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High Pressure Water Jet Contaminant Remediation of Intertidal Sediment via Distributed Granular Activated Carbon

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ABSTRACT

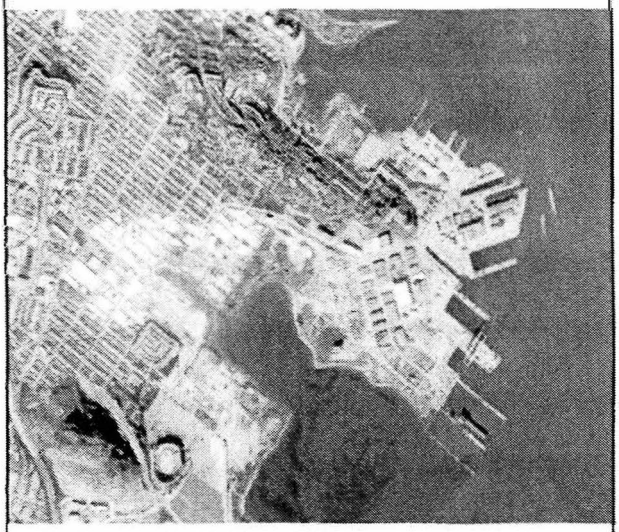
Hunters Point Naval Shipyard lies on western intertidal coastline and is designated as a Superfund site. Studies indicate sediment dwelling organisms that usually thrive in this intertidal area are now suffering and dying from PCB toxins. Experts have discovered that PCBs adsorb onto Granular Activated Carbon (GAC) particles, a material commonly used for contaminant remediation. Using a water jet, the GAC can be distributed in situ throughout the top 10 cm. of sediment. Research measures will include reproducing the natural, intertidal habitat in the UMR High Pressure Water Jet Laboratory. Specifically, to realize optimal benefits from the remediation process, a mixture of 2% (by dry weight) surrogate material to the sediment must be attained.

The United States Department of Defense (DoD), Department of Energy (DOE), and Environmental Protection Agency (EPA) have stated that approximately 1 billion cubic yards of sediment underlying the nation's surface water is sufficiently polluted with toxins and has the potential to injure fish, wildlife and humans. (Ghosh, et al.) "Sediment serves as a contaminant reservoir from which aquatic organism can accumulate toxic compounds like PCBs and DDT that are passed up the food chain." (Stanford University) Scientists and engineers have proposed various methods to remediate these contaminated habitats. Marine and estuary sites pose great obstacles for remediation because equipment is difficult to maneuver in situ, therefore a combination of remedial approaches are necessary. One proposed method uses high pressure waterjets to inject remediation material into the contaminated aquatic sediment. This method eliminates the need to relocate the sediment and minimizes the risk to the environment of the local organisms. In situ treatment of the sediment via the water jet treatment is the best method of remediation for this habitat so that minimal risk is posed to indigenous life forms. An additional benefit of this approach is that the costs are relatively low when compared to other remediation options.

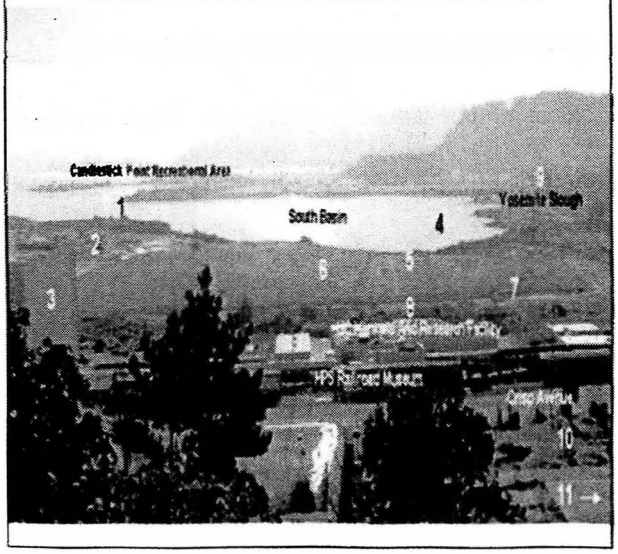
BACKGROUND: HUNTERS POINT NAVAL SHIPYARD

Hunters Point Naval Shipyard is a 936 acre property located in San Francisco Bay, California.(1) From 1869 through 1987 this property was used by the Navy and its leasees for ship building repair, servicing and testing. By 1987, the Environmental Protection Agency (EPA) confirmed unacceptable levels of contamination including polychlorinated biphenyls (PCBs), trichloroethylene, pesticides, lead, and other contaminants. In 1989, the EPA listed Hunters Point Naval Shipyard (HPNS) on the

Figure 1
Hunters Point Naval Shipyard Aerial Photo



Hunters Point Naval Shipyard South Basin



National Priorities List for Superfund sites. This site was separated into 6 parcels, labeled A through F, to optimize remediation efforts. In at least 5 of these parcels, PCBs and other contaminants remain on site and require remediation.

The main intertidal zone of PCB contamination lies in the awkwardly accessible South Basin area. (Figure 1) Clams, worms, and amphipods live in approximately the top 10 centimeters of this contaminated sediment. During the few hours of low tide in this area, access is restrictive because sediment is spongy, can reach far past the ankle and thus limits remediation options.

GRANULAR ACTIVATED CARBON

Granular Activated Carbon (GAC) is a common water filtration material and contaminant remediation substrate. It is an adsorbent material with a somewhat corrugated sheet structure, which gives it an increased surface area compared to other materials. The surface area per gram can be as high as 2500 m^2.(2) PCBs and other

contaminants readily adsorb to GAC not only because of the high surface area, but also due to its high porosity. (3)

HIGH PRESSURE WATER JETS

High Pressure Waterjets have been used for decades to cut rock and other material. They are the ideal tool for many applications because they are precise, produce little byproduct, and are versatile. Waterjets cut materials by combining high pressure water and an abrasive sand, usually garnet. An amendment of xanthan gum or guar is used to suspend the abrasive in a mixture which is then transported through the waterjet delivery system.

EXPERIMENT

Remediation of the South Basin using High Pressure Waterjets with a surrogate abrasive, specifically the Granular Activated Carbon, is possible if we use lower pressures to target the top 5-10 centimeters of sediment where the majority of the contaminants reside. A target concentration of 2% GAC by dry weight for optimal remediation is accomplished by applying waterjet technology. Approximately 400 grams of kaolinite is used per sample, therefore the GAC content must be greater than or equal to 8 grams. A slurry of 90% water, 9.91% GAC, and 0.09% xanthan gum was determined by experimental analysis.

SEDIMENT MODELLING

Sample sediment was retrieved from a surface water source that mimicked similar conditions as the South Basin. Analysis of this sample revealed the density of the sediment, ρ=0.91 g/cm^3, and a water content of approximately 30%. In the lab, kaolinite

is utilized as the surrogate sediment using these characteristics. A total of 64 mason jars were prepared to contain the sediment slurry samples.

NOZZLE DESIGN AND SELECTION

The optimal waterjet configuration to deliver the GAC consists of a pump, reactor system, hose, and nozzle. (Figure 2)

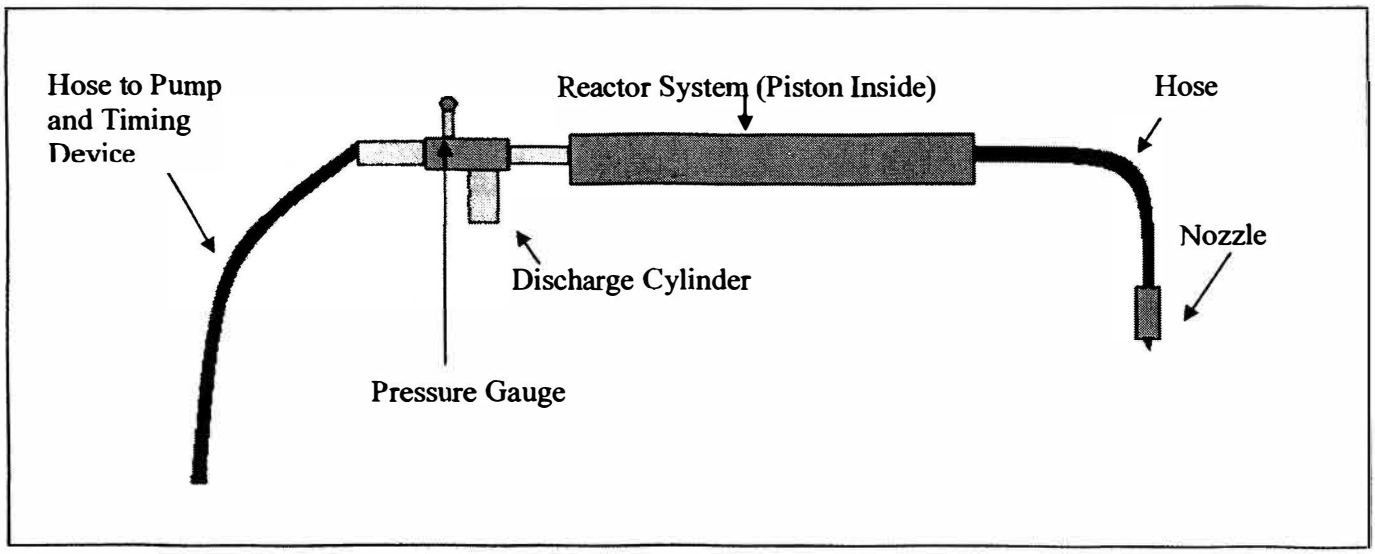


Figure 2

When the timing device is begun, the pump pressurizes the assembly; the high pressure water moves the piston within the reactor tube and pushes the GAC slurry out through the hose and nozzle apparatus.

The nozzle diameter used is directly related to the flow rate with the corresponding equation:

$$Q = \frac{(C_d)(\Pi R^2)(12\sqrt{P})(12*60)}{231}$$

Where Q is the flow rate in gallons per minute, C_d is the discharge coefficient using a constant value of 0.85, and P is pressure measured in psi. (Appendix A) Nozzle diameters used in this experiment are 0.030 in., 0.040 in., 0.050 in., and 0.060 inches. These diameters are commonly used in waterjet applications. In using these specific diameters, the amount of GAC injected into the surrogate sediment can be estimated. These numbers are estimations only because pump pressures can spike and injection times can be delayed due to air compression within the reactor tube.

The project has been conducted as a factorial experiment using 64 samples of surrogate sediment subjected to varying time periods, pressures, and nozzle diameters. (Appendix B) Factorial experiments eliminate redundancy and reduce the number of samples necessary to obtain optimal data points. This layout provides only one sample for a given set of parameters, whereas other layouts develop several samples for the same information.

After the GAC was injected into the surrogate material, the samples were cooked in an oven between 150° F and 175° F for at least two weeks. Drying the samples over a long period of time minimized fracturing and allowed for a cleaner removal of the sample from the mason jar, resulting in more accurate analysis. Foam was inserted into the jars after they were dry to enable a waterjet to cut off the top of each.

The target of 2% GAC by dry weight is the goal so that an optimal pressure, nozzle diameter, and time period may be determined. The 64 core drill samples were analyzed utilizing a grey scale gradient. (Appendix C) A comparison of each sample to the gray gradient has been performed to determine the concentration of GAC achieved.

A qualitative analysis of the samples using a grey scale gradient was performed. Nozzle diameters of 0.03, 0.03, 0.05, and 0 06 inches were used, although use of the 0.03 inch nozzle yielded no results due to the high viscosity of the GAC slurry. Therefore, experiments using the 0.06 inch nozzle were duplicated with differing back pressures to determine if there is any difference in results. From calculations, the 0.06 inch nozzle was the only diameter to have the capacity to achieve 8 grams within the 400 gram surrogate sediment, specifically 2% by dry weight. The differing back pressures were determined to make little or no difference in the results.

Within the 0.06 diameter nozzle range, samples using 1200, 1500, and 1800 PSI for time ranges of 0.7 to 1.3 seconds attained optimal GAC saturation. (Appendix D) The specific combinations of pressures and time intervals are as listed in Table 1.

Nozzle Diameter, inches	Pressure, PSI	Time Interval, seconds
0.06	1500	0.7
0.06	1200	1.3
0.06	1800	0.7
0.06	1200	0.7
0.06	1200	1

Table 1

Although several sample colors appear to be within the required range, these samples were deemed inadmissible. This is because some of the original kaolinite was displaced from the jar upon penetration by the waterjet, and therefore achieved the target concentration by subtraction of sediment rather than the addition of carbon.

After experimental analysis reviewed, field experimentation by established professionals will be conducted; it is outside the scope of this experiment. When experimental results are available, possible field equipment that utilizes waterjet technologies include:

- Low ground pressure vehicles that can drag injectors such as the ArgoATV
- Dry solid injection tools such as the Dryject which uses waterjets to blast a holes in soil and inject sand, but may be adaptable to this application and
- Slurry injection normally used for soil/sediment stabilization with cement mortar

If High Pressure waterjets can be used to deliver granular activated carbon, then they can be used to deliver a wider range of materials for soil remediation. In fact, one project already in progress models an unconsolidated aquifer and will utilize waterjets to deliver other remediation substances such as EHC, a combination of cellulose and iron, and zero valent iron into soil.

LEARNING EXPERIENCE

Performing research in the field of geological engineering has given me a more realistic perspective of the work involved in research and development. In this discipline, one must be physically and mentally prepared to meet the challenges required to solve problems of today. Although the internet, library, and school books were important informational resources, my advisor, colleagues, and fellow students have become my best informational resources that I have developed. I have learned some fundamentals of qualitative, quantitative, and mixed methods experimental design. This research experiment used qualitative analysis with a grey-scale gradient.

REFERENCES

1. Environmental Protection Agency. "Hunters Point Naval Shipyard." (February 27,2004) n. pag. Online. Internet. EPA Region 9 ID # 1170090087 http://yosemite.epa.gov/r9/sfund/overview.nsf/o/...

2. Ghosh, Dr. Upal, et al. "In Situ Bioavailability Reduction of PCBs in Sediments: From Bench-Scale to Field Demonstration." Strategic Environmental Research and Development Program, DoD, DOE, EPA. February 18-19, 2004. Remediation Technology Development Forum. Baltimore, Maryland.

3. Stanford University. "Contaminated Sediment Processes and Bioavailability." (February 25, 2004) n. pag. Online. Internet. http://www-ce.stanford.edu/faculty/luthy/LuthyResearch.html

ACRONYMS

DoD – Department of Defense

DOE – Department of Energy

EPA – Environmental Protection Agency

GAC – Granular Activated Carbon

HPNS – Hunters Point Naval Shipyard

PCB – Polychlorinated Biphenyls

PSI – Pounds per Square Inch

ZVI – Zero Valent Iron

GLOSSARY

Discharge Coefficient – (C_d) The ratio of the actual rate of flow of a fluid through a meter to the rate computed by a theoretically derived equation or by empirical equation

EHC – a remediation product used for the in situ treatment of groundwater and saturated soil impacted by heavy metals and persistent organic compounds such as chlorinated solvents, pesticides and energetics.

Factorial Experiment – an experiment in which the effects of multiple factors are investigated simultaneously

Granular Activated Carbon - A highly porous adsorbent material, produced by heating organic matter, such as coal, wood and coconut shell, in the absence of air, which is then crushed into granules. Activated carbon is positively charged and therefore able to remove negative ions from water.

Guar - drought-tolerant herb grown for forage and for its seed which yield a gum used as a thickening agent or sizing material

Intertidal – a shore area above low-tide mark

PCB - any of several compounds that are produced by replacing hydrogen atoms in biphenyl with chlorine, have various industrial applications, and are poisonous environmental pollutants which tend to accumulate in animal tissues

Xanthan Gum - a thickening and suspending agent used especially in pharmaceuticals and prepared foods

Zero Valent Iron – used for in situ remediation of selected metals in groundwater

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Poppa, Kerry. Student, University of Missouri – Rolla

Meyer, Mark Andrew. Student, University of Missouri - Rolla

APPENDIX A

Flow Rate of Injected Granular Activated Carbon

Size (inches	PSI	Rate (GPM)	Duration (seconds)	% GAC Concentration	GAC Delivered (grams)
0.03	1000	0.710646	0.5	0.091	0
0.03	1500	0.870360	0.7	0.091	0
0.03	1800	0.953431	1.0	0.091	0
0.03	1200	0.778473	1.3	0.091	0
0.04	1000	1.263370	0.5	0.091	1.668070547
0.04	1500	1.547306	0.7	0.091	2.860145187
0.04	1800	1.694989	1.0	0.091	4.475902961
0.04	1200	1.383952	1.3	0.091	4.750927304
0.05	1000	1.974016	0.5	0.091	2.60636023
0.05	1500	2.417665	0.7	0.091	4.468976854
0.05	1800	2.648420	1.0	0.091	6.993598377
0.05	1200	2.162426	1.3	0.091	7.423323912
0.06	1000	2.842582	0.5	0.091	3.753158731
0.06	1500	3.481438	0.7	0.091	6.43532667
0.06	1800	3.813725	1.0	0.091	10.07078166
0.06	1200	3.113893	1.3	0.091	10.68958643

$Q=C_d*\pi*r^2*[12*\sqrt{P}]*12*60/231$

APPENDIX B

Intertidal PCB Remediation via Water Jet Distribution

Data Factorial Sheets

T_1	0.5	P_1	P_2	P_3	P_4
0.5		1000	1500	1200	1800
D_1	0.04	1	5	9	13
D_2	0.05	17	21	25	29
D_3	0.06	33	37	41	45
D_4	0.06	49	53	57	61

T_2	0.7	P_1	P_2	P_3	P_4
0.7		1000	1500	1200	1800
D_1	0.04	2	6	10	14
D_2	0.05	18	22	26	30
D_3	0.06	34	38	42	46
D_4	0.06	50	54	58	62

T_3	1	P_1	P_2	P_3	P_4
1		1000	1500	1200	1800
D_1	0.04	3	7	11	15
D_2	0.05	19	23	27	31
D_3	0.06	35	39	43	47
D_4	0.06	51	55	59	63

T_4	1.3	P_1	P_2	P_3	P_4
1.3		1000	1500	1200	1800
D_1	0.04	4	8	12	16
D_2	0.05	20	24	28	32
D_3	0.06	36	40	44	48
D_4	0.06	52	56	60	64

Experiment = Sample Number

P_1=	1000	D_1=	0.04	T_1=	0.5
P_2=	1500	D_2=	0.05	T_2=	0.7
P_3=	1200	D_3=	0.06	T_3=	1
P_4=	1800	D_4=	0.06	T_4=	1.3

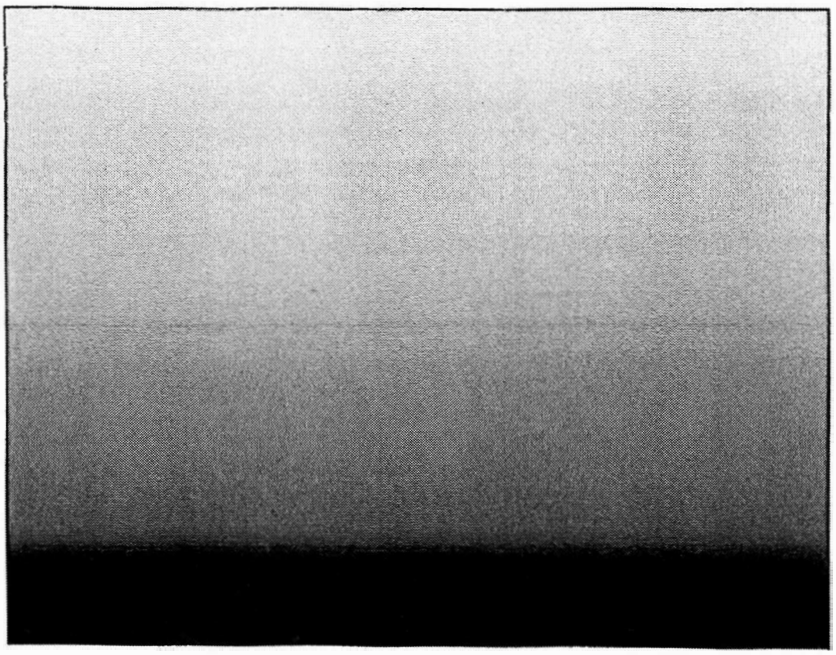
APPENDIX C

Grey Scale Gradient Analysis

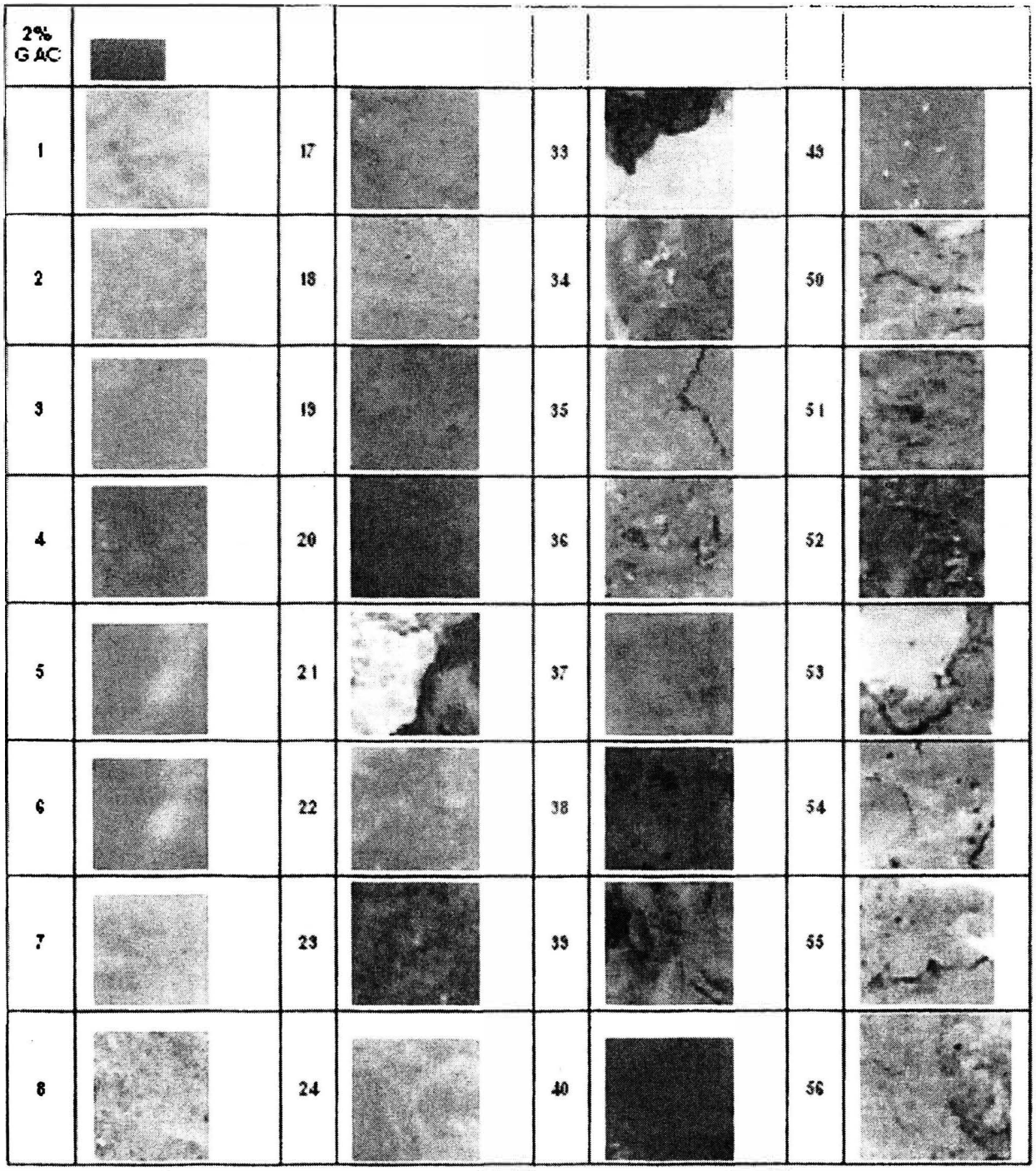
Kaolinite--------

2% GAC--------

>2% GAC------



Appendix D


2% GAC
1
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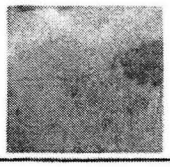
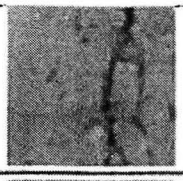
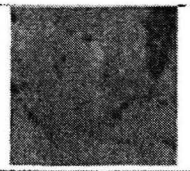
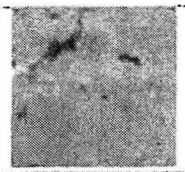
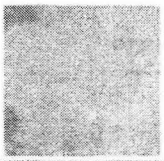
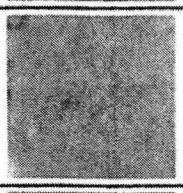
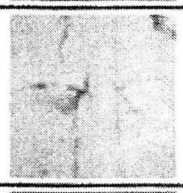
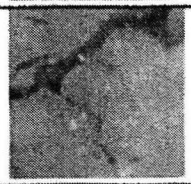
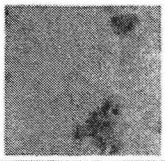
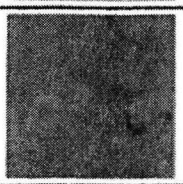
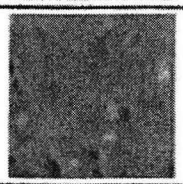
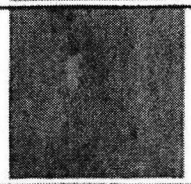
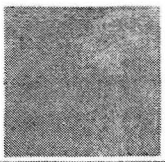
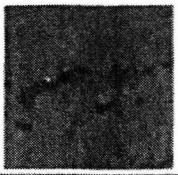
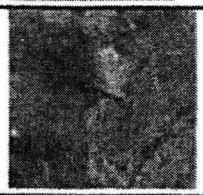
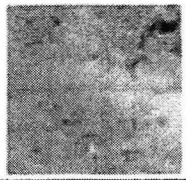
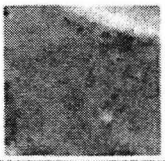
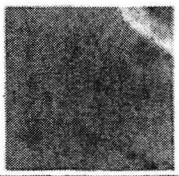
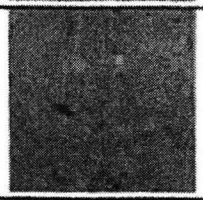
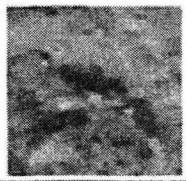
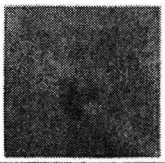
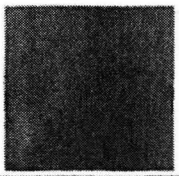
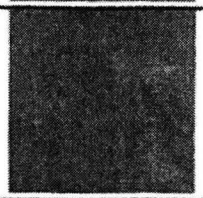
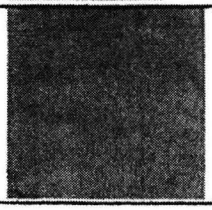
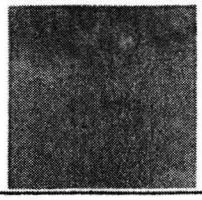
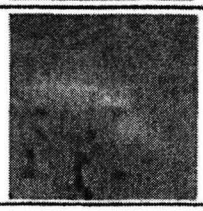
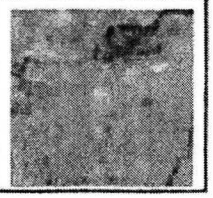
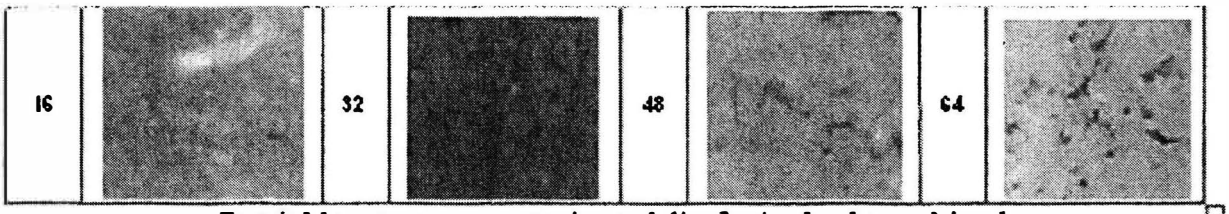
9		25		41		57	
10		26		42		58	
11		27		43		59	
12		28		44		60	
13		29		45		61	
14		30		46		62	
15		31		47		63	



Text in blue = target concentration and distribution has been achieved.