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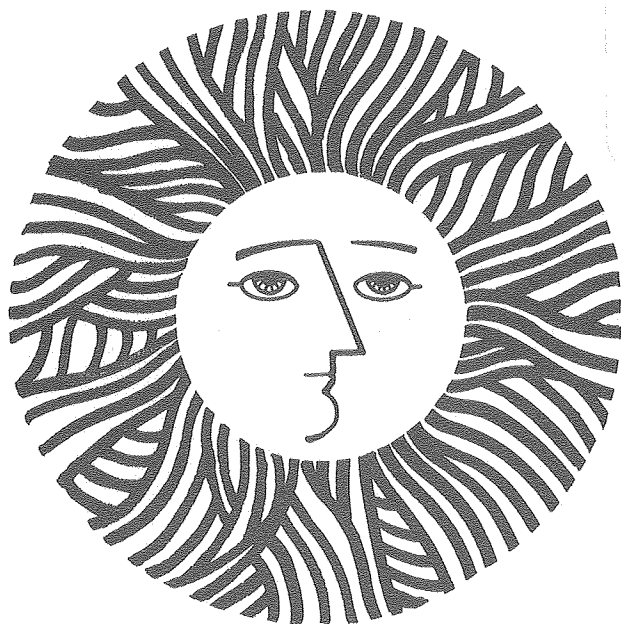
J. P. Fox, D. E. Jackson, and R. H. Sakaji

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POTENTIAL USES OF SPENT SHALE
IN THE TREATMENT OF OIL SHALE RETORT WATERS

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ABSTRACT

This paper evaluates two potential uses of spent shale for the treatment of in-situ oil shale process waters--in-situ treatment in an abandoned retort and surface treatment by columns of spent shale. Batch and column studies were conducted using four in-situ retort waters, one gas condensate, and six spent shales. The effect of spent shale contact on the organic and inorganic carbon, conductivity, and pH of the waters was determined and related to specific surface area of the shale and retort operating conditions. These studies indicate that spent shale may be used to reduce the organic and inorganic carbon, conductivity, color, and odor and to elevate the pH of retort waters and gas condensate. Spent shale reduces the inorganic carbon by 47 to 98%, the organic carbon by 7 to 66%, and elevates the pH from initial levels of 8 to 9 up to 10 to 11. TOSCO II spent shale was the best adsorbent for organic carbon, while Lurgi and simulated in-situ spent shales achieved the highest inorganic carbon reduction.

These results suggest that a packed bed of spent shale could be placed ahead of an ammonia removal step in a retort water treatment system. The increase in pH achieved by the spent shale column would convert ammonium to ammonia which could be readily stripped. The simultaneous reduction in electrical conductivity and dissolved organic and inorganic carbon by the spent shale column would decrease the load of these constituents on subsequent treatment steps.

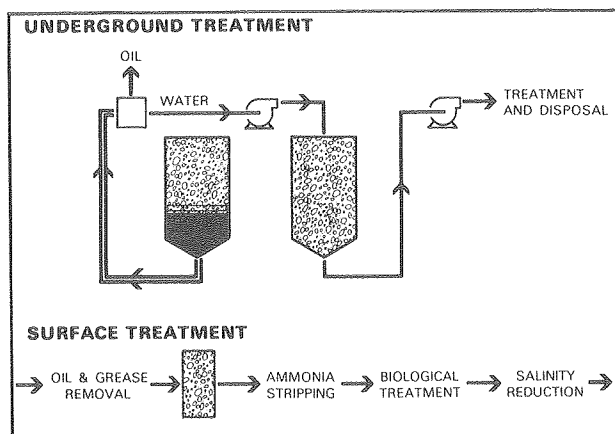
INTRODUCTION

Production of synthetic crude from oil shale generates from 16 to 3500 liters (0.10 to 22 barrels) of water and 11 to 45 Kg (25 to 100 pounds) of solid waste per barrel of oil, depending on the specific process used. The water, referred to as retort water, originates from combustion, mineral dehydration, from steam and moisture in the input gas, and from groundwater intrusion (in-situ

processes only). The organic content of retort water may reach 3% while inorganic concentrations of as much as 5% are typical. The principal organic constituents are carboxylic acids and nitrogen-containing organic compounds, and the principal inorganic components are ammonium, sodium, and bicarbonate, with lesser but significant amounts of thiosulfate, chloride, sulfate, and carbonate. The solid waste, referred to as spent shale, is a porous material that contains weight percent concentrations of sodium, calcium, magnesium, iron, potassium, and inorganic carbon. The spent shale and retort water pose a significant disposal problem for the oil shale industry.

The retort water would be a valuable resource for the arid regions in which oil shale deposits are located if effective and economical treatment methods can be found. However, past attempts to adapt conventional treatment technologies, such as anaerobic fermentation, activated sludge, and carbon adsorption, to remove organics and inorganics from retort waters indicated that these methods have serious technical and/or economic limitations. However, an observation made at Lawrence Berkeley Laboratory (LBL) during the course of other work suggested that spent shale might be used to economically reduce some organic and inorganic components of retort water.

This paper explores two potential uses of spent shale for treatment of in-situ retort waters (Figure 1). In the first application, an abandoned in-situ retort would be directly used in a treatment system. Water generated in one retort would be circulated through an adjacent spent retort to reduce contaminants in the water and to cool the in-situ spent retort in preparation for grouting. In the second application, spent shale produced in surface retorts would be used in packed columns similar to granular activated carbon columns. The exhausted spent shale would be disposed with other solid wastes in an on-site solid waste disposal facility.



XBL 805-1050

Figure 1. Potential uses of spent shale in the treatment of retort waters.

EXPERIMENTAL

The use of spent shale in the treatment of retort water was evaluated in this work by means of batch and column studies using five process waters and six spent shales. The dissolved organic carbon (DOC), dissolved inorganic carbon (DIC), electrical conductivity (EC), and pH were measured in the original waters and effluents. A gas chromatography (GC) fingerprinting technique was developed to monitor the effect of spent shale on individual organic constituents. This section describes the experimental procedures used in these investigations.

Samples

Six separate spent shales were contacted with up to five different process waters in the batch and column studies. Two types of oil shale process waters were studied, retort water and gas condensate. Major emphasis was placed on retort waters. These process waters are produced within the retort system as a vapor that is condensed out with the oil. These vapors originate primarily from combustion, dehydration of minerals, steam and moisture in the input gas, and groundwater seepage into underground retorts. Most of the oil and water in a commercial plant will be condensed before the product-collection system in an underground sump at the bottom of the retort (retort water). Entrained oil mist and the balance of the water vapor will be removed at the surface in a condenser train (gas condensate). The relative proportions and composition of each type of water depend on the exit gas temperature and product-collection system design and operation. The retort water travels down

the packed bed of shale in an emulsion with the oil, and thus may leach constituents from the shale matrix and from the oil itself. Therefore, this water is expected to contain high concentrations of some elements by virtue of its contact with the oil and shale. The gas condensate, on the other hand, leaves the retort as steam and is removed from the gas stream in the condenser train. This water will contain gaseous species not removed at the product sump such as ammonia, carbon dioxide, hydrogen sulfide, mercury, and some organics.

Five separate samples of in-situ process waters were selected for use in these studies. Pertinent retort operating conditions for each of these waters are summarized in Table 1. Most of these waters are from laboratory retorts operated to simulate in-situ conditions because very few in-situ field experiments had been conducted when this work was undertaken. The simulated in-situ retorts from which waters were collected are: Lawrence Livermore Laboratory's (LLL) 6000-Kg retort (L-2) and Laramie Energy Technology Center's (LETC) 136-tonne (150-ton) retort. Two of the samples, Omega-9 and Geokinetics, were obtained from actual field experiments. The Omega-9 sample was collected by Farrier et al. (1977) from the 1976 Rock Springs Site 9 true in-situ oil shale combustion experiment conducted by LETC (Long et al., 1977), and has been the subject of an intensive characterization program (Fox et al., 1978). The Geokinetics sample was from a horizontal true in-situ experiment at Book Cliff, Utah.

Several surface and in-situ spent shales were selected for evaluation in this work. Pertinent retort operating conditions for each of these spent shales are summarized in Table 2. The three in-situ spent shales were obtained from laboratory retorts operated to simulate in-situ conditions because no field spent shales were available. The samples studied here are from LLL's 125-kg retort (S-14), LLL's 6000-Kg retort (L-1), and LETC's 9.1-tonne (10-ton) retort (S-55). The surface spent shales are from pilot-plant operation of the Lurgi, Paraho, and TOSCO II processes.

Analytical Methods

Dissolved organic carbon (DOC) and DIC were measured by a combustion-infrared (IR) technique. DOC was measured by eliminating carbonates, combusting the sample in an oxygen stream at 950°C, and measuring evolved CO₂ with a non-dispersive IR

Table 1. Retort operating conditions and shale characteristics for in-situ process waters.

Water	Retort	Shale Source	Shale Size (cm)	Atmosphere	Maximum Temperature (°C)	Isothermal Advance Rate (m/day)
L-2 ^a	LLL 6000-Kg	Anvil Points, Colorado	0.24-5.1	air/steam	890	1.8
136-tonne (150-ton)	LETC 136-tonne (150-ton)	Anvil Points, Colorado	finer - 183	air	816	1.2
Omega-9	LETC Site 9 ^b	Rock Springs, Wyoming	--	air	c	--
Geokinetics Retort 16		Book Cliff, Utah	--	air	c	--

- a) Retort water and gas condensate were collected from run L-2. Retort water was taken from the oil collection tank between the retort and the condenser train (referred to as "L-2 High" on Figures 3 and 4) and gas condensate was taken after the 15°C condenser (referred to as "L-2 Low").
- b) See Long et al. (1977) for a process description and Fox et al. (1978) for a description of water sampling and characterization.
- c) Field retorting temperatures are not accurately known due to corrosion and other problems with thermocouples. However, mineral analyses of spent shales from Occidental field retorts suggest temperatures may locally reach 1000°C.

Table 2. Retort operating conditions for spent shales evaluated in batch and column studies.

Spent Shale	Retort	Shale Source	Shale Size (cm)	Atmosphere	Maximum Temperature (°C)	Isothermal Advance Rate (m/day)
<u>Simulated in-situ processes:</u>						
S-14	LLL 125-Kg	Anvil Points, Colorado	0.001-7.6	air/steam	1010	1.6
L-1	LLL 6000-Kg	Anvil Points, Colorado	0.001-30 + blocks	air/N ₂	995	1.7
S-55	LETC 9.1-tonne (10-ton)	Anvil Points, Colorado	finer - 61	air/steam	650	0.93
<u>Surface retorting processes:</u>						
Lurgi ^a	Lurgi	Colorado	finer - 0.3	air	530 ^a /700 ^a	--
Paraho ^b	Paraho direct	Anvil Points, Colorado	0.6-7.6 ^d	air	590	--
TOSCO II ^c	TOSCO II	Colony Mine, Colorado	finer - 1.5 ^d	air	480	--

- a) Spent shale (from electrostatic precipitator) collected from a Lurgi pilot plant operated for Amoco Oil Co. and described by York (1978). The shale was retorted at 530°C and burned at 700°C.
- b) Collected by Dr. J. S. Fruchter from the Anvil Points pilot plant operated in the direct mode. See Fruchter et al. (1979).
- c) Retorted in TOSCO retort and stored in surface disposal pile (exposed to weather) four years prior to experiment. Received from L. Ludlam, Colony Development Co.
- d) Size range is for raw shale feed--spent shale particles are smaller. Electrostatic precipitator fraction was used.

spectrophotometer. Samples were filtered through a 0.45 μm Millipore filter, diluted to less than 100 ppm total carbon, acidified to pH 2 with 85% phosphoric acid, and sparged with nitrogen for 1-2 minutes to remove carbonates. The resulting sample was injected directly into the 950 $^{\circ}\text{C}$ total carbon combustion tube of a Beckman 915A Carbon Analyzer. The DIC was determined by subtracting DOC from total carbon measured by injecting a second, untreated sample of the same water into the 950 $^{\circ}\text{C}$ combustion tube. These techniques were verified by making measurements of DOC and DIC by independent methods.

Conductivity was measured on filtered samples with a Lab-Line 11000 Mho-Meter and pH with a Corning 125 pH meter.

Surface area measurements were carried out with a Quantsorb BET apparatus. A variable mixture of nitrogen and helium was passed over the samples at liquid nitrogen temperatures. The samples were then re-equilibrated at room temperature and the nitrogen desorbed from the shale surface was monitored with a thermal conductivity detector. The resulting data were substituted in the Brunauer-Emmett-Teller equation to compute surface area.

The effect of spent shale on individual organic components was evaluated using a GC fingerprinting technique. Retort waters were extracted at alkaline and acid pH before injection into the GC. Twenty-five ml of sample were extracted with two 15 ml portions of methylene chloride. The organic fraction was dried over anhydrous Na_2SO_4 and then evaporated under dry nitrogen to approximately 1 ml. In an effort to minimize the loss of volatile constituents, no attempt was made to control solvent cooling which occurred during evaporation. The methylene chloride fraction was added to 5 ml of heptane and the mixture evaporated to a total volume of 5 ml in a stream of nitrogen. No insoluble residues were detected. Four μl of the heptane extract were injected into a 0.64 cm $\text{od} \times 1.78\text{m}$ column packed with 5% Carbowax 20M TPA on Chromosorb W. The carrier gas was high purity helium at a flow rate of 40 cc/min. A flame-ionization detector was used.

Batch Experiments

Batch experiments were used to screen several water-shale combinations. In these studies 50 g of shale and 50 ml of process water were agitated in a flask for 120 hrs. The shale was weighed,

placed in a 250 ml Erlenmeyer flask, and a measured amount of retort water was added. Flasks were sealed and placed on a mechanical shaker for varying amounts of time. Samples were obtained by filtering the entire supernatant and much of the slurried solids through a 0.45 μm Millipore filter.

Column Experiments

Two column experiments were conducted. In the first, 253.5 g of Paraho spent shale was packed into a 230 ml, 2.5 cm diameter glass Altex chromatographic column. The column was operated in an upflow configuration, and Geokinetics water was pumped through the column at a nominal flow rate of 5 ml/hr using a Sage model 375A peristaltic pump. Problems were encountered with column plugging and failure of tubing connections under pressure. The GC fingerprinting technique was used during this experiment to investigate the effect of spent shale on classes of organic compounds.

The second column experiment was conducted using L-2 spent shale and 136-tonne (150-ton) retort water to determine the number of pore volumes that can be treated before column exhaustion. A 0.91 m long, 2.5 cm ID Lucite column was packed with 18-25 mesh L-2 spent shale and operated in an upflow mode at a surface loading rate of 4.1 l/min(m^2) (0.1 gpm/ ft^2). Headloss through the column was measured by a series of pressure gauges along the column and DIC, DOC, electrical conductivity, and pH were measured in the column influent and effluent.

RESULTS AND DISCUSSION

Spent Shale Surface Area

The surface area measurements of the six spent shales are compared with activated carbon and surface areas computed from equivalent diameter spheres in Table 3. Since the surface areas of equivalent diameter spheres are two orders of magnitude lower than the measured surface areas, the measured surface area must be due to internal porosity. This is consistent with results reported by Burnham (1979a) and Sletteveid et al. (1978). Measurements of two or more particle size ranges for the surface-retorted shales indicate that, except for the Lurgi, the surface area is approximately independent of the particle size. This suggests that there is little inaccessible internal porosity, in agreement with Burnham's (1979a)

Table 3. Specific surface area of spent shales determined by N₂ adsorption.

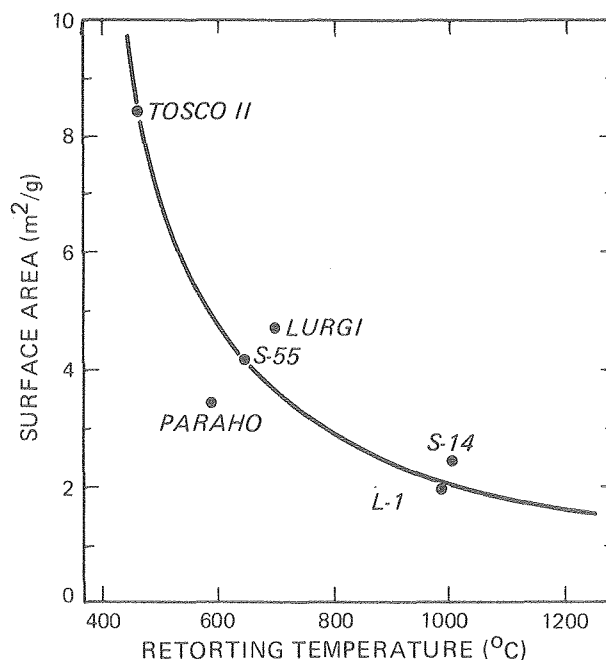
Sample	Particle Size Range (μm)	Specific Surface Area (m ² /g)	Specific Surface Area for Sphere ^a (m ² /g)
<u>Powdered Activated Carbon</u>	45	1000-1100	0.053
<u>Surface retorted</u>			
Paraho	<63	3.50	>0.038
	63-250	3.37	0.010-0.038
Lurgi	<63	4.76	>0.038
	63-250	4.77	0.010-0.038
TOSCO II	<63	6.63	>0.038
	63-250	9.20	0.010-0.038
	>250	10.19	<0.010
<u>Simulated In Situ</u>			
L-1	<250	2.10	>0.010
S-14	63-250	2.40	0.010-0.038
S-55	<300	4.20	>0.008

a) Estimated for a sphere with a diameter equivalent to the particle size range and a density of 2.5 g/cm³ from $S_w = 6/(\text{density} \times \text{diameter})$ after Stettevold et al. (1978).

results. The TOSCO II spent shale is different from the others studied. Surface area is dependent on particle size and the surface area increases for larger particles. The cause for this behavior is unknown.

The effect of retorting temperature on surface area is shown in Figure 2 which indicates that surface area decreases as the retorting temperature increases. This trend is difficult to interpret as a number of other variables, including carbon content of the spent shale and isothermal advance rate, may affect final surface area. Burnham (1979a) showed that residual carbon may make a significant contribution to spent shale surface area in samples that are not decharred. He showed that the surface area of residual carbon in spent shales ranges from 284 to 404 m²/g as determined by CO₂ adsorption (Burnham, 1979b). Although residual carbon measurements are not available for the samples studied here, it is known that the majority of the residual carbon was burned off of all of these spent shales except TOSCO II and Lurgi. The L-1, S-14, S-55, and Paraho spent shales were produced by combustion retorting, and residual carbon was partially burned to supply process heat. The majority of the residual carbon is burned off of the LLL in-situ spent shales (L-1

and S-14) which have the lowest surface areas. The surface areas measured by Burnham (1979a) by N₂ adsorption for decharred spent shales by the BET



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Figure 2. The effect of retorting temperature on surface area of spent shales.

method, 2.1 and 2.8 m²/g, are very close to the values measured here for L-1 and S-14 spent shales, 2.1 and 2.4 m²/g.

Batch Studies

The effect of spent shale treatment on dissolved organic and inorganic carbon, electrical conductivity, and pH in several process waters is summarized in Table 4. The specific adsorption ranged from 0.00 to 1.6 mg organic carbon per gram of shale. TOSCO II is the best adsorbent for organic carbon in the waters investigated, followed by Paraho spent shale. The remaining four shales, Lurgi, L-1, S-14, and S-55, are as much as an order of magnitude poorer in organic adsorptive capacity than the TOSCO II and Paraho samples. The percent reduction in organic carbon ranged from near zero for in-situ spent shales to 66% for TOSCO II shale and was the lowest for spent shales retorted at high temperatures.

(Figure 3). This effect is due to the decrease in surface area of spent shales at higher temperatures (Figure 2). There was a positive correlation between surface area and adsorption for all spent shales except Paraho. Paraho spent shale, with a relatively small specific surface area, is one of the best organic adsorbers. This suggests that the chemical nature of the spent shale surfaces may be significantly different.

The data in Table 4 also indicate that the amount of organic carbon adsorbed from solution is not controlled merely by the concentration of organic carbon remaining in the water or by saturation of the shale's adsorptive capacity, but is also a function of the chemical nature of the solute. Paraho shale, for example, adsorbs neither a consistent weight nor a consistent percentage of organics from the four process waters. This suggests that some components are adsorbed

Table 4. Specific adsorption of organic carbon and percent change in organic carbon, inorganic carbon, electrical conductivity, and pH of retort water after 120 hours of contact with spent shale in batch experiments using 50 g shale and 50 ml retort water.

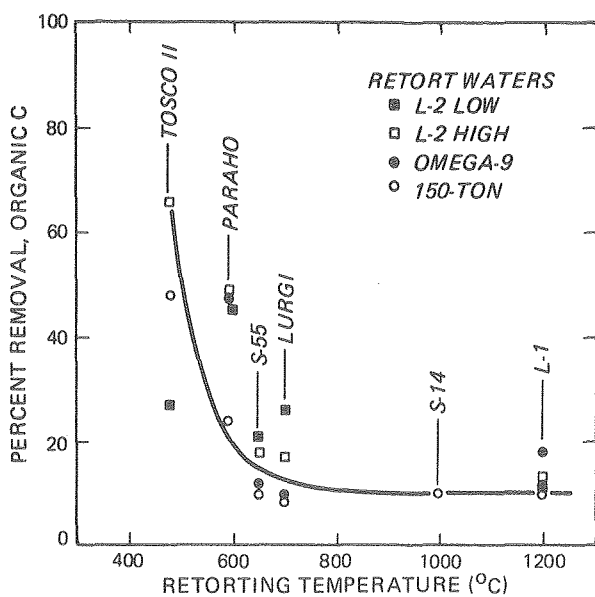
Parameters Measured in Retort Water	Initial Concentrations (mg/l)	PERCENT CHANGE ^a						
		Surface Spent Shales			In-Situ Spent Shales			
		Paraho	Lurgi	TOSCO II	L-1	S-14	S-55	
Omega-9	Organic Carbon	915	-49/0.44 ^c	NS ^b	-- ^d	-18/0.18	NS	-12/0.11
	Inorganic Carbon	3,450	-91	-98	-- ^d	-98	-98	-98
	Electrical Conductivity	26,200	-28	-6	-- ^d	-20	--	-31
	pH	8.78	+116	+119	-- ^d	+131	--	+136
L-2 Retort Water	Organic Carbon	3,300	-24/0.82	NS/0.12	-48/1.6	NS/0.12	NS	-7/0.23
	Inorganic Carbon	6,400	-89	-97	-60	-98	-97	-98
	Electrical Conductivity	36,000	-40	--	NS	-36	--	-54
	pH	8.80	+111	+110	NS	+116	--	+119
L-2 Gas Condensate	Organic Carbon	1,675	-51/0.89	-17/0.30	-66/1.1	-13/0.22	NS	-18
	Inorganic Carbon	6,660	-89	-96	-47	-97	-98	-98
	Electrical Conductivity	38,100	-54	--	--	-60	--	-60
	pH	8.66	+117	+109	--	+126	--	+123
L-2 Gas Condensate	Organic Carbon	1,300	-45/0.57	-21/0.27	-27/0.95	-11/0.16	NS	NS
	Inorganic Carbon	3,640	-91	-93	-65	-97	-99	-97
	Electrical Conductivity	24,100	-49	--	--	-54	--	-75
	pH	9.20	+111	+113	--	+121	--	+127

a) A negative value indicates that the concentration was reduced by the indicated amount while a positive value indicates an increase in the retort water.

b) No statistically significant change.

c) Specific adsorption in mg DOC/g shale.

d) TOSCO II was also evaluated with Geokinetics retort water. The specific adsorption for this combination was 1.3 mg/g and the inorganic carbon reduction was 83%. Changes in pH and conductivity were not significant.



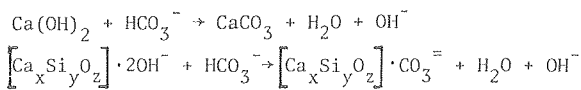
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Figure 3. The effect of retorting temperature on the percent removal of organic carbon from retort waters.

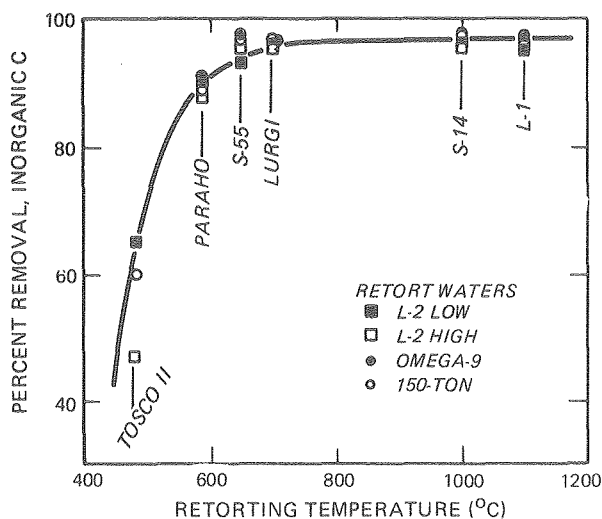
preferentially and that the organic composition of these waters varies.

Spent shale may also remove up to 98% of the dissolved inorganic carbon from process water samples. The percent reduction increases approximately linearly up to 700°C and levels off at higher temperatures to 98% (Figure 4). Spent shales with the highest organic adsorptive capacity appear to be least effective in removing inorganic carbon. Thus, Paraho and TOSCO II spent shales effect the least inorganic carbon reduction and the remaining spent shales, Lurgi, L-1, S-14, and S-55, are the most effective in this respect. The reason for the inverse relationship between organic and inorganic carbon percent reduction is unknown, but is probably related to different removal mechanisms.

The reduction in inorganic carbon is hypothesized to be due to chemical reactions between the carbonate species in retort water and hydroxides formed from the hydration of CaO and other metal oxides present in spent shale. This type of reaction can be summarized by the following equations:



This type of mechanism is consistent with the effect of spent shales on electrical conductivity and pH. The batch studies demonstrated (Table 4) that the reduction in inorganic carbon is accom-



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Figure 4. The effect of retorting temperature on the percent removal of inorganic carbon from retort waters.

panied by a decrease in electrical conductivity and an elevation in pH from initial levels of 8 to 9 to final levels of 10 to 11. The decrease in conductivity is due to the removal of dissolved inorganic carbon (i.e., carbonate and bicarbonate) and possibly ammonia from the water. The increase in pH is due to the release of hydroxide when hydrated metal species react with bicarbonate. Although not measured here, the increase in pH would convert ammonium to ammonia which could be stripped from the waters on passage through a column.

Column Studies

A preliminary column study was conducted using Paraho spent shale and Geokinetics retort water. The characteristic color and odor of retort water was almost completely removed by the spent shale column. This may be related to the removal of organic components responsible for the color and odor of these waters.

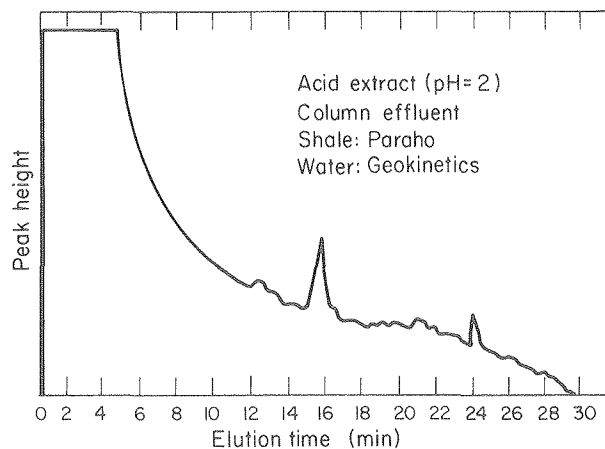
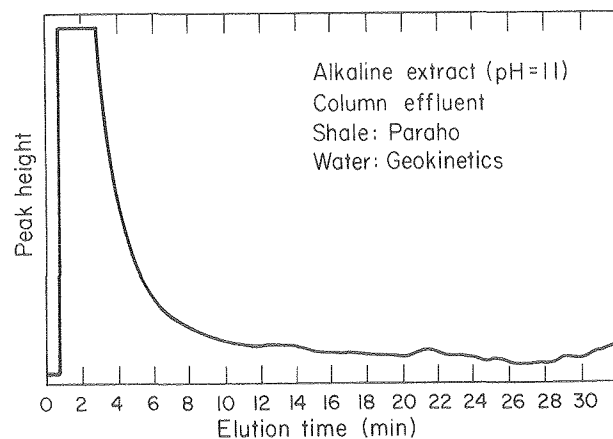
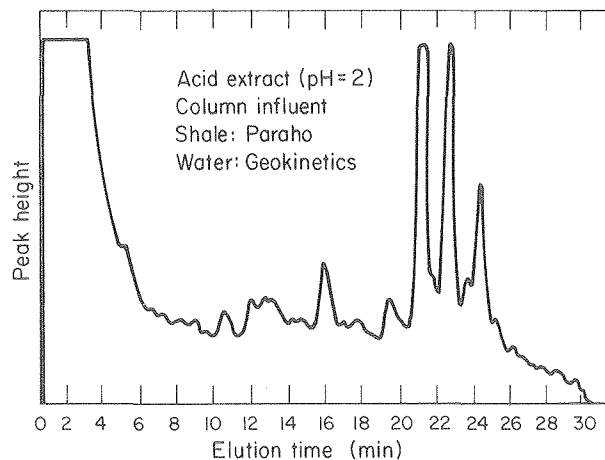
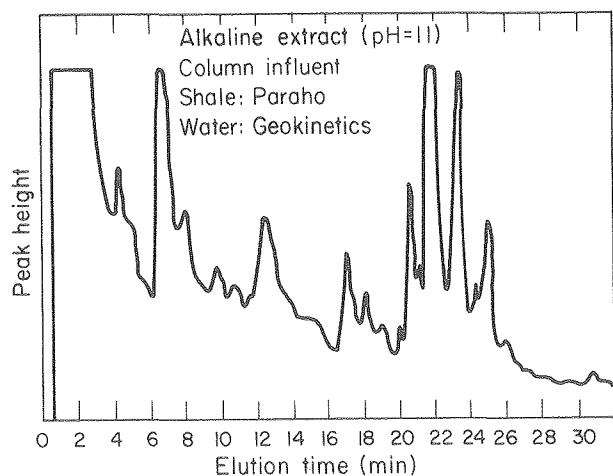
This study indicated that spent shale adsorption may not be effective for removing gross organics (dissolved organic carbon) because column breakthrough occurred before two pore volumes were treated. This means that operation and maintenance costs of a spent shale column may be excessive. However, spent shale columns may be useful for removing specific organic compounds or classes of organic compounds or for reducing color and odor.

The nature of the specific organic compounds removed by columns of spent shale was investigated spectrophotometrically and by gas chromatography.

The methylene chloride extractable components in retort water were reduced during spent shale treatment. Figure 5 shows the complete removal of basic extractables while Figure 6 shows only one major peak remaining in the acid extract. This not only demonstrates the effectiveness of spent shale as an adsorbent for at least some of the organic contaminants in retort water, but also indicates that the organic carbon that is not adsorbed is the most polar and soluble fraction. This is predictable since non-specific adsorption is inversely related to solubility. Thus, we expect that those compounds which are least soluble in water will be removed most easily from aqueous solution by adsorption onto spent shale.

The second column experiment using L-2 spent shale and 136-tonne (150-ton) retort water was conducted using refined equipment and techniques to assess the number of void volumes that could be

treated before column breakthrough occurred. The DIC and pH of the column effluent as a function of time into the run is shown in Figure 7. The dashed lines show the initial DIC and pH. The number of void volumes is shown along the x-axis by small triangles. The spent shale column achieved an initial DIC reduction of 99% which was not sustained; after three void volumes had been treated, the DIC reduction dropped to 50%. Similarly, the pH elevation capability of the spent shale was short-lived. The pH of the retort water was increased from 8.8 in the column influent to 10.4 in the initial effluent; after three void volumes had passed through the column, the pH of the column effluent dropped to 9.4. Analyses of the column effluent indicated that no organic carbon was removed by the L-2 spent shale. This is consistent with the results of the batch experiments reported in Table 4.



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Figure 5. Gas chromatography fingerprints of alkaline extracts of Paraho/Geokinetics column influent and effluent.

Figure 6. Gas chromatography fingerprints of acid extracts of Paraho/Geokinetics column influent and effluent.

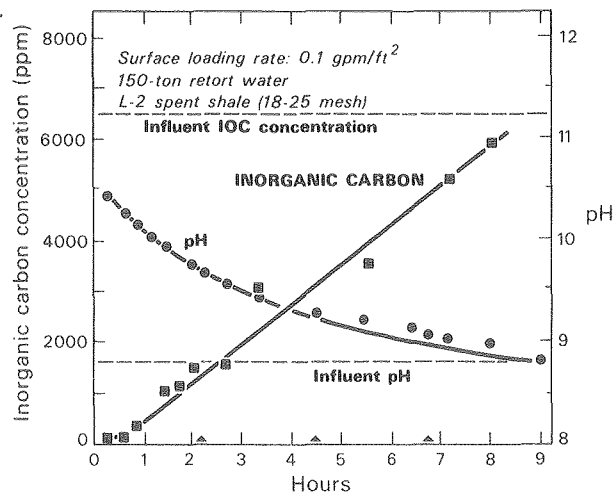


Figure 7. Effect of a column of L-2 spent shale on inorganic carbon concentration and pH of 136-tonne (150-ton) retort water.

Head loss readings taken during the column run indicate that this will not be a significant factor in determining the operational life of the column. Head loss was less than 1.5 m (5 ft) throughout the life of the column. The duration of column operation will be determined by its capacity to remove DIC and DOC and by its ability to elevate the pH of the retort water.

The short duration of pH elevation and DIC removal in the specific shale-water combination studied suggests operational life may limit the use of fixed-bed columns in retort water treatment. Additional work with other spent shales and retort waters is required to further investigate this tentative conclusion. However, the treatment of retort water with a spent shale slurry may be feasible. The spent shale could be finely pulverized (not feasible in column operation due to fluidization problems) and well-mixed to ensure good shale-water contact, thus maximizing the treatment capacity of spent shale. Experiments are currently being designed to test the slurry concept.

Application to Treatment of Retort Waters

These studies indicate that spent shale may be used to reduce the organic and inorganic carbon, electrical conductivity, color, and odor, and to elevate the pH of retort and gas condensate waters. These characteristics have important and immediate applications to the treatment of these waters. Conventionally, retort water would be treated using a system similar to that shown in Figure 8a. Oil

and grease removal would be followed by steam stripping to remove ammonia, biological treatment to reduce soluble organics, and a desalination step to remove dissolved salts. The results of this work suggest that a system similar to that shown in Figure 8b is feasible. A packed bed of spent shale could be placed ahead of the ammonia removal step. The increase in pH achieved in the spent shale column would convert ammonium to ammonia which could be removed from the water by air stripping instead of steam stripping, resulting in a cost saving. Air stripping may be cheaper than steam stripping due to reduced energy requirements. The simultaneous reduction of electrical conductivity and dissolved organic and inorganic carbon through the spent shale column would decrease the load of these constituents on subsequent treatment steps, allowing the use of smaller units. The removal of toxic organic components may improve the operation of the biological treatment system. These features of spent shale columns could result in considerable cost savings over conventional treatment systems. Similar considerations apply to gas condensate. Additional work, however, is required to study breakthrough characteristics of spent shale columns and to develop design parameters.

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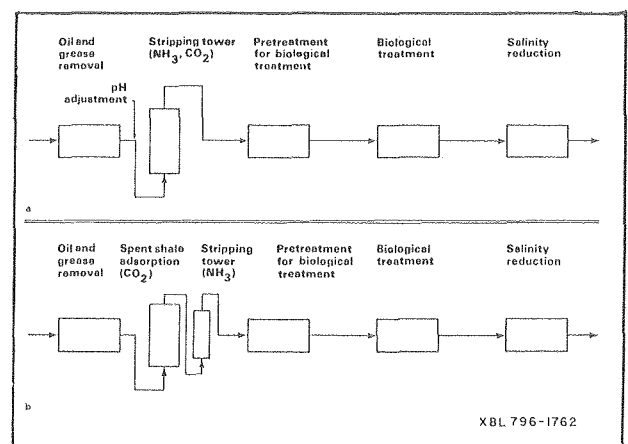


Figure 8. Proposed treatment system for upgrading retort water (a) using conventional technology; (b) using columns of spent shale.

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