

Oil Shale Water Pollutants

Introduction

The types and amounts of water contaminants that are likely to be produced by major kinds of oil shale facilities are discussed here,

Water Pollutants Produced by Major Oil Shale Processes

Types and Origins of Pollutants

The following summarizes the major sources of each class of waterborne contaminants found in oil shale facilities.

- **Suspended solids** will occur primarily in water from the dust-control systems used in shale mining and crushing operations. Mine drainage water will also contain suspended solids, as will a retort condensate stream that picks up fine shale particles as it trickles down through the broken shale. In aboveground retorts, some fine shale may be entrained in the retort gas and captured in the gas condensate, but levels should be low, thus should not be a problem to treat. Cooling water will pick up dust from the atmosphere, particularly if the cooling tower is near a shale crushing or disposal site. Precipitated salts and biological matter may also be present in the cooling tower blowdown.
- **Oil and grease** will be present in the retort condensate water that is removed from the in situ retort together with the product oil. Some oil remains in the water after product recovery and must be removed prior to further treatment. Part of the oil forms an emulsion in the water and its removal may be difficult. ¹ Volatile hydrocarbons leave with the retort offgas and condense in the gas condensate water. Tests indicate that the oil in the gas condensate occurs in well-defined droplets that can be separated without difficulty. ² Oils in the coker and hydrotreater condensates are expected to be similar to those in the gas condensate.
- **Dissolved gases** include all of the NH_3 and some of the CO_2 and H_2S formed in the retorting process. These gases dissolve in the retort and gas condensates. Any NH_3 and H_2S that are formed during upgrading will appear in the hydrotreater condensates.
- **Dissolved inorganic** will be found in mine drainage water and retort condensates because these streams leach sodium, potassium, sulfate, bicarbonate, chloride, calcium, and magnesium ions from the shale that they contact. ³ In addition, some inorganic volatilize and may be captured from the gas phase in the retort. Of the heavy metals present in raw oil shale, cadmium and mercury (probably as their respective sulfides) are expected to be present in the gas condensate in low concentrations. ⁷ An analysis of TOSCO II gas condensate water showed the presence of cyanide, sodium, calcium, magnesium, silica, and iron ions, with only trace amounts of some of the heavy metal elements. ⁵
- **Dissolved organics** arise largely from the organic compounds in the raw oil shale, which may be altered during pyrolysis and end up in the retort, gas, or hydrotreater condensates. The types of organics in each condensate will probably depend on the volatility and volubility of the organics and the temperature at which the wastewater is condensed. No data are available on this subject but it is known that a wide range of compounds, particularly carboxylic acids and neutral compounds, can be expected. ⁶ Many of the individual compounds should be biodegradable, but studies have shown that less than 50 percent of the organic matter can be removed by conventional biological oxidation. This poor performance is attributed to the effect of toxic compounds on waste-treatment bacteria. Both inorganic and organic toxic substances may be responsible. The specific types of toxic pollutants will differ with the retorting process and with raw shale composition. ⁷⁸⁹
- **Trace elements and metals** are not expected to occur in large concentrations in the major waste streams except those streams dis-

cussed under dissolved inorganics.^{10 11} Chromium was used for corrosion control in older cooling-water systems but other agents are now available and should be used to avoid the problem of chromium contamination of blowdown streams. If trace element and metal removal is required, chemical treatment, specific ion exchange, and membrane processes are available.

- **Trace organics** are toxic or hazardous organic compounds present in low concentrations. They may occur in the retort and gas condensate streams and in the wastewater stream from the upgrading section. These constituents can generally be removed together with other dissolved organics by ultrafiltration with carbon adsorption for final cleaning (“polishing”).
- **Toxics**, including carcinogens, mutagens, priority pollutants, and other hazardous-sub-

stances, have been reported for various types of oil shale processing wastes. Any toxic substances present in the wastewater streams will be removed along with the trace organics or inorganic substances. It is not expected that thermal oxidation, which is often employed to destroy hazardous organic compounds, will be required for the wastewater streams, although it may be considered for concentrates or sludges. However, the presence of toxic substances may interfere with biological oxidation processes used for bulk organic removal. If this is a problem, the substances could be removed in any of several conventional pretreatment steps.

- **Sanitary wastes** in “domestic” and service waste streams can be kept separate and treated in commercially available package biological treatment units.

The Amounts of Pollutants Produced

Table C-1 indicates the principal contaminated process streams and their flow rates for four commercial-scale [50,000 bbl/d]* oil shale facilities. These facilities correspond to the plants for which water requirements are estimated in chapter 9. The “aboveground direct” plant uses directly heated aboveground retorts like the Paraho direct or gas combustion. The “aboveground indirect” uses indirectly heated retorts like TOSCO II. It is similar to the design proposed by Colony Development. The “MIS” plant uses Occidental’s

MIS process. It is similar to the design proposed by Occidental and Tenneco for tract C-b. The “MIS/aboveground” plant combines Occidental’s MIS process-with Lurgi-Ruhrgas indirectly heated aboveground retorts. It is similar to Rio Blanco’s design for tract C-a.

The flow rate estimates were derived from tables 71, 74, and 75. (See ch. 9.) Estimates have been added for the internally recycled gas washing and hydrotreater wash streams that were not considered in chapter 9. (The water availability

*Barrels per stream day.

Table C-1 .--Flow Rates of Contaminated Streams in Oil Shale Facilities Producing 50,000 bbl/d of Shale Oil Syncrude (acre-ft/yr)

	Aboveground direct	Aboveground redirect	MIS	MIS/aboveground
Cooling tower blowdown	1,550-1,820	1,320-2,070	1,040-1,280	910-1,130
Boiler blowdown ...	325	370-405	370	350
Boiler feedwater treatment wastes	165	190-210	185	180
Gas washing condensate ..	1,070-1,190	(a)	3,320-3,640	2,270-2,500
Gas condensate (net) ..	490-540	730-800	2,160-2,370	1,480-1,630
Retort condensate,	(a)	(a)	1,240-1,370	850-940
Coker condensate. . .	60	60	60	60
Hydrotreater wash condensate	875	875	875	875
Net hydrotreater condensate			40	40
Excess mine drainage	(a)	(a)	0-10,000	0-10,000

^aNeglected for processes designs or sites considered

SOURCE R F Probst, H Gold, and R E Hicks, *Water Requirements, Pollution Effects and Costs of Water Supply and Treatment for the Oil Shale Industry*, prepared for OTA by Water Purification Associates October 1979

analysis presented there deals only with streams that cross the project boundaries.) These additional streams are of significance for water quality analysis because they contain all of the NH_3 , most of the CO_2 , and some of the H_2S that is removed from gas streams in the plants. Flow rate ranges are shown in some cases to account for the expected variations in shale grades and plant designs, as discussed in chapter 9. The following points should be noted with respect to the flow rate estimates.

- Cooling tower blowdown varies substantially among the plants, largely because of different modes of power generation.
- Boiler blowdowns are fairly uniform because it is assumed that boilers will generate steam for use in the upgrading units, which are identical for all four plants.
- For the same reason, all four plants have the same flow rates for coker condensate, hydro-treater wash condensate, and net hydro-treater condensate.
- Excess mine drainage is indicated for the MIS and MIS/aboveground plants because it was assumed that they would be located in the ground water areas of the Piceance basin. The other two plants were assumed to be located in drier areas (e.g., in the Uinta basin or along the edge of the Piceance basin).
- No retort condensate is shown for the AGR plants because it was assumed that condensation in the retort would be avoided by adjusting the operating temperature. A large

value is shown for the MIS retort condensate because of unavoidable condensation in the lower portions of the MIS retorts. The value for MIS/aboveground is a weighted average of Lurgi-Ruhr gas (no condensate) and MIS (large quantities of condensate).

- Large values are also shown for gas condensate and gas washing condensate in all systems except the aboveground indirect. In the aboveground direct and the two MIS operations, large quantities of moist retort gas must be treated, resulting in large volumes of condensate. Much of the moisture is a combustion product. In contrast, the above-ground indirect has no combustion within the retort and produces less gas that must be cooled and cleaned.

In table C-2, estimates are presented of the concentrations of contaminants in the condensate streams. It is important to note that extensive data on contaminant concentrations are not available for the process condensate streams and that published measurements show considerable variation. Only the estimate for the aboveground indirect gas condensate is based on extensive field measurements.¹³ The other values are consistent with material balance calculations and information from the literature but they are at best approximate. Moreover, only concentrations of major contaminants are shown. Trace contaminants, including most toxic elements, are not indicated because information on their occurrence is even more limited. Although toxic elements are not ex-

Table C-2.—Contaminant Concentrations in Oil Shale Process Condensate Streams (mg/l)^a

Contaminant	Gas condensate			Retort condensate	Hydrotreater condensate
	Aboveground direct	Aboveground redirect	MIS or MIS/aboveground	MIS or MIS/aboveground	All plants
N	17,990 ^c	5,150	21,330 ^c	720	41,000 ^d
H	206 ^c	810	118 ^c	—	18,000 ^c
C	32,400 ^c	6,150	41,800 ^c	9,940	None
Calcium	Low ^f	6	Low	20	Low
Magnesium	Low	2	Low	17	Low
Potassium	Low	0.4	Low	100	Low
Sodium	Low	5	Low	3,600	Low
Chloride	Low	5	Low	280	Low
Fluoride	Low	0.3	Low	39	Low
Boron	Low	Low	Low	25	Low
Sulfate	Low	Low	Low	1,200	Low
Organic carbon	—	6,100	—	—	—
BOD	10,000	10,000	2,200	2,220	10,000

^aTrace elements and organics for which data are unavailable are not shown

^bBicarbonate and carbonate concentrations reported as CO_2 equivalent

^cInternal acid wash before gas separation and wash recycle

^dBased on available data or estimates

^eBiochemical oxygen demand estimated at one half of the theoretical oxygen demand

SOURCE R. F. Probst, H. Gold, and R. E. Hicks, *Water Requirements, Pollution Effects and Costs of Water Supply and Treatment for the Oil Shale Industry*, prepared for OTA by Water Purification Associates, October 1979

pected to be present to any significant extent in the gas condensates, some could be present in the MIS retort condensate. ”

The hydrotreater condensate concentrations were developed for Colony’s upgrading unit, but they should be typical of values for any facility (MIS or aboveground) that processes Green River shale oil. A retort condensate is shown only for the MIS and MIS/aboveground facilities, for reasons mentioned previously. Significant differences are indicated for the three gas condensate streams with respect to NH₃, H₂S, and CO₂ concentrations. The aboveground indirect stream is much lower in CO₂ and NH₃ because of the lack of combustion (which produces soluble CO₂ and NO_x gases) in the retort. H₂S concentration is higher in the aboveground indirect stream because there is little oxygen available in the retort to oxidize the H₂S to SO₂. A lack of data prevents evaluation of process-related effects on concentrations of other contaminants.

In table C-3, the likely rates of pollutant production are shown for the gas condensate streams.

Table C-3.—Production Rates for Principal Pollutants in Gas Condensate Streams (ton/d)^a

Contaminant	Type of facility			
	Aboveground direct	Aboveground Indirect	MIS	MIS/aboveground
N	75.6	147	276	189
H ₂ S ^b	0.87	2.3	15	1.1
CO ₂	136	17.5	541	371
BOD ^c	19.2	28.5	185	127

^aTons per stream day for production of 50000 bbl/d shale oil syncrude

^bAdditional sulfur is recovered directly from the retort gas

^cBiochemical oxygen demand

SOURCE R F Probst, H Gold, and R E Hicks *Water Requirements, Pollution Effects, and Costs of Water Supply and Treatment for the Oil Shale Industry* prepared for OTA by Water Purification Associates, October 1979

The values shown were obtained by multiplying the flow rates in table C-1 by the pollutant concentrations in table C-Z. Only a single value is shown for each contaminant in table C-3 and in the other pollutant production-rate tables that follow. The rates shown were calculated for average stream flows wherever a range is shown in table C-1. This approximation is justified because the uncertainty in pollutant concentrations is larger than the relatively narrow range shown for the flow rates. These uncertainties result from a paucity of published data, and also because large differences can occur in some plants with different feed waters and process designs.

Table C-4 indicates the pollutant production rates for the retort condensate streams produced

Table C-4.—Production Rates for Principal Pollutants From MIS Retort Condensates (ton/d)^a

Contaminant	Type of facility	
	MIS	MIS/aboveground
N	349	2.40
H ₂ S	—	—
CO ₂	48.2	33.1
Calcium	0.10	0.07
Magnesium	0.08	0.06
Potassium	0.49	0.33
Sodium	17.5	12.0
Chloride	1.36	0.93
Fluoride	0.19	0.13
Boron	0.12	0.08
Sulfate	5.82	3.99
Biochemical oxygen demand	10.07	7.32

^aTons per stream day for production of 50000 bbl/d shale oil syncrude

SOURCE R F Probst, H Gold, and R E Hicks *Water Requirements, Pollution Effects, and Costs of Water Supply and Treatment for the Oil Shale Industry* prepared for OTA by Water Purification Associates, October 1979

in MIS retorting. It is assumed that retort condensates are produced only with MIS processing. These condensates leach inorganic salts from shale in the retort, as indicated by the contaminant production rates shown.

Table C-5 shows the production rates for the principal contaminants in the process waste waters generated in the upgrading portion of the Colony design. This is the only plant for which an upgrading section has been described in the literature. Since shale oils produced by different retorts are not markedly different in their nitrogen and sulfur contents, it is reasonable to apply the pollutant production estimates for the TOSCO H upgrading section to all of the facilities considered.

In table C-6, the pollutant production rates for all of the process condensate streams are combined. It can be seen that the biochemical oxygen demand (BOD) does not have a wide range between facilities. This is in large measure a result

Table C-5.—Production Rates for Principal Pollutants in Upgrading Condensates (ton/d)^a

Contaminant	Waste stream	
	Hydrotreater condensate	Coker condensate
NH ₃	133	1.15
H ₂ S	58.6	0.18
CO ₂	0	1.37
Biochemical oxygen demand	1.49	2.23

^aTons per stream day for production of 50,000 bbl/d shale oil syncrude Based on a TOSCO H process design. Similar values anticipated for the other process models

^bAdditional sulfur is recovered directly from the retort gas

SOURCE R F Probst, H Gold, and R E Hicks *Water Requirements, Pollution Effects, and Costs of Water Supply and Treatment for the Oil Shale Industry*, prepared for OTA by Water Purification Associates, October 1979

Table C-6. —Sum of the Production Rates for Principal Pollutants in Retorting and Upgrading Condensates (ton/d)^a

Contaminant	Type of facility			
	Above-ground direct	Aboveground indirect	MIS	MIS/aboveground
NH ₃	210	149	414	326
H ₂ S	597	611	603	599
CO ₂	137	189	591	405
BOD ^b	229	322	329	237

^aTons per stream day for production of 50,000 bbl shale oil/syncrude

^bAdditional sulfur is recovered directly from the retort gas

^cThis does not represent total CO₂ production; CO₂ is also generated in combustion and lost up the gas stacks as in the MIS/aboveground process and in steam and power production

^dBiochemical oxygen demand

SOURCE R. F. Probst, H. Gold and R. E. Hicks, *Water Requirements, Pollution Effects and Costs of Water Supply and Treatment for the Oil Shale Industry*, prepared for OIA by Water Purification Associates, October 1979

of the BOD concentrations assumed. The H₂S production, which represents about a third of the total sulfur recovered in the plant, varies little among the different facilities. This is reasonable, since the amount of sulfur removed per unit of shale oil produced should be similar for the different processes. However, this H₂S includes only that amount that dissolves in the condensate streams; it does not include the gas that goes directly to the sulfur recovery units.

The most striking estimate in table C-6 is the extremely high CO₂ production rate for the MIS facility. The rate for the aboveground indirect facility is lowest because decomposition of carbonate minerals to CO₂ is much less at the lower retorting temperatures (about 900°F or 500°C) than in the higher temperature (about 1,500°F or 800°C) MIS or aboveground direct processes. The rate is highest for MIS because the shale remains at high temperatures for a long time, thus allowing nearly complete decomposition of the carbonates. The combined MIS and AGR facility shows a correspondingly lower value—a weighted average of MIS and Lurgi-Ruhrgas rates. It should be emphasized that CO₂ is also produced by combustion in the indirect AGR plant, which does not show up in the condensate streams because it is lost directly up flue gas stacks. However, even if this gas were included, the ratio of CO₂ produced in MIS or aboveground direct to that in indirectly heated retorting would still be large.

Differences in NH₃ production rates also result from combustion in MIS and directly heated aboveground retorts. The aboveground indirect process produces the least NH₃ because it is essentially one of pyrolysis in which the nitrogen is mostly obtained from the organic matter in the shale. In fact, almost all of the NH₃ that will be produced in the indirectly heated AGR will be

manufactured in the upgrading section when nitrogen is removed from the crude shale oil by hydrotreating. Differences in BOD yields are not statistically significant, given the lack of precision in the data base.

In order to calculate pollutant concentrations in cooling tower blowdown and waste streams from boiler feedwater treatment, it is necessary to know the raw water composition to the plant. Table C-7 shows the raw water compositions assumed for this assessment. The surface water quality is that of the Colorado River near Cameo, Colo., and the mine drainage water is a composite of the expected quality of water to be drawn from the bedrock aquifers of the Piceance Basin.^{15*} The raw water compositions are only approximate.

Table C-8 presents the estimated composition of the cooling tower blowdown of four facilities

*The bedrock aquifer system, and other water resources in the oil shale region, are described in ch. 9.

Table C-7.—Composite Water Quality Data for Colorado River Water and Mine Drainage Water in the Piceance Basin (mg/l)

Contaminant	Source of process water	
	Surface water	Mine drainage water
NH ₃	—	1.2
Bicarbonate	168	750
Boron	—	3
Calcium	72	50
Carbonate	—	50
Chloride	205	20
Fluoride	—	15
Magnesium	19	60
Phenol	—	25 x 10 ⁻³
Silica	7	15
Sodium	153	300
Sulfate	158	350
Total dissolved solids	734	1,350

SOURCE R. F. Probst, H. Gold and R. E. Hicks, *Water Requirements, Pollution Effects and Costs of Water Supply and Treatment for the Oil Shale Industry*, prepared for OIA by Water Purification Associates, October 1979

Table C-8.—Estimated Concentrations of Principal Contaminants in Cooling Tower Blowdown (mg/l)

Contaminant	Type of facility	
	AGR with surface water supply	MIS retorting with mine drainage water supply
Calcium	215	200
Chloride	615	80
Fluoride	—	60
Magnesium	60	240
Sodium	460	1,200
Sulfate	840	1,400

SOURCE R. F. Probst, H. Gold and R. E. Hicks, *Water Requirements, Pollution Effects and Costs of Water Supply and Treatment for the Oil Shale Industry*, prepared for OIA by Water Purification Associates, October 1979

considered, based on an average of three cycles of concentration for AGR (surface water supply) and four cycles of concentration for MIS retorting (mine drainage water supply). The relatively low numbers assumed for concentration cycles are based on the assumption that all of the blowdown water is needed for solid waste disposal. Under this assumption there is no advantage to the more costly procedure of using a larger number of cycles.

Table C-9 gives the estimated composition of the waste streams from treating the raw supply

Table C-9.—Estimated Concentrations of the Principal Contaminants in an Ion Exchange Regenerant Waste Stream From Boiler Feedwater Treatment^a (mg/l)

Contaminant	Type of facility	
	AGR with surface water supply	MIS retorting with mine drainage water supply
Calcium	950	660
Chloride	2,400	790
Magnesium	250	4,600
Sodium	990	2,200
Sulfate	2,080	3,460

^aVolume of regenerant wastewater assumed to be approximately 75 percent of the volume of treated water

SOURCE R F Probst, H Gold, and R E Hicks, *Water Requirements, Pollution Effects, and Costs of Water Supply and Treatment for the Oil Shale Industry*, prepared for OTA by Water Purification Associates, October 1979

water by ion exchange to obtain a high-quality water for boiler feed. The estimates assume the removal of all the calcium, magnesium, and sulfate ions from the supply water. Most of the other ions will also be removed but only the principal ones are shown for the waste streams. The waste volume is about 7.5 percent of the water treated. This corresponds to a fairly efficient ion exchange treatment system. Boiler blowdown waste composition is not shown because the quality of this water is usually equivalent to that of the raw water entering the plant. It can therefore be mixed with the raw water and used as a makeup source.

Table C-10 gives the estimated pollutant production rates in the cooling tower blowdown and boiler waste treatment streams based on the compositions of tables C-8 and C-9. Also shown are the total production rates from these two sources; the streams would usually be combined in the plant and used for solid waste disposal. There is not a great deal of difference in the total quantities of pollutants produced by the facilities considered.

In table C-1 it was assumed that oil shale mines in ground water areas might result in production of from 0 to 10,000 acre-ft/yr of excess mine drainage water for a 50,000-bbl/d in situ facility. At this time, it is not known whether the water will be treated for discharge to surface streams,

Table C-10.—Production Rates for Principal Pollutants in Cooling Tower Blowdown and Boiler Treatment Wastes (ton/d)

Contaminant	Aboveground direct	Aboveground indirect	MIS	MIS/aboveground
Calcium	1.35	1.36	0.86	0.76
Chloride	3.85	3.88	0.35	0.30
Fluoride	—	—	0.26	0.23
Magnesium	0.38	0.38	1.04	0.91
Sodium	2.88	2.90	5.18	4.55
Sulfate	5.26	5.29	6.04	5.31
Boiler treatment wastes				
Calcium	0.58	0.71	0.45	0.44
Chloride	1.47	1.79	0.54	0.53
Magnesium	0.15	0.19	3.16	3.08
Sodium	0.61	0.74	1.51	1.47
Sulfate	1.28	1.55	2.38	2.32
Total				
Calcium	1.93	2.06	1.32	1.20
Chloride	5.33	5.66	0.89	0.83
Fluoride	—	—	0.26	0.23
Magnesium	0.53	0.56	4.20	3.99
Sodium	3.49	3.64	6.69	6.02
Sulfate	6.54	6.84	8.42	7.63
Total	17.82	18.76	21.78	19.90

SOURCE R F Probst, H Gold, and R E Hicks, *Water Requirements, Pollution Effects, and Costs of Water Supply and Treatment for the Oil Shale Industry*, prepared for OTA by Water Purification Associates, October 1979

or reinfected into the aquifer from which it was drawn. The question has economic as well as environmental implications. If it is to be discharged, then it must be treated, and wastewater streams will be produced that will require management and disposal. The level of treatment is not known at present. In DRI's analysis of the costs of environmental protection, "less strict" and "more strict" pollutant discharge criteria were assumed.¹ In table C-1 their estimates are given for the total quantities of pollutants produced by treatment for surface discharge of 10,000 acre-ft/yr of excess mine drainage water of the quality shown in table C-7 for the less strict and more strict regulations. These quantities could be appropriately scaled down or up for different rates of drainage-water production. The effect of the different standards on the total quantity of pollutants produced is not large. However, the costs of achieving the "more strict" criteria would be much higher.

Table C-1.—Rates of Pollutant Production From Treatment of 10,000 acre-ft/yr of Excess Mine Drainage Water for Surface Discharge

Contaminant	Regulatory scenario			
	"Less strict"		"More strict"	
	% Removal	Ton/d	% Removal	Ton/d
N H ³	85	004	91.7	004
Bicarbonate	77	21.47	94.3	2630
Boron	70	008	98.2	011
Calcium	99	184	99.9	1.86
Carbonate	90	1.67	95.8	1.78
Chloride	94	070	99.6	074
Fluoride	90	050	99.0	055
Magnesium	99	221	99.9	223
Silica	83	046	96.7	054
Sodium	94	10.49	99.7	11.12
Sulfate	97	1262	99.9	1300
Total		5208		5827

SOURCE: Adapted from T. D. Nevens et al. (DRI Water Purification Associates and Stone and Webster Engineering) *Predicted Costs of Environmental Controls for a Commercial Oil Shale Industry, Volume I: An Engineering Analysis*, Department of Energy, July 1979.

Appendix C References

¹D. S. Farrier, Division of Environmental Sciences, Laramie Energy Technology Center, Department of Energy, Laramie, Wyo., personal communication, July 1978.

²R. F. Probst, H. Gold, and R. E. Hicks, *Water Requirements, Pollution Effects, and Costs of Water Supply and Treatment for the Oil Shale Industry*, prepared for OTA by Water Purification Associates, October 1979, p. 81.

³Environmental Protection Agency, *A Preliminary Assessment of the Environmental Impacts From Oil Shale Development*, prepared by TRW and DRI under contract No. 68-02-1881 (EPA-600/7-77-069), July 1977.

⁴J. P. Fox, K. K. Mason, and J. J. Duvall, "Partitioning of Major, Minor, and Trace Elements During Simulated In Situ Oil Shale Retorting in a Controlled-State Retort," *Proceedings of the Twelfth Oil Shale Symposium* (J. H. Gary, ed.), Colorado School of Mines Press, Golden, Colo., 1979, pp. 58-71.

⁵F. C. Haas, "Analysis of TOSCO II Oil Shale Retort Water," paper presented at ASTM Symposium D-199.33 on Analysis of Wastes Associated With Alternative Fuel Production, Pittsburgh, Pa., June 4-5, 1979.

⁶Ibid.

⁷E. W. Cook, "Organic Acids in Process Water From Green River Oil Shale," *Chemistry & Industry*, May 1, 1971, p. 485.

⁸G. W. Dawson and B. W. Mercer, "Analysis, Screening and Evaluation of Control Technology for Wastewater Generated in Shale Oil Development," *Quarterly Reports, Battelle Pacific Northwest Laboratory, Richmond, Wash.*, January 1977-March 1979.

⁹Water Purification Associates, *A Study of Aerobic Oxidation and Allied Treatments for Upgrading In Situ Retort Waters*, contract No. EW-78-C-20-0018 with Laramie Energy Technology Center, Department of Energy, Quarterly Status Report, August 1979.

¹⁰E. F. Bates and T. L. Thoen (editors), *Pollution Control Guidance for Oil Shale Development*, Revised Draft Report, Environmental Protection Agency, Cincinnati, Ohio, July 1979.

¹¹Supra No. 4.

¹²Supra No. 5.

¹³Ibid.

¹⁴Supra No. 4.

¹⁵Denver Research Institute, *Predicted Costs of Environmental Controls for an Oil Shale Industry; Volume I—An Engineering Analysis*, prepared for the Department of Energy under contract No. IZP-78-S-02-5107, July 1979.

¹⁶Ibid.