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Project Summary

Field Studies on Paraho Retorted Oil Shale Lysimeters: Leachate, Vegetation, Moisture, Salinity, and Runoff, 1977-1980

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A disposal scheme for Paraho retorted shale utilizing lysimeters to simulate a low-elevation (dry site) and a high-elevation (moist site) was constructed. The study site was located in western Colorado at the Department of Energy oil shale research facility at Anvil Points. The lysimeters were constructed in 1976 and filled with retorted shale in 1977. Objectives of the study were to investigate 1) vegetative stabilization of Paraho retorted shale, as affected by leaching and soil cover treatments; and 2) moisture and soluble salt movement through the soil/shale profile.

After intensive management and four growing seasons, only a sparse (2% to 3%) cover of perennial vegetation resulted on the Paraho retorted shale. In contrast, good to excellent cover was established and maintained on the soil control and soil-covered retorted shale treatments.

Initial leaching and irrigation for plant establishment produced percolate from drains below the compacted shale zone. The percolate from the Paraho retorted shale treatment measured a maximum electrical conductivity (EC) of 35 mmhos/cm and pH of 11.4. The soil control produced percolate with a maximum EC of 8.5 mmhos/cm and a pH of 8.3. Each spring the high-elevation lysimeter received supplemental irrigation to simulate a zone of higher precipitation. Percolate produced from these irrigations exhibited a general overall reduction in both EC (33 to 11.4 mmhos/cm) and pH (11.4 to 8.6) by 1980 on the Paraho retorted shale treatment. The low-elevation lysimeters did not receive additional spring irrigations and no percolate was produced from the unleached treatments. When the constructed lysimeters were filled with freshly retorted shale a high temperature (60°C) was maintained at a 1-m depth for 30 days. Prolonged, elevated temperatures of retorted shale disposal piles could significantly affect both the amount and composition of vegetative cover.

This report deals most specifically with the collection, measurement, and interpretation of data from 1978 through 1980. A more detailed description of all measurements and analyses for 1976-1977 was reported in Harbert et al. (1979).

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

In recent years, the need to develop new energy resources within the United States has become increasingly important. In 1973, the U.S. Department of Interior estimated that the western oil shale reserves, consisting of over 64,750 square kilometers in Colorado, Wyoming, and Utah, contained over 9.5 x 10^{13} l (600 billion barrels) of recoverable crude oil. These previously undeveloped areas, used largely as range and wildlife habitats, will be subject to vast land disturbances with the development of an oil shale industry.

Various waste products will be generated by shale processing methods making it necessary to develop control technology in order to limit the environmental impact. One of the major environmental problems associated with oil shale development is the disposal of the massive amounts of waste material produced. The U.S. Department of Interior (1973) estimated that a mature oil shale industry of 1.6 x 10^8 l of oil/day (one million barrels oil/day) would generate approximately 20,000 ha-m/year of waste material with surface retorting methods. Part of this waste might be returned to mined areas, but a large proportion would require surface disposal. Not only the large volume, but also the chemical and physical characteristics of the waste will create challenges for the development of control technology.

Thus, the following study was initiated to evaluate a variety of intensive management techniques and practices for the disposal of processed oil shale. A model was designed to simulate the disposal of Paraho retorted shale (direct-heated) at both a low-elevation (dry site) and a high-elevation (moist site). Lysimeters were constructed to measure both the quality and quantity of percolate which might result from a processed shale disposal pile. Various treatments such as leaching and soil cover were used to investigate the establishment of vegetative cover on the Paraho retorted shale.

Methods and Materials

In 1976, a series of concrete lysimeters were constructed to aid in modeling a disposal scheme for Paraho retorted (direct-heated) oil shale. The lysimeters were designed to simulate a canyon fill disposal site having the following features:

1. The back face of the canyon fill gently sloped (2% to 5%) upstream.
2. The front face of the dam steeply sloped (25% to 50%) downstream.
3. The body of the disposal pile highly compacted.
4. The exposed surface of either uncompacted retorted shale or soil-covered retorted shale of a sufficient depth to provide adequate plant rooting and moisture storage.

A study site was selected at the U.S. Department of Energy, Anvil Points Research Facility in western Colorado. The study site, on public land managed by the Bureau of Land Management, was characteristic of a semi-arid, low-elevation disposal site, with an elevation of 1737 m, and an average annual precipitation of 28 cm.

Two identical sets of lysimeters were constructed at this site. One set was used to simulate the natural low-elevation site, while the other was to simulate a high-elevation disposal site. Because of proximity to water, electricity, retorted shale, and construction supplies, both sets of lysimeters were built at the low-elevation site. Sprinkler irrigations simulated the increased precipitation associated with a high-elevation site.

The following replicated treatments were tested with each lysimeter set on both a 2%, north-aspect slope, and 25%, south-aspect slope:

1. Paraho retorted shale, leached.
2. 20 cm soil cover over Paraho shale, leached.
3. 40 cm soil cover over Paraho shale, unleached.
4. 60 cm soil cover over Paraho shale, unleached.
5. 80 cm soil cover over Paraho shale, unleached.
6. Soil control, unleached.

Each of the treatments, except the soil control, contained 90 cm of compacted Paraho retorted shale, covered with uncompacted shale, and various amounts of soil cover (for some treatments) to equal a total profile depth of 240 cm. Drains were built into the lysimeters at both the interface of the compacted and uncompacted zones and beneath the compacted zones.

During the filling operation, temperature measurements of the retorted shale were made with a thermocouple probe. A series of thermocouples were later used to measure surface temperatures throughout the 1977 and 1978 growing season.

The lysimeters were instrumented with tensiometers, piezometers, neutron probe access tubes, and salinity sensors to monitor the water and salt movement through the uncompacted zones. Tensiometers were installed at 15, 30, 60, 90, 120, and 150 cm depths to measure soil and shale matric potential for 1977. The tensiometer data were used by other researchers for a hydrological modeling study, and are not included in this report (Chandler, 1979). Piezometers were installed to a depth of 150 cm (the interface of the compacted and uncompacted zone) and read during the 1977 season. Neutron probe access tubes were also set to a depth of 150 cm. Monthly readings of soil moisture by volume were taken during each growing season. Salinity sensors were placed at depths of 15, 30, 60, 90, 120, and 150 cm. Because of erratic readings, the use of the sensors was discontinued in 1978.

The subsurface drain system within each treatment area was fitted with a plastic container for collecting leachate, an electric sump pump, and a totalizing flow meter to measure both the rate and volume of leachate from the lower drain. Any percolate from the upper drain, in the interface area, was collected in a plastic can.

A surface runoff collection system for each treatment plot consisted of a metal gutter, pipe, and a culvert with a plastic container. The system was completed in 1977 and used to collect snowmelt runoff and summer storm runoff of later seasons.

Details on the leaching, fertilization, and seeding of the treatments, are provided in the main report. Vegetative analysis for 1977 was done by the quadrat method to determine vegetative cover. For vegetative measurements 1978-1980 the line-transect method was used. Vegetative cover as well as species composition was determined.

In September of 1977, core samples were taken from various treatments in 20-cm increments to a depth of 160 cm. These samples were analyzed by the CSU Soil Testing Laboratory for common cations and anions, pH, and EC. Core samples were again taken in the fall of 1979 for EC analysis.

Ambient air temperature, precipitation, and pan evaporation have been monitored since establishment of the lysimeters.

Results and Discussion

The SAR (Sodium Adsorption Ratio) is a measure of the ratio of sodium to calcium and magnesium of soils or waters and estimates the dispersion potential posed by exchangeable sodium, when soluble salts are leached. A potential sodium dispersion problem may exist when SAR values exceed 15. The SAR value of the Paraho retorted shale suggested such a problem. Other analyses indicated that the retorted shale would require fertility amendments for successful vegetative growth. While plant-available phosphorus was low for the retorted shale (as well as the soil), potassium seemed adequate, but nitrate-nitrogen was low.

Wet-Dry Cycles

After filling of the lysimeters was completed, a series of wetting and drying cycles were used to reduce the pH of the retorted shale. Although the pH was successfully reduced from 11.4 to 9.2, the EC increased from 4 to 6.1. The increase in EC was probably due to the greater solubility of Ca and Mg salts at a lower pH. Apparently, the amount of carbonate decomposition was minimal with the Paraho direct retorting process, and this allowed rapid recarbonation of the retorted shale. The pH of the retorted shale would likely have decreased with the natural weathering process.

Retorted Shale Temperature

Temperatures of the retorted shale in the uncompacted zone were monitored with a thermocouple probe following the filling of the lysimeters in 1977. Although a sharp drop in the temperature of the shale (230 to 64-80°C) occurred within 10 days after placement, an additional 30 days was required for the shale to drop below 60°C at the 1-m recording depth. This suggested that a droughty site could develop if freshly retorted shale was covered with soil before cooling. A xeric site would significantly affect both the amount and composition of vegetation cover.

Vegetation

The quadrat method was used for the first year of growth in 1977 to estimate germination and establishment. The line-intercept method was used in later years to provide more quantitative measurements. The Paraho retorted shale treatments supported only a very minimal (2% to 3%) perennial vegetative cover (Table 1). Observations of the few perennial species on the Paraho shale indicated severe stunting and physiological stress. Caution must be advised when comparisons of total vegetative cover between the Paraho retorted shale and other treatments are made. Values as high as 48% vegetative cover on the Paraho retorted shale, 2%-slope, north-aspect of the high-elevation lysimeters must be carefully scrutinized. This vegetative cover was almost completely composed of annual species such as kochia. This annual was at its vegetative peak when measured and with its extremely short-lived habit, left the treatment almost totally bare and exposed by mid to late summer.

After four growing seasons the inability of shrubs (where seeded, on the low-elevation lysimeters) to either increase in number or size was observed on the soil-covered Paraho retorted shale treatments.

Trace Elements in Vegetation

In 1977 and 1978, plant samples were collected from the lysimeter plots for trace element analyses. Large stands of alfalfa were present as a result of seed introduced with the hay mulch, so this species was sampled. Overall, molybdenum levels of plants from Paraho retorted shales were judged to be high (11.5 to 23.5 ppm Mo) (Kilkelly and Lindsay, 1979). This, combined with low to moderate copper levels, could limit the use of this vegetation for animal forage.

Moisture

In a semi-arid region where seasonal precipitation seldom exceeds evapotranspiration, percolation and water movement within a pile of retorted shale should be limited, provided a satisfactory vegetative cover exists. In this study, seasonal precipitation over a four-year period provided a spring recharge of approximately 20% moisture by volume (to depths of 60 to 120 cm). Those treatments with a good vegetative cover were reduced to approximately 10% moisture by volume by fall. The moisture extracted during the growing season by vegetation resulted in a renewal of reservoir capacity to contain yearly precipitation, especially spring snowmelt. Without satisfactory vegetative cover, moisture within the profile could be moved downward with each yearly recharge and pollution of ground water could result.

Each year, since establishment, irrigation of the high-elevation lysimeters produced percolate from the lower drain of most treatments. The purpose of the extra irrigation was to simulate a region of higher elevation where seasonal precipitation exceeded the evapotranspiration of the native plant community. The collection and analysis of percolate from these treatments could then be used for predicting the potential for environmental pollution.

The Paraho retorted shale, despite leaching, continued to support far less vegetative cover than other treatments, thereby reducing the extraction of surplus moisture in the profile. Moisture recharge and depletion patterns between other treatments were similar, with the greatest amount of moisture used by the dense vegetative cover on the soil control.

Runoff

The first year that runoff samples were collected from the newly established lysimeters was 1978. The runoff was of low salinity hazard.

Runoffs from south slopes of both high- and low-elevation lysimeters were measured and samples were collected on March 8, 1979. Recorded runoff for south slopes was greater than for north slopes due to the fact that snowmelt was slower on the north side and the slope more gradual. Samples of runoff collected on March 22 were sent to the CSU Soil Testing Laboratory for water quality analyses (Table 2). The salinity hazard for all samples was low to medium, while the sodium hazard was low.

Spring snowmelt in 1980 resulted in runoff only from north slopes. Field observations indicated that the ground on the north slopes was frozen with a thin covering of ice. The south slope ground was thawed, allowing moisture to enter the soil or shale, resulting in little runoff. The low sodium and salinity hazard combined with the negligible sediment yield suggested that the runoff never actually came in contact with the soil or shale surface, but merely ran over the layer of ice. No runoff from summer storms resulted.

Percolate

In 1977, after some treatments were leached, both high- and low-elevation lysimeter studies were irrigated to aid the establishment of vegetation. Only the high-elevation lysimeter study received additional irrigation in the early spring of 1978 and 1979. These differences were designed to study both the quantity and quality of the percolate resulting. In 1980, percolate from the high-elevation lysimeters resulted from

Table 1. *Vegetative Cover by Species Composition for Paraho Retorted Shale, Soil-Covered Paraho Retorted Shale, and Soi Control, 1978-1980*

		High-Elevation Lysimeter					
		2% Slope North Aspect			25% Slope South Aspect		
Treatment	Species Categories	1978	1979	1980	1978	1979	1980
		%					
Paraho Retorted Shale	Perennial grasses	19	5	3	14	6	2
	Shrubs	2	—	—	—	—	—
	Other	29	46	48	26	48	39
20 cm Soil Cover/Paraho	Perennial grasses	59	72	31	60	71	47
	Shrubs	—	—	—	—	—	—
	Other	2	11	15	8	21	9
40 cm Soil Cover/Paraho	Perennial grasses	57	63	32	49	65	46
	Shrubs	—	—	—	—	—	—
	Other	5	39	13	4	30	16
60 cm Soil Cover/Paraho	Perennial grasses	47	60	43	44	67	40
	Shrubs	—	—	—	—	—	—
	Other	7	29	24	5	31	13
80 cm Soil Cover/Paraho	Perennial grasses	40	59	29	39	73	46
	Shrubs	—	—	—	—	—	—
	Other	16	27	22	10	26	11
Soil Control	Perennial grasses	86	93	33	73	95	29
	Shrubs	—	—	—	—	—	—
	Other	14	2	—	19	2	2

		Low-Elevation Lysimeter					
		2% Slope North Aspect			25% Slope South Aspect		
Treatment	Species Categories	1978	1979	1980	1978	1979	1980
		%					
Paraho Retorted Shale	Perennial grasses	8	<1	<1	2	<1	—
	Shrubs	1	1	2	5	3	3
	Other	6	24	24	15	27	19
20 cm Soil Cover/Paraho	Perennial grasses	42	18	7	26	31	23
	Shrubs	2	2	1	3	—	—
	Other	23	80	61	39	38	48
40 cm Soil Cover/Paraho	Perennial grasses	45	28	12	41	20	17
	Shrubs	<1	—	—	2	<1	2
	Other	18	69	59	19	61	47
60 cm Soil Cover/Paraho	Perennial Grasses	39	22	13	47	16	12
	Shrubs	3	3	2	<1	<1	—
	Other	29	62	51	12	79	43
80 cm Soil Cover/Paraho	Perennial grasses	59	48	25	45	22	13
	Shrubs	3	2	4	2	<1	1
	Other	8	24	33	11	57	43
Soil Control	Perennial grasses	45	51	20	61	52	22
	Shrubs	4	6	3	15	18	10
	Other	33	29	30	8	14	20

- This species category was not observed on line-transects used for analyses of vegetation.

seasonal snowmelt alone; no supplemental irrigation was made. Only data from the lower drains, below the compacted zone, are discussed since 99% of the total volume of percolate was collected from these drains.

Total cumulative volumes for all treatments of both the high-elevation lysimeter and low-elevation lysimeter are shown in Table 3. Only the Paraho retorted shale on the 25% slope of the high-elevation lysimeter produced one pore volume of leachate. Percolate volumes from other treatments were generally limited. The objective of supplying additional irrigation water, on a yearly basis, to the high-elevation lysimeter was to evaluate the quantity and quality of percolate which might result from a processed oil shale disposal pile at an elevation where seasonal precipitation exceeded evapotranspiration and resulted in percolate.

After the initial leaching and irrigation for plant establishment (which resulted in a minimal amount of percolate) no further irrigation was applied to the low-elevation lysimeters. In these treatments, the vegetation was able to deplete the plant-available moisture in the profiles of most treatments, allowing a reservoir for spring recharge. Consequently, a significant amount of percolate did not result in later years.

Because of the limited percolate volume from most treatments, the EC values fluctuated considerably. The maximum EC was not always associated with the initial percolate from a particular lysimeter, nor were minimum EC values associated with the final percolate flowing from a lysimeter. Overall, however, a general drop in EC values was observed for treatments through which greater amounts of water had passed, such as the Paraho retorted shale, 25% slope, of the high-elevation lysimeter. In 1977, maximum EC values for leachate from this treatment were 31.0 mmhos/cm, dropped to 15.1 mmhos/cm by 1979, and returned to 23.9 mmhos/cm in 1980. Much greater volumes of water leached through the lysimeters would be required in order to stabilize the chemical composition of the percolate.

Laboratory analyses of the initial percolate collected in 1977 are reported in Table 4. Analyses for EC, pH, TDS, and common cations and anions were made in order to judge the quality of the percolate.

The percolate collected from the lower drains of the lysimeters had a

Table 2. *Water Quality Analyses of Spring Snowmelt Runoff from the High-Elevation and Low-Elevation Lysimeters, North-Aspect, 2% Slope, March 22, 1979*

	High-Elevation		*Low-Elevation*		
	20 cm Soil Paraho	*40 cm Soil Paraho*	*Paraho Retorted Shale*	*80 cm Soil/ Paraho*	
	H6	*H10*	*L4*	*L18*	*L20*
Runoff (cm)	0.22	0.17	0.16	0.12	0.26
pH	6.9	7.1	7.3	7.7	7.4
EC (µmhos/cm)	280	620	280	500	390
Na (meq/l)	0.7	2.1	0.6	2.2	1.3
Ca (meq/l)	0.9	1.0	0.6	1.0	1.0
Mg (meq/l)	0.9	1.0	1.8	1.0	0.6
K (meq/l)	0.2	0.5	0.2	0.7	0.3
CO_3 (meq/l)	0	0	0	0	0
HCO_3 (meq/l)	1.3	2.2	1.6	2.1	2.1
NO_3 (meq/l)	0.3	0.02	0.06	0.15	0.03
SO_4 (meq/l)	0.7	2.6	1.3	1.6	1.0
Cl (meq/l)	0.5	1.8	0.5	1.5	1.0
SAR	0.7	2.1	0.6	2.2	1.4
Salinity Hazard	low	low-med	low	low	low
Sodium Hazard	low	low	low	low	low

Table 3. *Total Percolate Volume from the Lysimeter Study, 1977-1980*

Treatment	*Slope*	*1977*	*1978*	*1979*	*1980*	*Total*
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High Elevation						
Paraho Spent Shale	2%	9,513.8	4,149.1	903.1	0	14,566.0
	25%	34,110.4	8,527.6	7,171.8	318.7	50,128.5
20 cm Soil/Paraho	2%	2,179.0	462.5	223.7	0	2,865.2
	25%	24,636.6	8,658.2	5,969.3	91.2	39,355.3
40 cm Soil/Paraho	2%	447.4	1,092.7	817.6	0	7,357.7
	25%	3,860.7	5,969.0	5,059.0	22.7	14,911.4
60 cm Soil/Paraho	2%	0	107.1	0	0	107.1
	25%	1,308.9	2,879.6	2,487.9	0	6,676.4
80 cm Soil/Paraho	2%	0	946.3	199.1	0	1,145.4
	25%	1,771.8	4,087.0	3,384.2	0	9.243.0
Soil Control	2%	219.0	1,105.2	12.0	0	1,336.2
	25%	5,649.1	5,216.5	4.0	0	10,869.6
Low Elevation						
Paraho Spent Shale	2%	1,042.6	5.0	15.0	0	1,062.6
	25%	706.8	0	0	0	706.8
20 cm Soil/Paraho	2%	771.4	20.0	5.0	0	796.4
	25%	4,638.5	180.0	60.0	0	4,878.5
40 cm Soil/Paraho	2%	0	0	0	0	0
	25%	0	0	0	0	0
60 cm Soil/Paraho	2%	0	0	0	0	0
	25%	0	0	0	0	0
80 cm Soil/Paraho	2%	0	0	0	0	0
	25%	0	0	0	0	0
Soil Control	2%	0	0	0	0	0
	25%	0	0	0	0	0

Table 4. *Laboratory Analyses of the Initial Percolate from the High-Elevation Lysimeter, 1977*

	Percolate from Retorted Shale			Percolate from Soil		
	6/8/77	6/17/77	9/2/77	8/1/77	8/23/77	8/31/77
EC, µmhos/cm	12,983	27,222	10,500	4600	5100	5100
pH	6.3	7.1	7.0	7.5	8.2	8.3
TDS, ppm	14,328	31,984	*	*	*	*
SAR	52.8	116.8	30.0	10.8	9.7	9.7
Cations, meq/l						
Ca	16.4	23.0	17.4	8.8	6.9	5.4
Mg	9.0	5.1	1.5	8.5	21.4	19.8
Na	148.8	429.3	90.0	31.5	36.1	34.0
K	11.2	45.1	11.3	2.9	1.1	1.0
Anions, meq/l						
Cl	30.6	28.2	4.8	11.5	17.1	15.3
SO_4	157.7	449.6	119.0	35.6	37.5	36.2

*Not determined.

high soluble salt content from passing through 2.4 m of retorted shale. It can be predicted from these values that water moving through a retorted shale pile, several hundred meters thick, could be extremely saline.

Laboratory analyses also indicated that the SAR of the percolate was high. This suggested that the percolate could create soil dispersion problems in irrigated agriculture. The soil control produced percolate with a moderate SAR, increasing the possibility of a sodium dispersion problem in such soils if contaminated with retorted shale percolate.

Water Balance

Water balance calculations were made for all treatments of both lysimeters for the 1977 season (Harbert et al., 1979). An attempt was made to account for the total volume of water applied to each treatment by estimating various inputs and losses. Inputs of moisture were fairly well defined and limited, such as precipitation and irrigation. Losses were more difficult to measure and estimate, such as percolation, moisture storage in the profile, and evapotranspiration.

For all of the leached treatments, amounts of water applied could not be accounted for by a summation of losses as they were measured or estimated. A water balance for the unleached treatments resulted in just the opposite, in that water losses were calculated to be greater than water inputs. The moisture measurements for the soil control most nearly balanced inputs and losses. Other researchers have addressed the problem of water balances for the lysimeter study (Chandler, 1979).

Conclusions

Chemical and Physical Characteristics of Paraho Retorted Shale

1. After four wetting-and-drying cycles, the pH of Paraho retorted shale surface samples was reduced from 11.2 to 9.0.
2. After leaching, the Paraho retorted shale soluble salt content was reduced from 7.1 mmhos/cm to 3-4 mmhos/cm.
3. The unleached treatments averaged approximately 10 mmhos/cm throughout the retorted shale profile, although, there was no indication of upward migration of soluble salts by 1979.
4. Laboratory analyses of 1977 core samples suggested that imbalances of calcium, magnesium, and sodium might inhibit plant growth on the Paraho retorted shale.
5. Surface temperatures reach 80°C on south slopes of the black-colored Paraho retorted shale. This might be lethal to seedlings, while increasing surface evaporation.

Vegetation

1. After four growing seasons, perennial vegetation on the Paraho retorted shale remained minimal (2% to 3% cover).
2. A good to excellent vegetative cover was established and maintained on the soil control and soil-covered, retorted shale treatments, with western wheatgrass as the predominant species.
3. Differences between varying amounts of soil cover, with respect to vegetative cover, were insignificant.
4. Shrubs seeded on the low-elevation lysimeters were unable to significantly increase in either number or size over four growing seasons, indicating limited root tolerance for the Paraho retorted shale.

Percolate

1. Ninety-nine percent of the total percolate collected from all treatments was from the lower drain, under the compacted zone.
2. Core samples taken later suggested that moisture had moved through both the uncompacted and compacted profile.
3. Abrupt textural changes from the fine-textured soil to the coarse-textured Paraho retorted shale below, delayed the uniform downward movement of moisture through the profile.
4. Irrigation (except for 1980) of the high-elevation lysimeters resulted in percolate each spring.
5. Only the treatments which had been leached (Paraho retorted shale and 20-cm soil/Paraho retorted shale) of the low-elevation lysimeters produced percolate.
6. On unleached treatments of the low-elevation lysimeters moisture did not move below 105 cm.

Water Quality

1. The maximum EC of percolate from the Paraho retorted shale was 35 mmhos/cm.
2. Overall, a decrease in percolate EC after four years was observed, however, EC values fluctuated considerably.
3. If water moves through the Paraho retorted shale a high pollution potential exists, with respect to EC and SAR values measured.
4. Greater total pore volumes must pass through the lysimeters before the chemical composition of the percolate stabilizes.

Disposal Pile Temperatures

1. The freshly retorted shale used in this study maintained 60°C temperatures for 30 days.
2. Prolonged, elevated temperatures could significantly affect both the

amount and composition of vegetative cover on disposal piles.

Recommendations

1. Because of the unsuitability of the Paraho retorted shale as a direct plant growth media, soil cover is recommended for successful establishment of vegetation on the retorted shale.
2. Poor establishment and growth of the fourwing saltbush suggested limited root penetration into the Paraho retorted shale. Additional studies are needed to evaluate root growth in retorted shale.
3. Efforts should be made to prevent movement of water through the retorted shale as leach water poses a pollution potential due to high soluble salt content.
4. Research is needed to insure that the compacted shale can be made impervious since, in this study, moisture moved through Paraho retorted shale compacted to a density of 1.5 to 1.6 g/cm^3.
5. Elevated temperatures maintained in the retorted shale disposal pile might adversely affect the establishment of vegetation. Further investigation under commercial disposal pile conditions is recommended.
6. The present fluctuations in chemical composition of leachate from the lysimeters require that additional pore volumes of water are needed to evaluate leachate quality.

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The complete report, entitled "Field Studies on Paraho Retorted Oil Shale Lysimeters: Leachate, Vegetation, Moisture, Salinity, and Runoff, 1977-1980," (Order No. PB 81-234 742; Cost: $9.50, subject to change) will be available only from:

National Technical Information Service
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