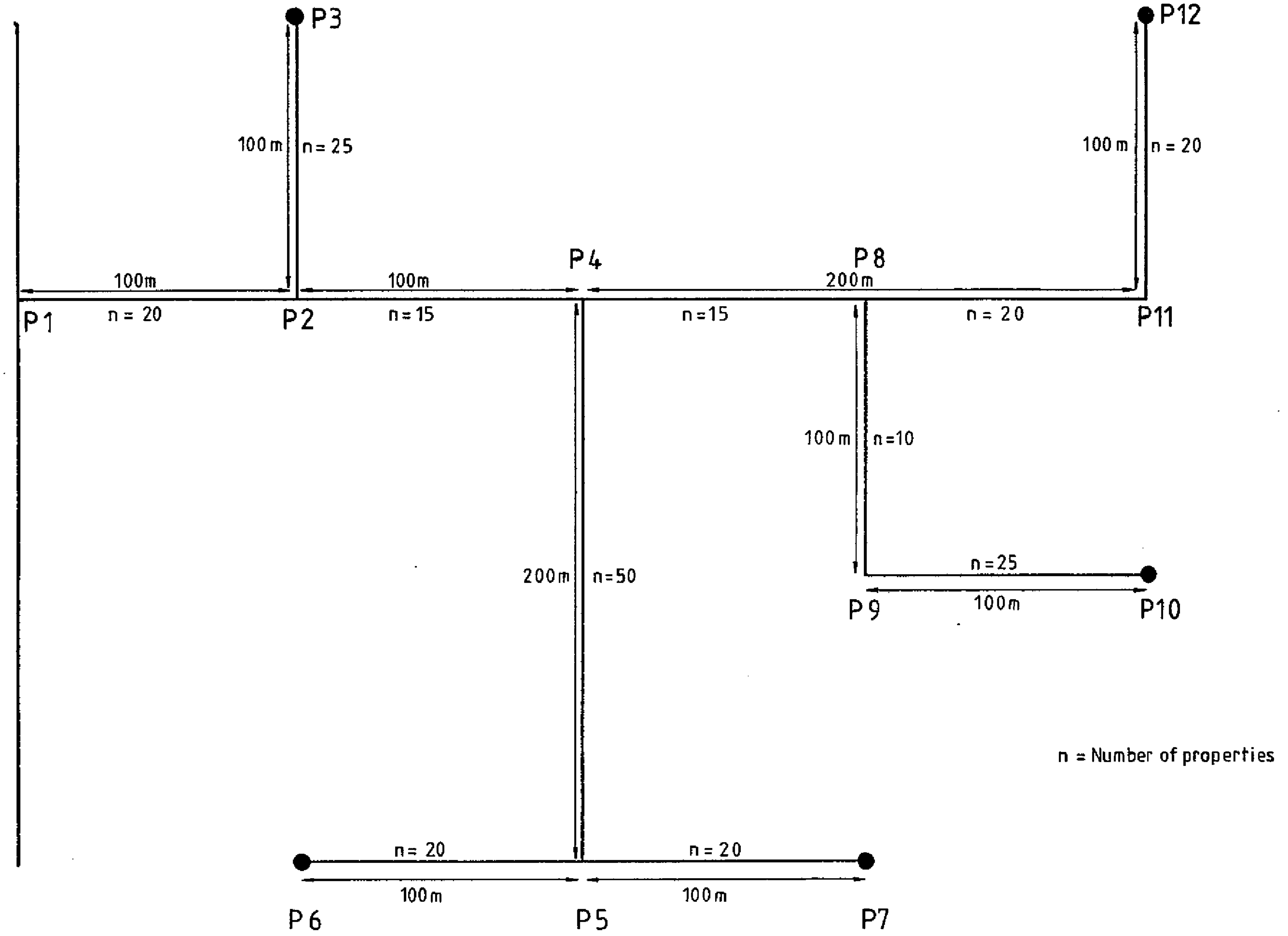
P_{10} = 8.08

P_{11} = 2.13

P_{12} = 9.19

If it was decided not to line mains with a contact time greater than 6 hours then all lengths could be lined except the dead ends P_2 - P_3, P_5 - P_6, P_5 - P_7, P_9 - P_{10} and P_{11} and P_{12}.

FIGURE A


P1
P2
P3
P4
P5
P6
P7
P8
P9
P10
P11
P12
100m
n = 20
100 m
n = 25
100m
n = 15
200m
n = 15
n = 20
100 m
n = 20
100 m
n = 10
n = 25
100m
200m
n = 50
n = 20
100m
n = 20
100m
n = Number of properties