BACKGROUND

The Ohio Department of Transportation is investigating the use of recycled concrete materials (RCM) in roadway applications. One of the potential uses for RCM is as an aggregate base in roadway construction or re-construction. Past problems encountered by ODOT with using RCM as an aggregate base include alkaline run-off (high pH of water flowing through RCM aggregate in sub-base).

PURPOSE

The purpose of this experiment was to determine pH levels of 100% RCM and mixtures of RCM and limestone, compare the results to the pH of virgin aggregates (limestone, gravel, natural sand, and manufactured sand), and compare pH results of all aggregates to the EPA limit of 9.00. To do this, ODOT devised the *Bucket Test* which consisted of soaking aggregates in buckets of water and then sampling the water for pH.

OVERVIEW

Various aggregates were subjected to submersion in de-mineralized water and periodically agitated by hand. The water was then sampled and analyzed for pH on specified days. Seven (7) separate trials were performed where the variation between trials included different gradations of materials, the mixture of two (2) materials together, whether or not the saturation water was changed periodically, and/or the sampling interval.

Trial #1 involved the continuous saturation of five (5) 304 base materials (limestone, gravel, and all 3 RCM) and two (2) sands (natural sand and manufactured sand). De-mineralized make-up water was added as necessary to account for losses due to sampling and evaporation. Water samples were taken and analyzed for pH on days 1, 2, 7, 14, 21, 28, 35, 42, 49, 56, and 63. It should be noted that samples were not taken after day 35 for both sands because their pH levels remained consistent and were below the EPA level of 9.00..

Trial #2 involved the continuous saturation of five (5) 304 base materials (limestone, gravel, and all 3 RCM). The saturation was drained and fresh de-mineralized water was added on days 7, 14, and 21. Water samples were taken and analyzed for pH on days 1, 2, 7, 8, 9, 14, 15, 21, 22, 23, 28, 35, 42, 49, 56, and 63.

Trial #3 involved mixing each RCM 304 base material with the limestone 304 base material at a proportion of 20% limestone to 80% RCM by weight and continuously saturating the three (3) mixed samples. De-mineralized make-up water was added as necessary to account for losses due to sampling and evaporation. Water samples were taken and analyzed for pH on days 1, 2, 7, 14, 21, 28, 35, 42, 49, 56, and 63.

Trial #4 involved mixing each RCM 304 base material with the limestone 304 base material at a proportion of 40% limestone to 60% RCM by weight, and continuously saturating the three (3) mixed samples. De-mineralized make-up water was added as necessary to account for losses due to sampling and evaporation. Water samples were taken and analyzed for pH on days 1, 2, 7, 14, 21, 28, 35, 42, 49, 56, and 63.

Trial #5 involved mixing each RCM 304 base material with the limestone 304 base material at a proportion of 40% limestone to 60% RCM by weight, and continuously saturating the three (3) mixed samples. De-mineralized make-up water was added as necessary to account for losses due to sampling and evaporation. Water samples were taken and analyzed for pH on days 1, 2, 7, 14, 21, 28, 35, 42, 49, 56, and 63.

Trial #6 involved the sieving of each RCM 304 base material to obtain plus #4 sieve size samples for each RCM, and the continuous saturation of the plus #4 sieve size samples. De-mineralized make-up water was added as necessary to account for losses due to sampling and evaporation. Water samples were taken and analyzed for pH on days 1, 2, 7, 14, 21, 28, and 35.

Trial #7 involved the continuous saturation of RCM materials that had been exposed to LA Abrasion materials (gravel, limestone, and all three (3) RCM were subjected to the *Soundness Test by LA Abrasion*, and after the test was complete, the materials retained on the 1.70 mm sieve and above were subjected to the *Bucket Test*). De-mineralized make-up water was added as necessary to account for losses due to sampling and evaporation. Water samples were taken and analyzed for pH on days 1, 2, 7, 14, 21, 28, and 35. In addition, gravel and limestone were sampled and tested on day 49 for pH.

SAMPLES

One (1) limestone, one (1) gravel, one (1) natural sand, one (1) manufactured sand, and three (3) RCM aggregates were obtained for the *Bucket Test* in accordance with ASTM D75. The limestone, gravel, and RCM aggregates were taken from stockpiles having gradations conforming to ODOT's 304 specification for base material, however the gradation for RCM 3 was out of spec for the #4 seive only by 4%. RCM aggregates were obtained from sources located in different geographical areas of Ohio (Cleveland, Columbus, and Cincinnati).

PROCEDURE

Bucket Test Procedural Summary

Trial #	# Buckets Needed	Material Being Tested (abbreviated)*	Test Sample Gradation	Amount of Test Sample Used	Days Water Sampled	Days Water Changed
1	7	LS, G, R1, R2, R3, NS, MS	304 base material	30% - 40% of 5-gallon bucket	1, 2, 7, 14, 21, 28, 35, 42, 49, 56, 63	N/A
2	5	LS, G, R1, R2, R3	304 base material	30% - 40% of 5-gallon bucket	1, 2, 7, 8, 9, 14, 15, 21,22, 23, 28, 35, 42, 49, 56, 63	7, 14, 21
3	3	20% LS + 80% R1 mix 20% LS + 80% R2 mix 20% LS + 80% R3 mix	304 base material	30% - 40% of 5-gallon bucket	1, 2, 7, 14, 21, 28, 35, 42, 49, 56, 63	N/A
4	3	40% LS + 60% R1 mix 40% LS + 60% R2 mix 40% LS + 60% R3 mix	304 base material	30% - 40% of 5-gallon bucket	1, 2, 7, 14, 21, 28, 35, 42, 49, 56, 63	N/A
5	3	60% LS + 40% R1 mix 60% LS + 40% R2 mix 60% LS + 40% R3 mix	304 base material	30% - 40% of 5-gallon bucket	1, 2, 7, 14, 21, 28, 35, 42, 49, 56, 63	N/A
6	3	R1, R2, R3	plus #4 sieve material	30% - 40% of 5-gallon bucket	1, 2, 7, 14, 21, 28, 35	N/A
7	5	LS, G, R1, R2, R3	LA Abrasion material	all material $\geq$ 1.70 mm sieve	1, 2, 7, 14, 21, 28, 35, 49**	N/A

* Material Abbreviations:

LS = Limestone G = Gravel
R1 = RCM 1 R2 = RCM 2 R3 = RCM 3
NS = Natural Sand MS = Manufactured Sand

** Only LS and G were sampled on day 49

1) 29 clean, standard sized 5 gallon buckets with lids were obtained and labeled as to which trial they were being used for and what material would be placed in them.

2) For trials #3, #4, and #5, limestone was mixed with each RCM to obtain 3 test samples for each trial. The mix ratios were as follows:
    a) 20% limestone with 80% RCM for trial #3;
    b) 40% limestone with 60% RCM for trial #4; and
    c) 60% limestone with 40% RCM for trial #5.

3) Test samples were placed into their corresponding buckets. For trials #1 - #6, each bucket was filled approximately 30% to 40% with test samples. For trial #7, all materials retained on the 1.70 mm sieve and up were used. as test samples.

4) Fresh de-mineralized water was added to each test sample until buckets were approximately 60% to 70% full, lids were placed over each bucket to minimize water loss due to evaporation, and test samples were allowed to soak.

5) Buckets scheduled to be sampled on a particular day were hand agitated on that day prior to sampling by tilting the bucket at an angle of approximately 20º and rolling for approximately 20 to 30 seconds.

6) Water samples were obtained on pre-determined days approximately 2 hours after agitation activities were complete.
    a) The bucket lid was removed and approximately 150 ml of water was obtained from each test sample bucket using a glass beaker.
    b) Samples were poured from the beaker into plastic containers that were labeled with the corresponding trial # (i.e. 1, 2 ... 7) and designation (i.e. LS, G, R1, R2, R3, NS, MS).
    c) Lids were placed on each sample container and the water samples were submitted to ODOT's Chemical section for pH analysis.
    d) The beaker was rinsed with clean tap water between each sampling event.
    e) Samples were obtained on the following days:
        i) 1, 2, 7, 14, 21, 28, 35, 42, 49, 56, and 63 days for trial #'s 1, 3, 4, and 5;
        ii) 1, 2, 7, 8, 9, 14, 15, 21, 22, 23, 28, 35, 42, 49, 56, and 63 days for trial #2;
        iii) 1, 2, 7, 14, 21, 28, and 35 days for trial #6; and
        iv) 1, 2, 7, 14, 21, 28, 35, and 49 days for trial #7. Only LS and G were sampled on day 49.

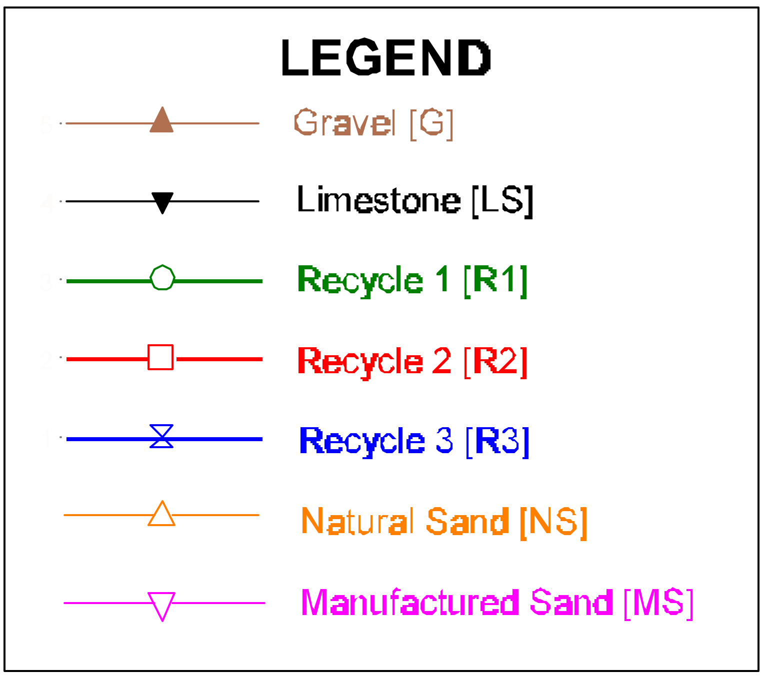
7) After each water sampling activity was complete, the level of water in the bucket was checked.
    a) If the amount of water above the test sample was approximately 2 inches or less, fresh de-mineralized water was added to raise the water level up to the initial water level of 60% to 70% bucket capacity.

b) For trial #2, if the sample day corresponded with a water change day, the water was drained from the bucket and fresh de-mineralized water was added up to the initial water level of 60% to 70% bucket capacity. Water change days for trial #2 occurred on days 7, 14, and 21.

8) After each sampling event (or the change or addition of fresh if applicable), the lid was returned to the corresponding bucket and the test samples remained in a submerged state with lid in place until the next agitation/sampling event.

RESULTS

Comments, tabular results, and graphical results for each trial are shown on following pages. The legend shown below can be used for all graphs.

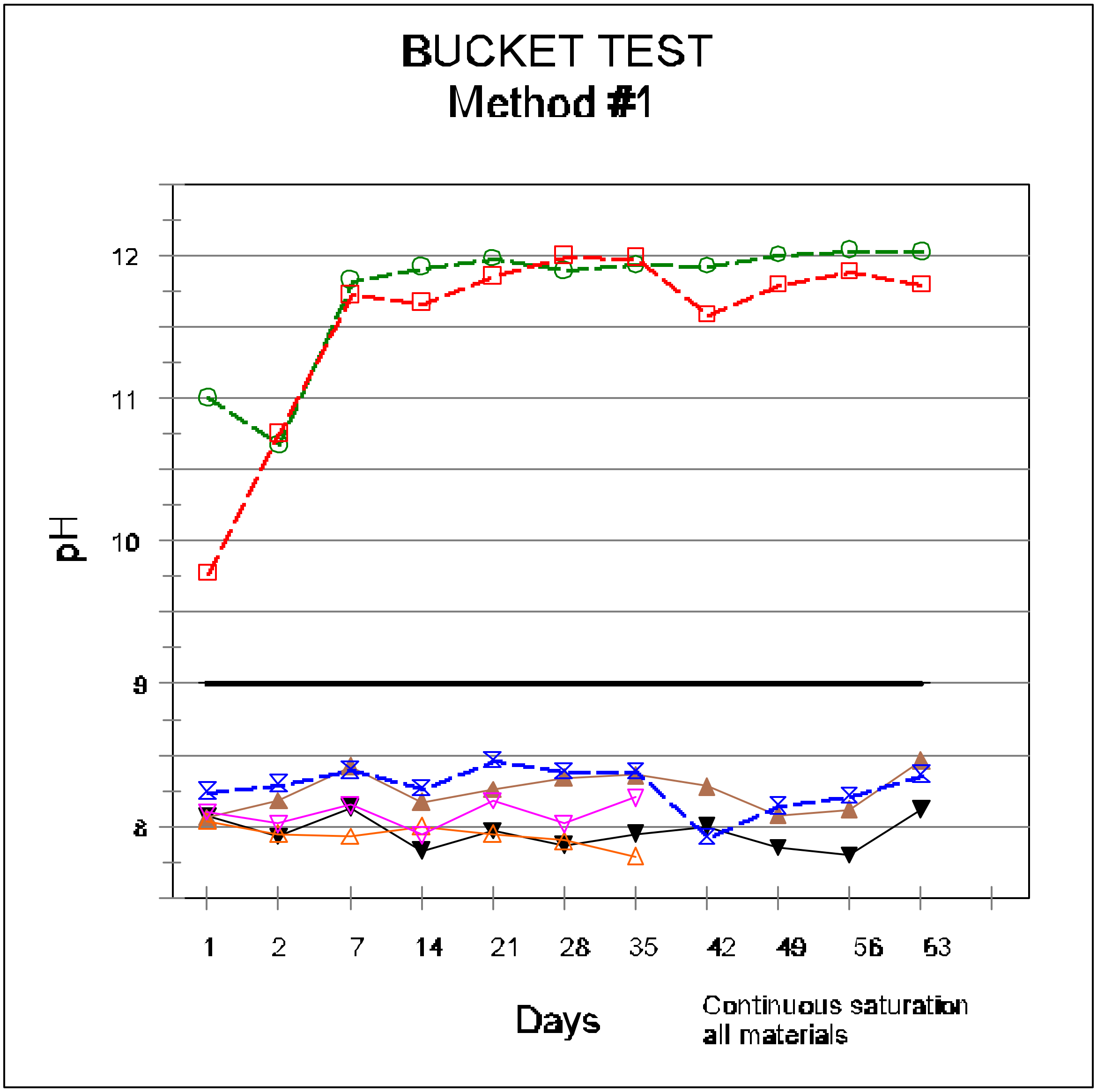


Trial #1

R1 and R2 exceeded the pH limit of 9.00 at every sampling interval and maintained steady pH readings above 11.50 from day 7 on. R3 as well as all virgin aggregates (LS, G, NS, MS) were under the pH limit of 9.00 at every sampling interval and maintained pH readings between 7.75 and 8.50 throughout the test.

Trial #1
304 Base Material and 2 Sands
Continuous Saturation

Day	LS	G	R1	R2	R3	NS	MS
1	8.07	8.06	***11.01***	***9.78***	8.25	8.04	8.10
2	7.93	8.18	***10.68***	***10.76***	8.30	7.95	8.02
7	8.13	8.42	***11.83***	***11.73***	8.40	7.93	8.15
14	7.83	8.17	***11.92***	***11.67***	8.27	8.00	7.94
21	7.97	8.26	***11.98***	***11.86***	8.47	7.95	8.18
28	7.87	8.34	***11.90***	***12.00***	8.39	7.90	8.02
35	7.95	8.36	***11.94***	***11.99***	8.39	7.79	8.20
42	8.00	8.28	***11.93***	***11.59***	7.93	Not Run	Not Run
49	7.85	8.08	***12.01***	***11.80***	8.15	Not Run	Not Run
56	7.80	8.12	***12.04***	***11.89***	8.22	Not Run	Not Run
63	8.12	8.46	***12.03***	***11.80***	8.37	Not Run	Not Run

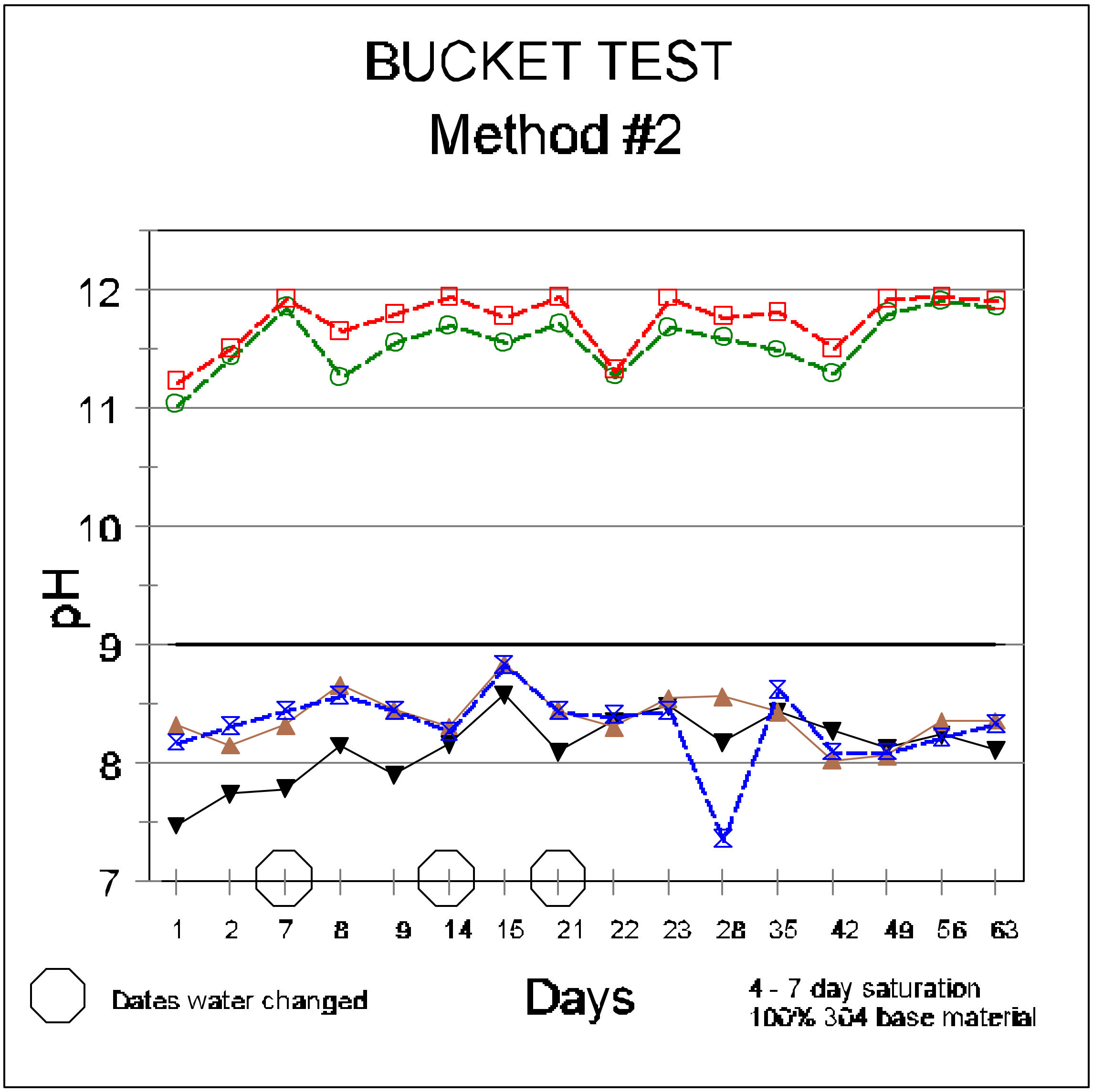

BUCKET TEST
Method #1
pH
12
11
10
9
8
1
2
7
14
21
28
35
42
49
56
63
Days
Continuous saturation
all materials

Trial #2

R1 and R2 exceeded the pH limit of 9.00 at every sampling interval and maintained steady pH readings above 11.00 throughout the test. R3 as well as all virgin aggregates (LS, G, NS, MS) were under the pH limit of 9.00 at every sampling interval and maintained pH readings between 8.00 and 9.00 with a few exceptions having pH readings below 8.00.

Trial #2 **304 Base Material** **Continuous Saturation with Water Change**					
Day	LS	G	R1	R2	R3
1	7.47	8.32	***11.04***	***11.23***	8.18
2	7.74	8.15	***11.44***	***11.51***	8.32
7*	7.78	8.32	***11.86***	***11.93***	8.45
8	8.15	8.66	***11.27***	***11.66***	8.58
9	7.90	8.45	***11.56***	***11.80***	8.45
14*	8.16	8.31	***11.70***	***11.95***	8.27
15	8.58	8.84	***11.56***	***11.78***	8.84
21*	8.09	8.44	***11.72***	***11.95***	8.44
22	8.35	8.30	***11.28***	***11.33***	8.41
23	8.48	8.54	***11.69***	***11.94***	8.45
28	8.17	8.56	***11.60***	***11.78***	7.36
35	8.43	8.43	***11.50***	***11.82***	8.63
42	8.27	8.02	***11.30***	***11.51***	8.10
49	8.13	8.06	***11.81***	***11.93***	8.10
56	8.24	8.35	***11.91***	***11.95***	8.22
63	8.11	8.36	***11.86***	***11.91***	8.33

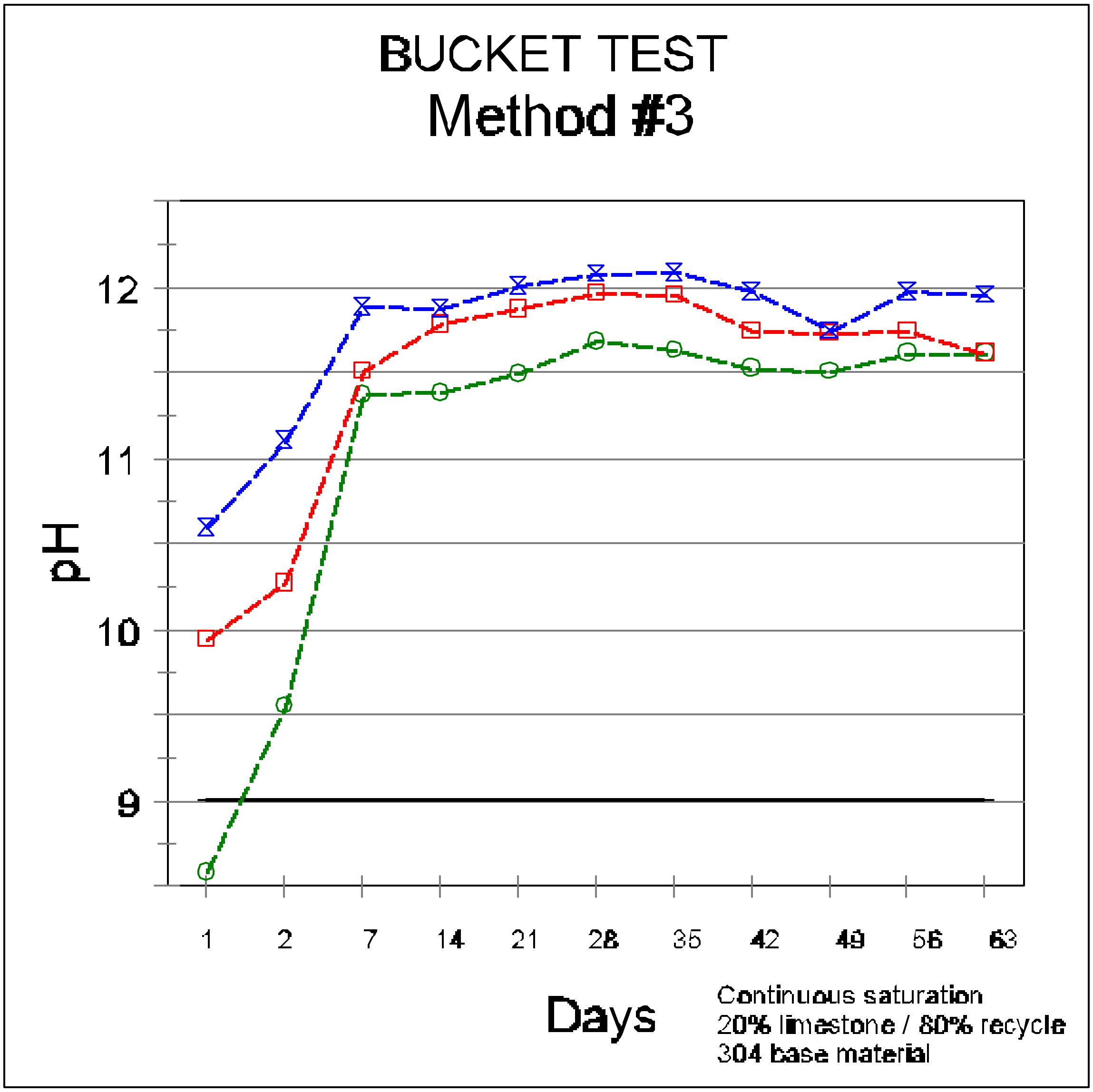
* Indicates days water was changed.


BUCKET TEST
Method #2
pH
12
11
10
9
8
7
1 2 7 8 9 14 15 21 22 23 28 35 42 49 56 63
Dates water changed
Days
4 - 7 day saturation
100% 304 base material

Trial #3

R1, R2, and R3 exceeded the pH limit of 9.00 at every sampling interval with the exception of R1 at day 1. From day 7 on, the pH results for all sampling intervals were above 11.00, and from day 21 on, the pH results for all sampling intervals maintained steady pH readings at 11.5 or above.

Trial #3 **304 Base Material, 20% LS + 80% RCM** **Continuous Saturation**			
Day	20% LS + 80% R1	20% LS + 80% R2	20% LS + 80% R3
1	8.59	***9.95***	***10.60***
2	***9.56***	***10.28***	***11.11***
7	***11.38***	***11.52***	***11.89***
14	***11.39***	***11.79***	***11.88***
21	***11.50***	***11.88***	***12.01***
28	***11.69***	***11.97***	***12.08***
35	***11.64***	***11.96***	***12.09***
42	***11.53***	***11.75***	***11.98***
49	***11.52***	***11.74***	***11.75***
56	***11.62***	***11.75***	***11.98***
63	***11.62***	***11.62***	***11.96***

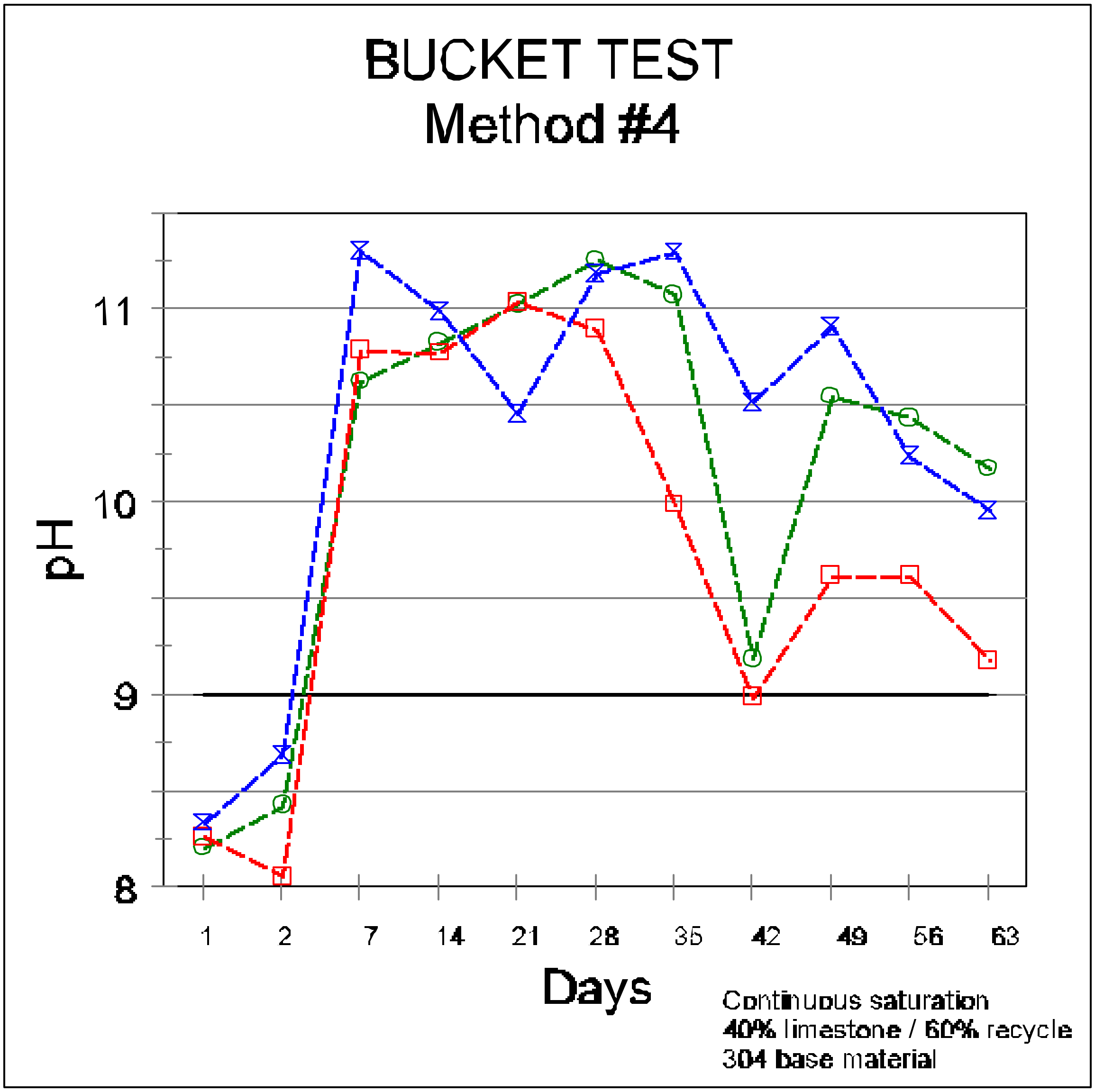

BUCKET TEST
Method #3
pH
12
11
10
9
1
2
7
14
21
28
35
42
49
56
63
Days
Continuous saturation
20% limestone / 80% recycle
304 base material

Trial #4

None of the LS/RCM mixtures exceeded the pH limit of 9.00 for the first 2 sampling intervals (day 1 and day 2). From day 7 on, the pH results for all sampling intervals were above 9.00 with the exception of the LS/R2 mix at day 42 which had a pH of 8.99. None of the LS/RCM mixtures maintained steady pH readings, and all readings appeared to be decreasing towards the end of the testing interval.

Trial #4
304 Base Material, 40% LS + 60% RCM
Continuous Saturation

Day	40% LS + 60% R1	40% LS + 60% R2	40% LS + 60% R3
1	8.21	8.27	8.34
2	8.43	8.06	8.69
7	***10.63***	***10.79***	***11.31***
14	***10.83***	***10.78***	***10.99***
21	***11.03***	***11.04***	***10.46***
28	***11.26***	***10.90***	***11.19***
35	***11.08***	***9.99***	***11.30***
42	***9.19***	8.99	***10.52***
49	***10.55***	***9.62***	***10.91***
56	***10.44***	***9.62***	***10.24***
63	***10.18***	***9.18***	***9.96***

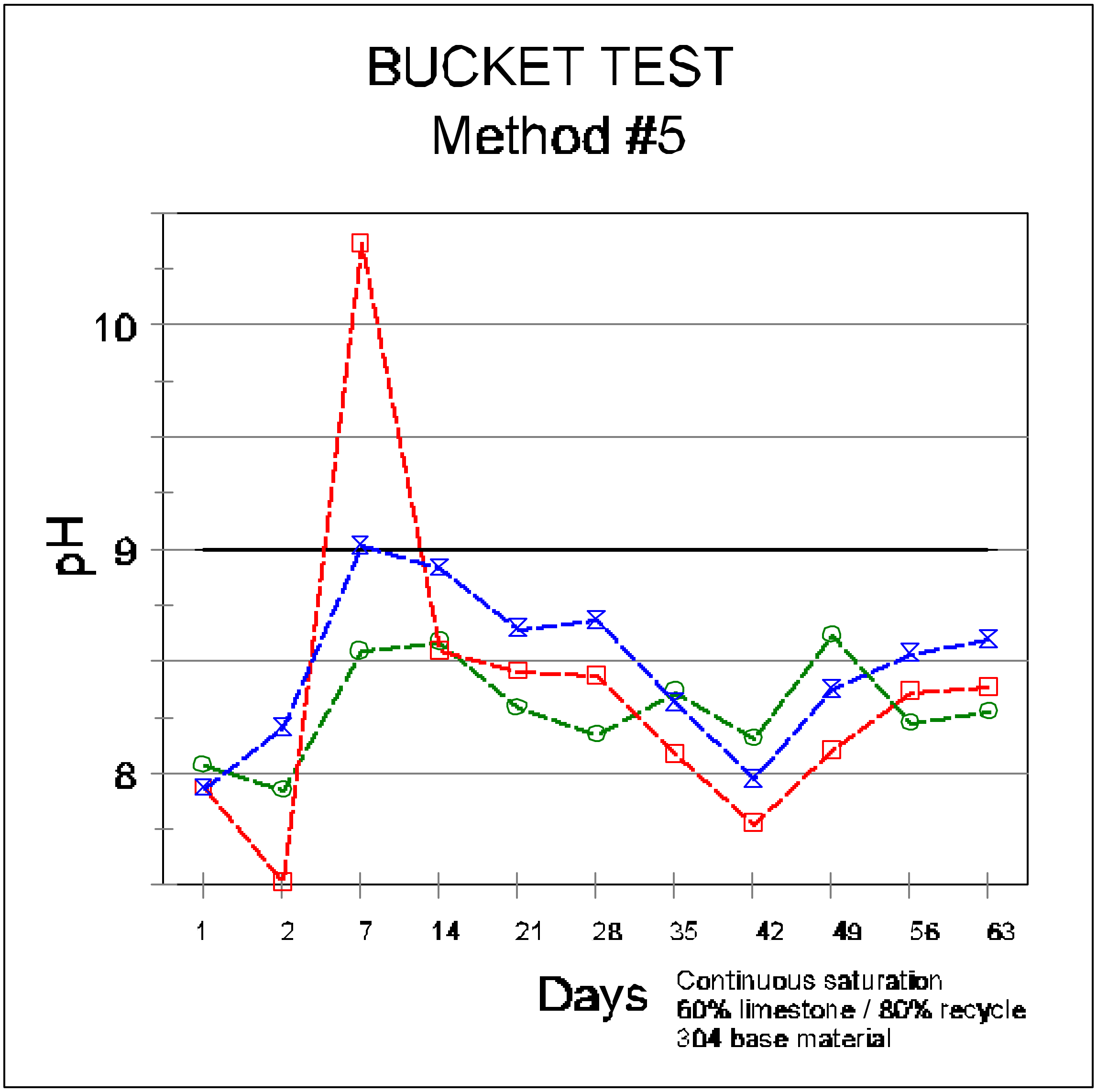

BUCKET TEST
Method #4
pH
11
10
9
8
1
2
7
14
21
28
35
42
49
56
63
Days
Continuous saturation
40% limestone / 60% recycle
304 base material

Trial #5

All of the LS/RCM mixtures remained below the pH limit of 9.00 for the entire testing interval except for the LS/R2 and LS/R3 mixtures at day 7 which were 10.37 and 9.02 respectively. Towards the end of the testing interval, all LS/RCM mixtures had steady readings in 8.25 to 8.75 range.

Trial #5
304 Base Material, 60% LS + 40% RCM
Continuous Saturation

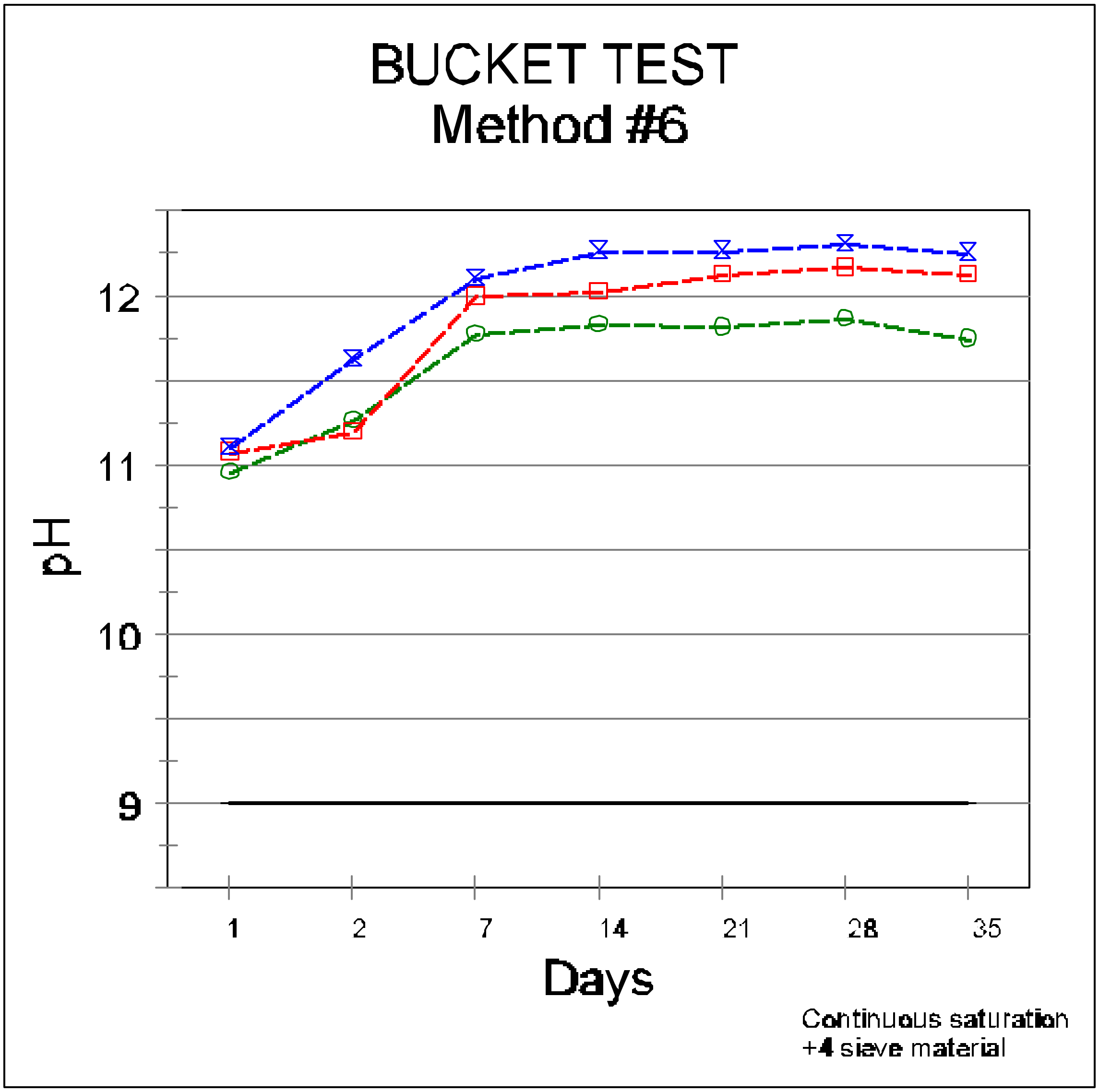
Day	60% LS + 40% R1	60% LS + 40% R2	60% LS + 40% R3
1	8.04	7.94	7.94
2	7.93	7.52	8.21
7	8.55	***10.37***	***9.02***
14	8.59	8.55	8.92
21	8.30	8.46	8.65
28	8.18	8.44	8.69
35	8.37	8.09	8.32
42	8.16	7.78	7.98
49	8.62	8.11	8.38
56	8.23	8.37	8.54
63	8.28	8.39	8.60


BUCKET TEST
Method #5
pH
10
9
8
1
2
7
14
21
28
35
42
49
56
63
Days
Continuous saturation
60% limestone / 80% recycle
304 base material

Trial #6

R1, R2, and R3 exceeded the pH limit of 9.00 at every sampling interval and maintained steady pH readings above 11.50 from day 7 on.

Trial #6 **+ #4 Sieve Material** **Continuous Saturation**			
Day	R1	R2	R3
1	***10.96***	***11.08***	***11.11***
2	***11.27***	***11.20***	***11.63***
7	***11.78***	***12.00***	***12.11***
14	***11.84***	***12.03***	***12.27***
21	***11.82***	***12.13***	***12.27***
28	***11.87***	***12.17***	***12.31***
35	***11.75***	***12.13***	***12.26***

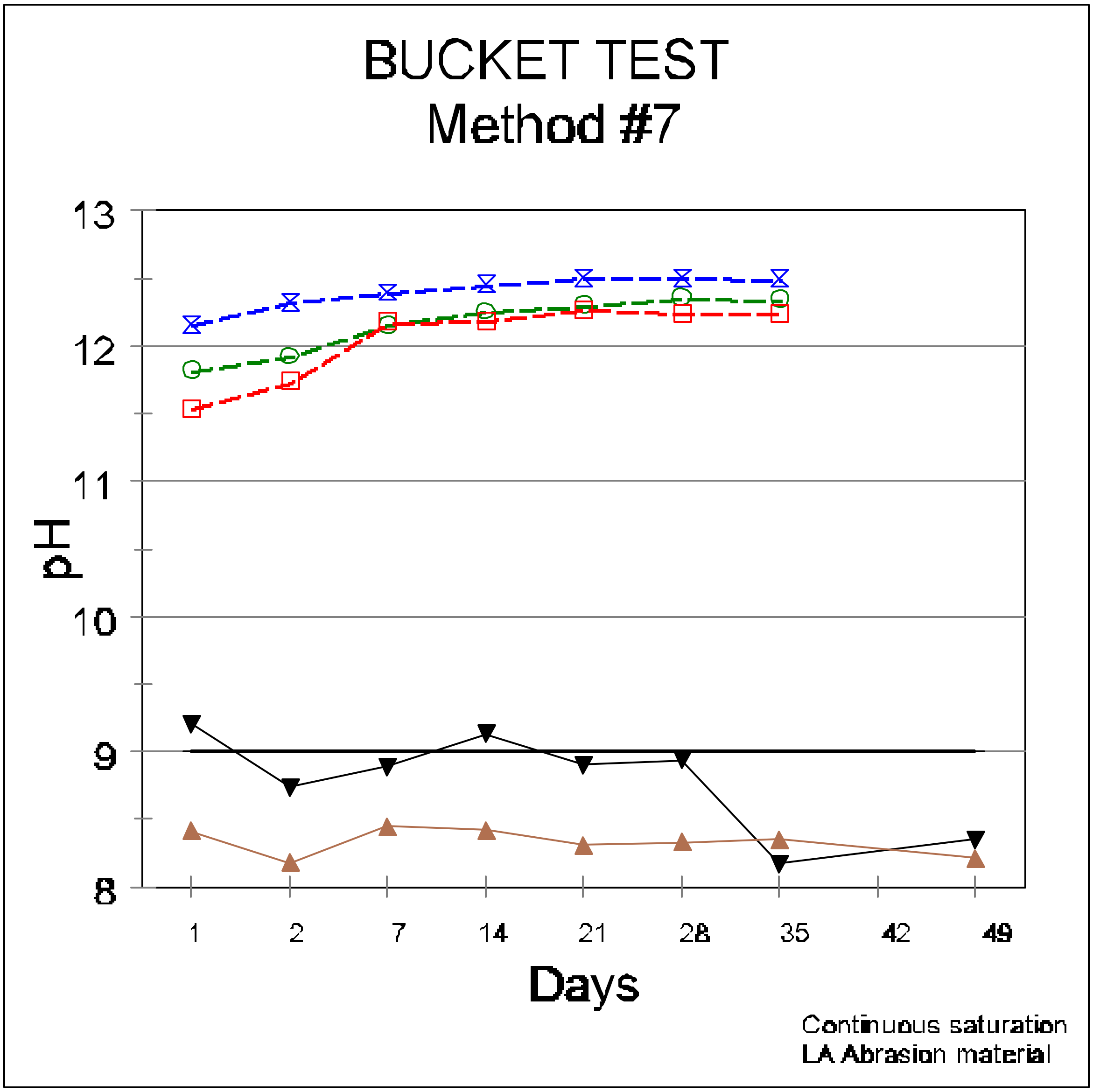

BUCKET TEST
Method #6
12
11
10
9
pH
1
2
7
14
21
28
35
Days
Continuous saturation
+4 sieve material

Trial #7

R1, R2, and R3 exceeded the pH limit of 9.00 at every sampling interval and maintained steady pH readings above 12.00 from day 7 on. LS slightly exceeded the pH limit of 9.00 on day 1 and day 14 and maintained a steady pH reading around 9.00 until the end of the testing innterval where it decreased below 8.50. G was below the pH limit of 9.00 at every sampling interval and maintained steady pH readings slightly less than 8.50.

Trial #7
LA Abrasion Materials
Continuous Saturation

Day	LS	G	R1	R2	R3
1	9.21	8.41	11.82	11.54	12.16
2	8.74	8.18	11.93	11.74	12.33
7	8.89	8.45	12.16	12.18	12.40
14	9.13	8.42	12.26	12.19	12.46
21	8.90	8.31	12.31	12.27	12.51
28	8.94	8.33	12.36	12.24	12.51
35	8.17	8.35	12.35	12.24	12.50
49	8.35	8.21	Not Run	Not Run	Not Run


BUCKET TEST
Method #7
13
12
11
10
9
8
pH
1
2
7
14
21
28
35
42
49
Days
Continuous saturation
LA Abrasion material

CONCLUSIONS

With respect to pH values for unmixed materials (trials #1, #2, #6, and #7):

1) The majority of RCM results were above 9.00. R1 and R2 were above 9.00 for every sampling interval and R3 was above 9.00 for every sampling interval in trials #6 and #7 but was below 9.00 for every sampling interval in trials #1 and #2.

2) The majority of virgin aggregates were below 9.00. LS, G, NS, and MS were below 9.00 for every sampling interval in trial #1. LS and G were also below 9.00 for every sampling interval in trials #2. In trial #7, G was below 9.00 for all sampling intervals but LS slightly exceeded 9.00 on 2 of the 8 sampling intervals (9.21 on day 1 and 9.13 on day 14). NS and MS were not tested in trials #2 or #7 and no virgin aggregates were tested in trial #6.

With respect to pH values for mixed materials (trials #3, #4, and #5):

1) The 20% LS + 80% RCM mixtures (trial #3) exceeded 9.00 for all sampling intervals except LS/R1 at day 1.

2) The 40% LS + 60% RCM mixtures (trial #4) were below 9.00 on day 1 and day 2 for all three (3) mixtures, but were above 9.00 for all three (3) mixtures for the rest of the testing interval except for the LS/R2 mixture on day 42 which was 8.99.

3) The 60% LS + 40% RCM mixtures (trial #5) were below 9.00 for all three (3) mixtures for all sampling intervals except day 14 where LS/R2 was 10.37 and LS/R3 was 9.02.

Changing the water in the buckets had very little long term effect on pH. Trials #1 and #2 included 304 base material for G, LS, R1, R2, and R3. In trial #1, the water was not changed. In trial #2, the water was changed. The results for both trials were virtually the same with R1 and R2 above 9.00 for all sampling intervals and remaining steady while R3, LS, and G were below 9.00 and remaining steady. In the short term, the pH would drop the day following the change of water, but then the pH would rise again to levels comparable to those in trial #1 where the water was not changed.

The gradation of the material did not appear to have an impact on pH for R1, R2, or G, but appears to have had a small impact on pH for R3 and LS. Trials #1 and #2 included material meeting ODOT's 304 base material gradation. Trial #6 included +4 sieve material only, and only the three (3) RCM's were tested in this trial. Trial #7 included LA Abrasion materials with sizes ≥ 1.70 mm up to 1". R1 and R2 remained above 9.00 for all sampling intervals in trials #1, #2, #6, and #7. G remained below 9.00 for all sampling intervals in trials #1, #2, and #7. R3 was below 9.00 for all sampling intervals in trials #1 and #2, but was above 9.00 for all sampling intervals in trials #6 and #7. LS was below 9.00 for all sampling intervals in trials #1 and #2, but exceeded 9.00 on two (2) sampling event in trial #7 and remained very close to 9.00 for most of the test.

In summary, RCM will generally yield pH values above 9.00 where virgin aggregates will yield pH values below 9.00. If RCM is to be mixed with virgin aggregates for use, the mix ratio will need to be approximately 60% virgin aggregate to 40% RCM to yield pH values below 9.00. FlushingRCM to lower pH does not appear to be effective. The gradation or size of the material may or may not have an impact on the pH.