APPENDIX D

Technologies for Managing Point Sources of Wastewater

Introduction

This appendix describes the wastewater streams that will be produced in oil shale facilities, including leachates from solid waste disposal. The physical, chemical, and biological treatment devices and systems are then described, Finally, developer plans are reviewed to show how water supply, wastewater treatment units and systems, and methods of disposition might be combined into comprehensive water management schemes for commercial-scale oil shale facilities.

Oil Shale Waste Streams That Will Require Treatment

The major point source streams that will require treatment are:

- excess mine drainage water—principally for plants near the center of the Piceance basin;
- retort condensates—especially and perhaps exclusively for in situ operations;
- gas condensates—for all systems;
- coker and hydrotreater condensates from all plants that have onsite upgrading or refining operations; and
- streams from service operations—including boiler feedwater treatment wastes and cooling tower blowdown.

The other streams are either relatively small or relatively clean and consequently require little treatment. They include boiler blowdown, rain and service water runoff, and sanitary wastes. Sanitary wastes will certainly need treatment, but they should be similar to typical domestic wastes and can easily be handled in commercially available biological u-nits.

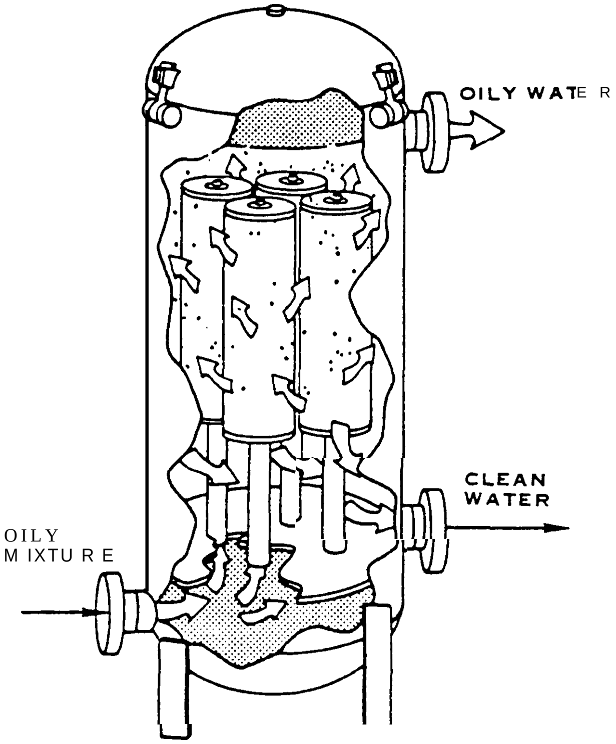
Leachate from spent or raw shale piles on the surface is not considered as a separate stream requiring treatment during the operating life of the plant. With proper compaction and irrigation, water will be either retained in the pile or lost by evaporation. There should therefore be little accumulation of leachates. [1] There will be storm and snowmelt runoff, but this will be in limited quantities and will have a low salt content.[2] The small quantity of water that may percolate through the pile after intentional leaching can be expected to be low in both organic and inorganic substances,] This water can be used for dust control in raw shale crushing operations and will thus find its way back to the retort, Leachate from spent in situ retorts poses a potential problem of unknown magnitude, Design concepts for its control are discussed in chapter 8.

Individual Methods for Point Source Wastewater Treatment

Physical Methods

- **Gravity separators** are used to treat nearly all oily wastewaters. They are especially common in refineries and chemical plants. The simplest are impingement-type devices such as API separators, corrugated plate interceptor separators and parallel plate interceptor separators. These devices are very inexpensive and reliable but they can be used only for first-stage oil removal. Additional treatment is usually needed before the wastewater can be sent to sensitive treatment systems like biological oxidizers.
- **Coalescing cartridge separators** (figure D-1) are more effective devices that can reduce oil concentrations to as low as 1 mg/l. In this type of separator, oily wastewater is pumped through a coarse filter medium within the cartridges, causing oil droplets and some mechanically emulsified oil to coagulate into large globules which float to the top of the separator

Figure D-1 .—Cartridge-Type Coalescing Oil-Water Separator

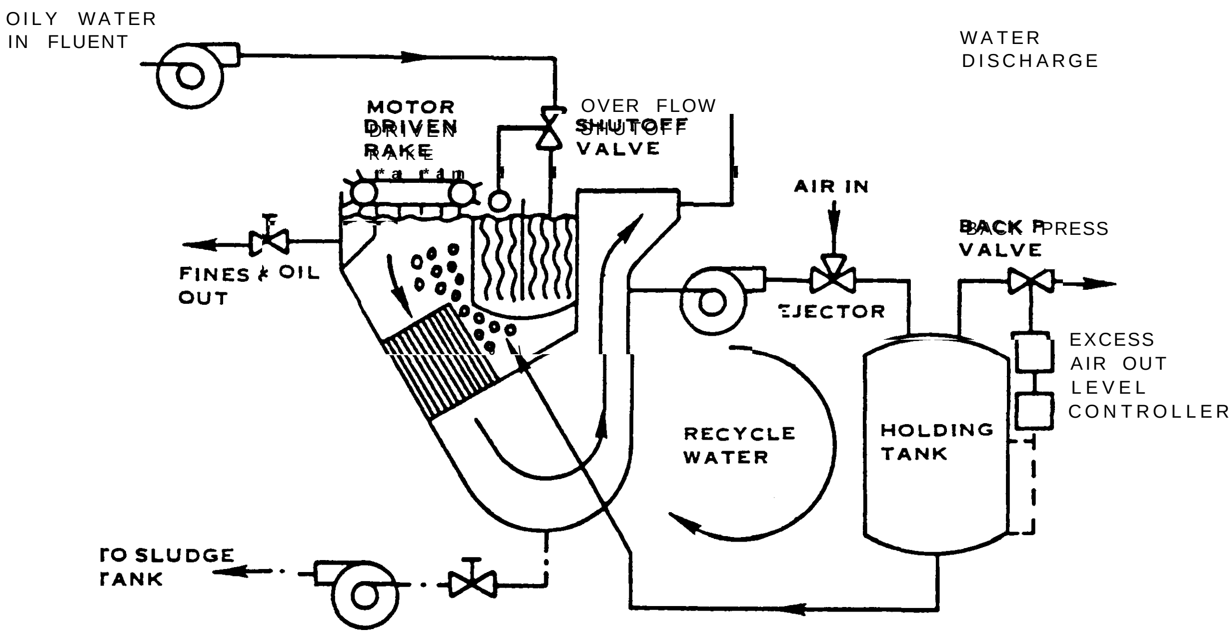


SOURCE. *Assessment of Oil Shale Retort Wastewater Treatment and Control Technology,* Hamilton Standard Division of United Technologies, July 1978, p 5-3.

and are removed. These devices have high removal efficiencies but tend to clog if the water contains suspended particles. They can also be fouled by growth of micro-organisms on the filter medium.

- **Air flotation** is even more effective but is relatively complex. One device—the dissolved air flotation cell—is shown in figure D-2. In this separator, air is injected into the oily wastewater as fine bubbles, The oil droplets adhere to the air bubbles and rise to the surface as a froth, which is skimmed off by a motor-driven rake, Some small suspended particulate contaminants can also be removed in the froth and others will settle to the bottom of the cell and can be removed as a sludge. Coagulant can also be added to aid removal efficiency. If lime is added, for example, it will precipitate some heavy metals and certain anions such as carbonates.
- **Clarification** [also called coagulation/sedimentation or precipitation/sedimentation) may be used to settle out oil, to remove suspended solids, or to precipitate toxic metals, carbonate, and other anions. A slant-tube clarifier is shown in figure D-3. Accumulation of oil droplets and particulate on the tubes greatly enhances separation of the materials compared with the performance of simpler gravity devices, Chemicals can also be added in an up-

Figure D-2.— Dissolved Air Flotation



SOURCE: *Assessment of Oil Shale Retort Waste water Treatment and Control Technology,* Hamilton Standard Division of United Technologies, July 1978, p. 5-3.

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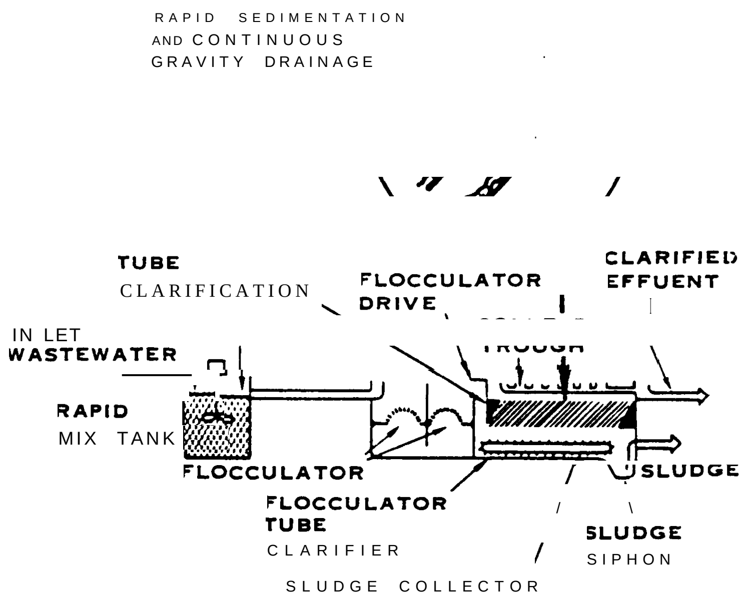
Figure D-3.—Clarification and Precipitation



SOURCE: *Assessment of* **Oil** *Shale Retort Wastewater Treatment and Control Technology,* Hamilton Standard Division of United Technologies, July 1978, p. 5-3

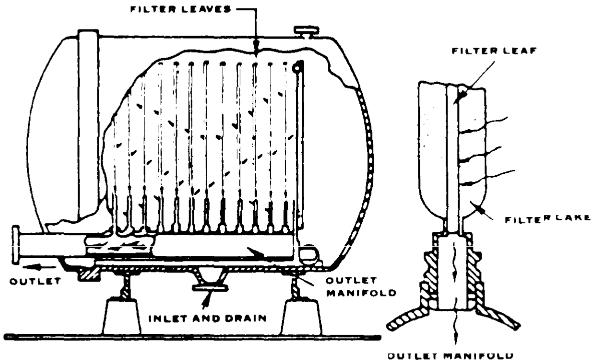
stream mixing tank to aid precipitation (such as sodium hydroxide) or coagulation (such as alum or a polyelectrolyte).

- **Filters** can be used to remove particles and in some cases oil. Some of the more common filtering devices are shown in figure D-4. Pressure filters are generally automatic devices in which the contaminated water is sucked inwards through a series of leaves on which a filter cake forms. The filter may be used to remove particles from dilute wastewaters as the first stage in a treatment system, or it can be used to dewater the sludge products from other separators. The filter cake is generally very low in moisture, which eases disposal problems.

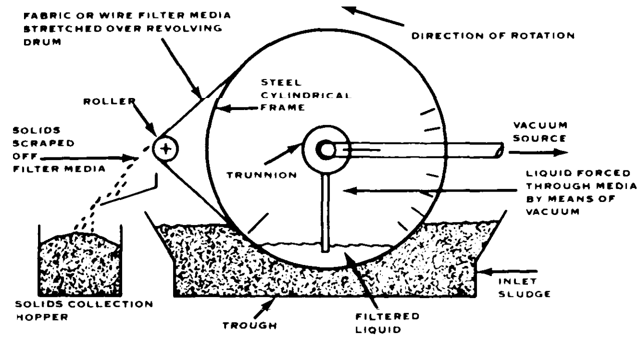
  Vacuum filtration can also be used to remove suspended particles from wastewater but is more suitable for dewatering concentrated streams and sludges. Two vacuum devices are shown in figure D-4, In the rotary vacuum filter, a rotating drum dips into a trough filled with wastewater, and suction is applied to the inside of the drum. Water is drawn through the perforated surface of the drum and solids are deposited on the outside as a filter cake. As the drum rotates, the dewatered sludge is scraped off and falls into a receiving trough. **A** filter press is functionally similar except that the wastewater is sucked or pumped through a series of plate-and-frame assemblies. The dewatered sludge is periodically removed from the filter medium by mechanical cleaning. Ultrafiltration, in which the wastewater is forced through a membrane, is often used for separation of oil and water. It is generally limited to separation of chemically stabilized emulsions and is not suitable for mechanical emulsions.

  In multimedia filters, granular materials such as sand forma filtering bed through which the wastewater is pumped. The water passes through a series of layers with granules of increasingly fine size, The collected solids are subsequently removed by backflushing with clean water. This filter produces a sludge, rather than a dry cake, which requires additional dewatering before disposal. The multimedia filter is generally more economical than pressure filters for high flow rates and dilute slurries.
- **Stripping** with steam (figure D-5) or with air or flue gases is used to remove NH_3 and sulfide gases from wastewater. The operation is carried out in a packed column or a plate column, and two-stage processing is sometimes employed to provide independent recovery of NH_3 and sulfuric acid, If the stripper is part of a treatment system that includes biological treatment, some NH_3 is usually left in the stripper product to act as a nutrient for the micro-organisms.

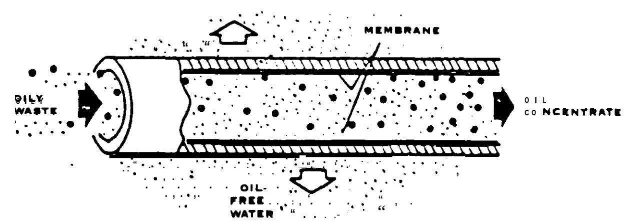
Figure D-4.—Filters for Wastewater Treatment



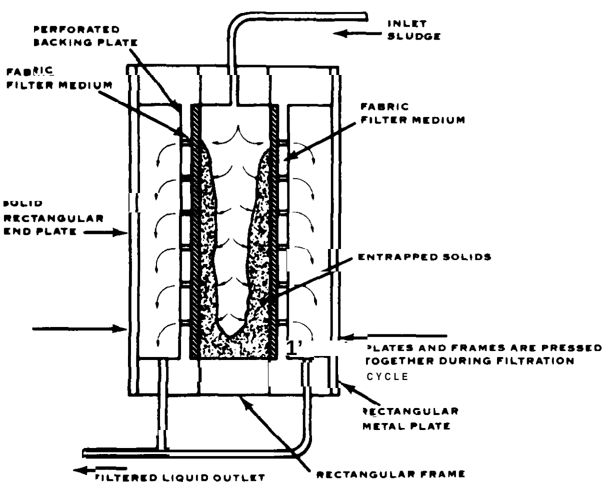
A. Pressure filter



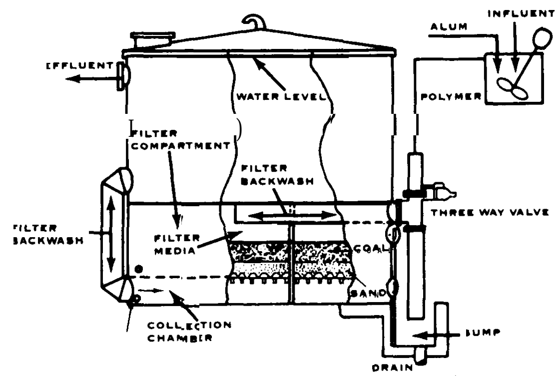
B. Rotary vacuum filter



C. Ultrafiltration



D. Filter press

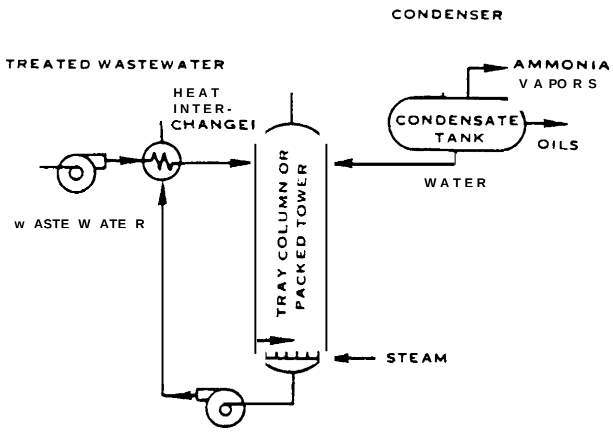


E. Multimedia filtration

SOURCE: *Assessment of Oil Shale Retort Wastewater Treatment and Control Technology,* "Hamilton Standard Division of United Technologies, July 1978, pp 5-4, 5-6, 5-11, and 5-12

- **Adsorption** is used to remove dissolved metals, organic compounds, and many toxic substances. Adsorption with regenerated carbon slurries and with resin particles is shown in figure D-6. Other systems use activated carbon particles that are contained in a fixed bed, either without regeneration or with regeneration within the column. In all cases, the separation involves physical adsorption of the contaminants on the surfaces of the particulate medium.
- **Distillation** (figure D-7) is a simple process in which wastewater is purified by boiling. The products are a very clean steam, which can be condensed with cooling water or in air-cooled condensers, and a highly contaminated concentrate. Very pure water can be obtained, but the process has large energy requirements. Cooling water is also needed in most applications.
- **Reverse osmosis** can also recover very pure water from concentrated salt solutions. Some dissolved organic materials can also be re-

Figure D-5.—Steam Stripping



SOURCE: *Assessment of Oil Shale Retort Wastewater Treatment and Control Technology,* Hamilton Standard Division of United Technologies, July 1978, p, 5-4

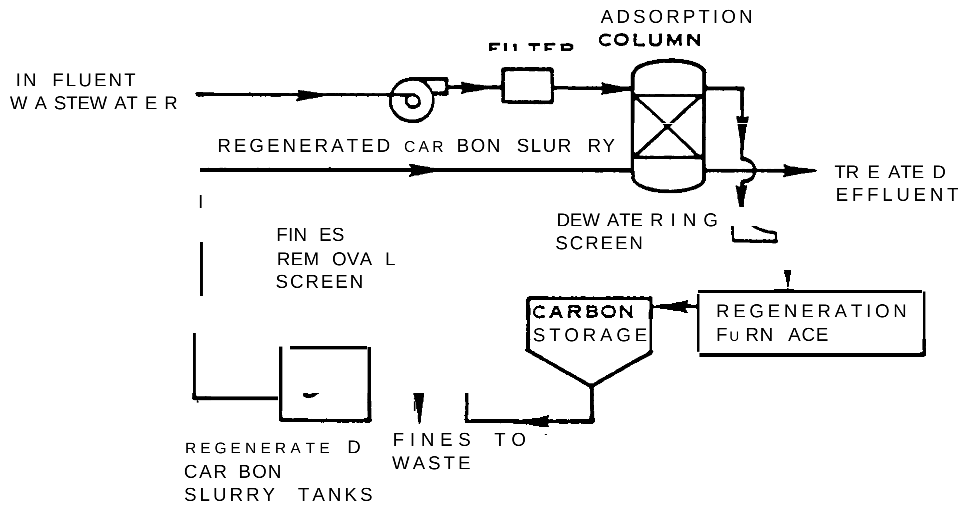
moved. **A** typical reverse osmosis system is shown in figure D-8. Each element in the separation system contains a membrane that separates the clean product (permeate) from the concentrated waste or residual. The membrane is pressurized on one side, which forces the pure water through the membrane and leaves the salt and organic contaminants on the other side. The process is very effective, but problems arise if the wastewater stream contains very fine suspended solids (colloids) that can clog the membranes and reduce their performance.

- **Electrodialysis** cells consist of an anode and a cathode separated by two membranes—one near the cathode through which cations (positively charged ions) can pass and one near the anode that is permeable to anions (negatively charged ions). A system consisting of several such cells is shown in figure D-9. The wastewater is pumped between the membranes. Upon application of an electric current, the anions migrate through one membrane towards the anode and the cations migrate through the other to the cathode. The concentration of ionic species in the central chamber is thereby reduced. The concentrated streams beyond the membranes are the waste products. Electrodialysis is very effective in removing dissolved salts but it is very expensive because each system must be specifically designed and manufactured for the particular application.
- **Thickeners** (figure D-1 O) are used between a sludge-generating step (such as clarification) and a sludge-dewatering step (such as vacuum filtration). These concentrate the sludge through gentle agitation and thereby reduce the amount of water that must be removed in subsequent processes.
- **Evaporation** (figure D-1 1) is a final step for concentrating solid residues. It is generally accomplished in evaporation basins, which are simply lined ponds into which the sludge is pumped and allowed to stand while the moisture evaporates, or in sludge drying beds, which contain a layer of coarse sand over a layer of fine sand over clay or perforated plastic drainage tiles. Both systems require large areas of land compared to other more compact devices such as vacuum filtration but they are inexpensive and require little maintenance. Sludge drying beds are faster but more expensive. Both systems require mechanical removal of the dried sludge, usually with a backhoe or front-loader.

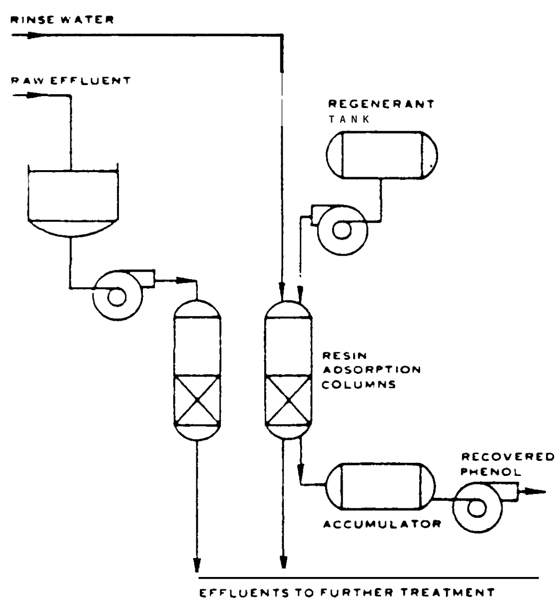
Chemical Methods

- **Ion exchange** is a process in which ions held by electrostatic charges on the surface of resins are exchanged for ions with similar charges in the wastewater. An example is a home water softening system in which sodium ions (from rock salt) are exchanged for calcium ions in the water supply, thereby reducing the hardness of the water. The process is classified as adsorption because the ion exchange occurs on the surface of the resin particles and the ions to be removed must undergo a change of phase: from the liquid phase of the wastewater to the solid phase of the resin. By this technique, harmful ions in the wastewater can be exchanged for the harmless ions of the resin. Ion exchange can be used only for removing ions (such as those from dissolved salts) from solution; it cannot be used for non-ionic contaminants such as organic compounds and suspended solids. A regenerating ion exchange system is shown in figure D-12. Such a system is suitable for recovery of valuable ions from dilute streams. It has a limited capacity, thus would not be useful for first- or second-stage salt removal but would more likely be reserved for "polishing" a treated effluent from another treatment technology.
- **Wet air oxidation was** developed for destruction of organic contaminants. In this process (see figure D-13), wastewater is exposed to air under elevated temperature and pressure, thus causing organic compounds to oxidize com-

Figure D-6.—Adsorption Systems for Wastewater Treatment



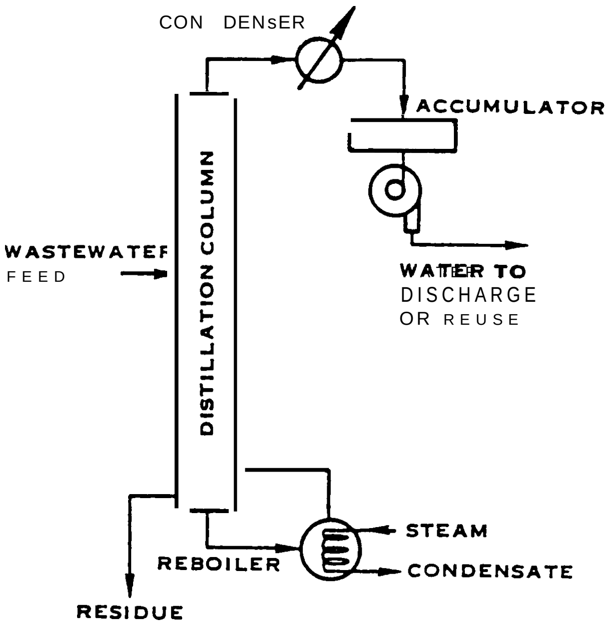
A. Carbon adsorption with external regeneration



B. A two-tank adsorption system

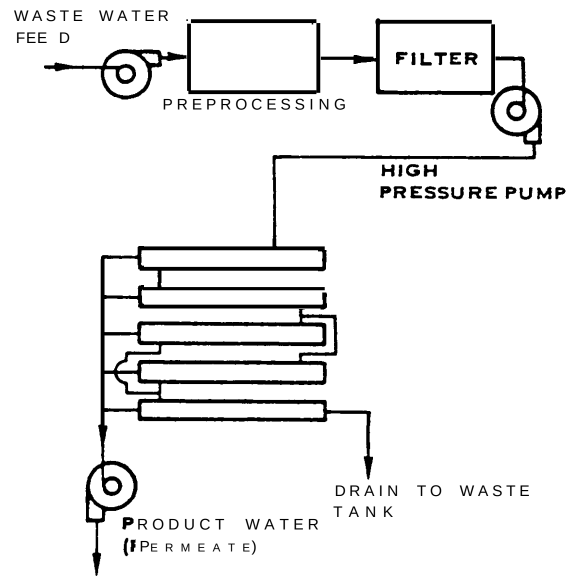
SOURCE: *Assessment of Oil Shale Retort Wastewater Treatment and Control Technology,* **Hamilton Standard Division of United Technologies, July 1978, pp. 5-4 and 5-6**

Figure D.7.– Distillation



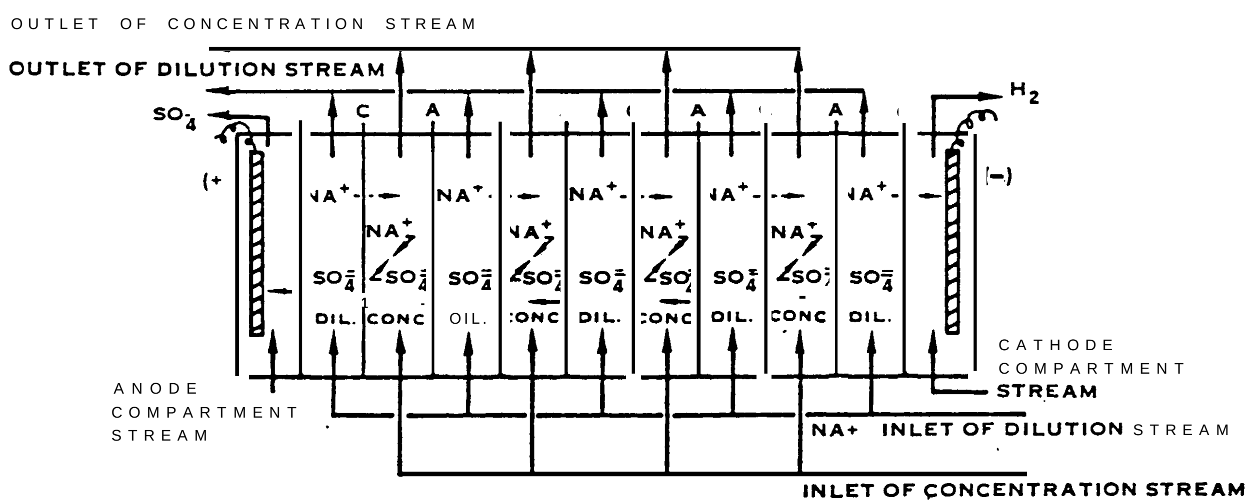
SOURCE: *Assessment of Oil Shale Retort Wastewater Treatment and Control Technology,* **Hamilton Standard Division of United Technologies, July 1978, p. 5-7**

Figure D-8.–Reverse Osmosis



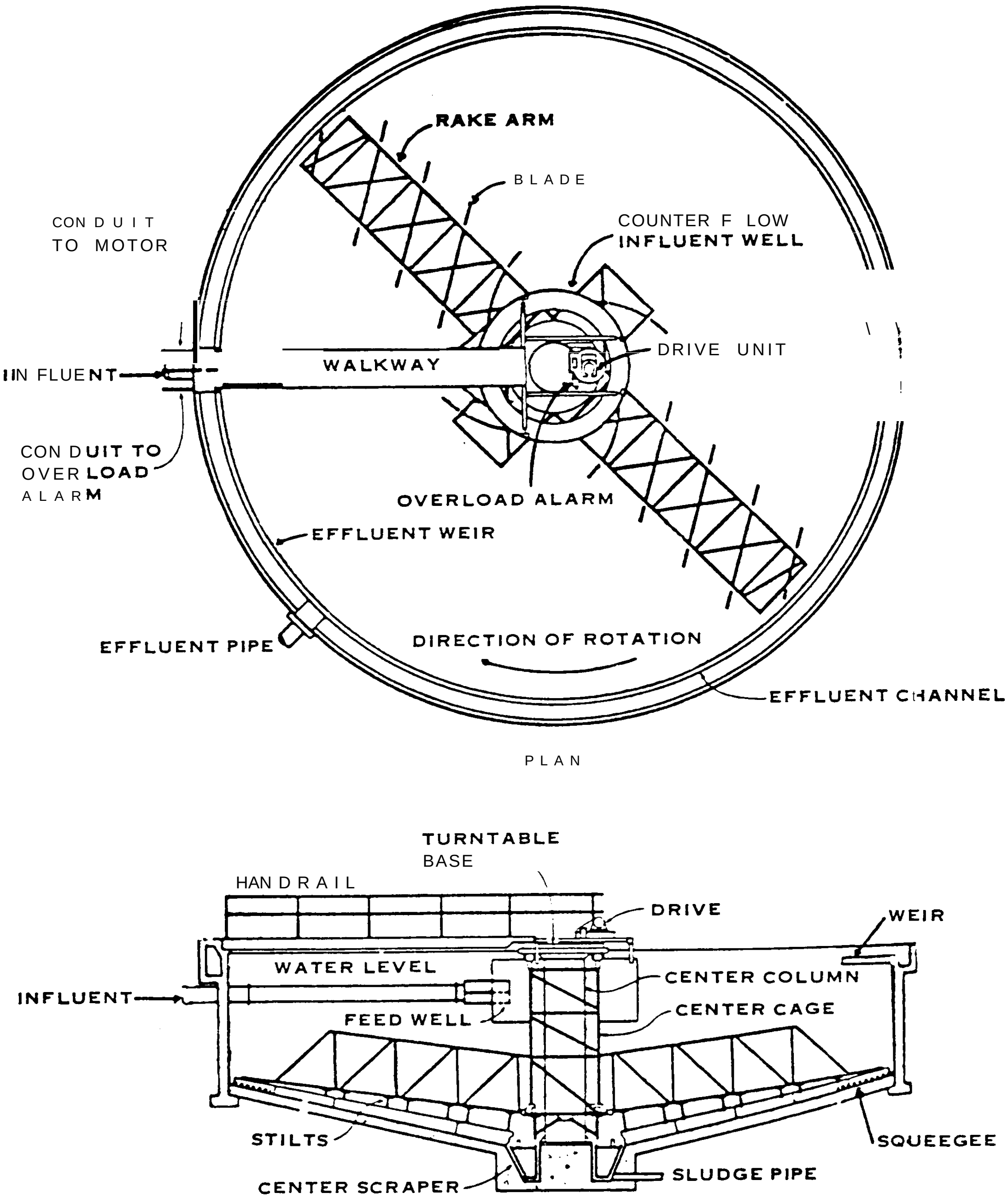
SOURCE: *Assessment of* **Oil** *Shale Retort Wastewater Treatment and Control Technology,* **Hamilton Standard Division of United Technologies, July 1978, p 5-7.**

Figure D-9.—Electrodialysis



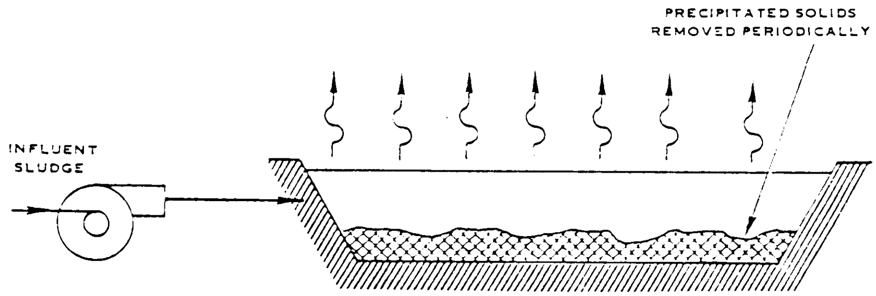
SOURCE: *Assessment of Oil Shale Retort Wastewater Treatment and Control Technology,* **Hamilton Standard Division of United Technologies, July 1978, p. 5-7.**

Figure D10.- Mechanical Sludge Thickening

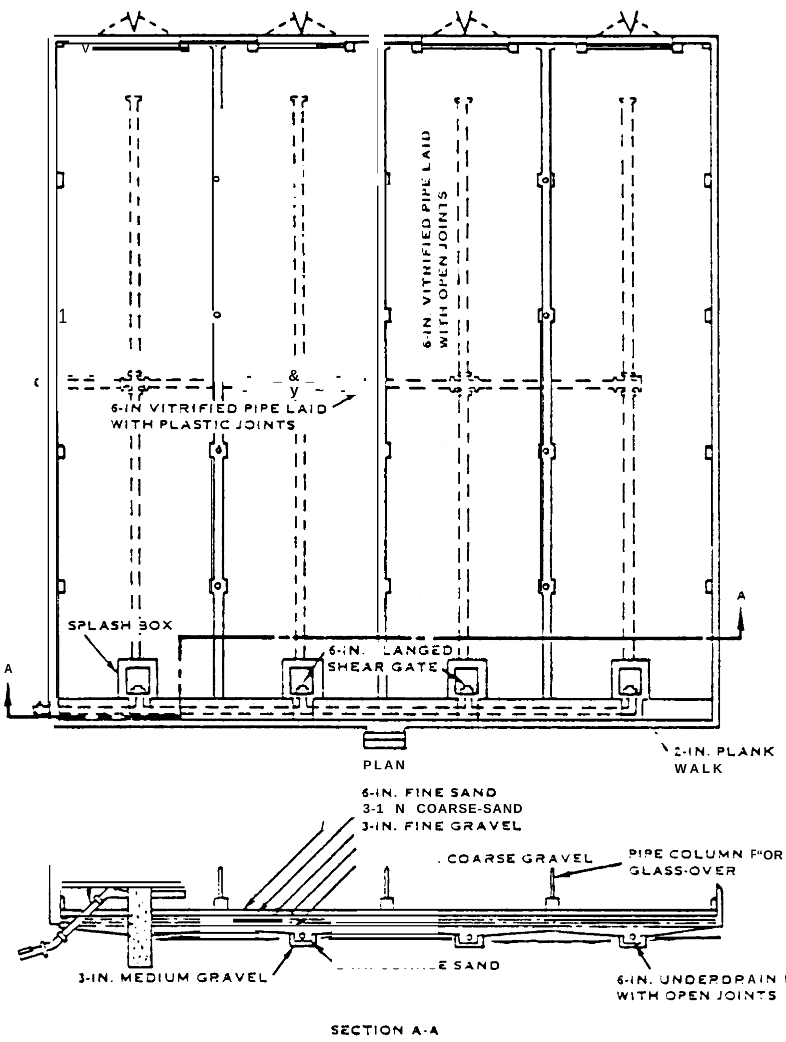


SOURCE: **Assessment of** Oil *Shale Retort* **Waste Water** Treatment anrd Control Technology, **Hamilton Standard Division of United** Technologies, **July 1978,** p. 5-9

Figure D-11 .—Evaporation Systems for Sludge Drying



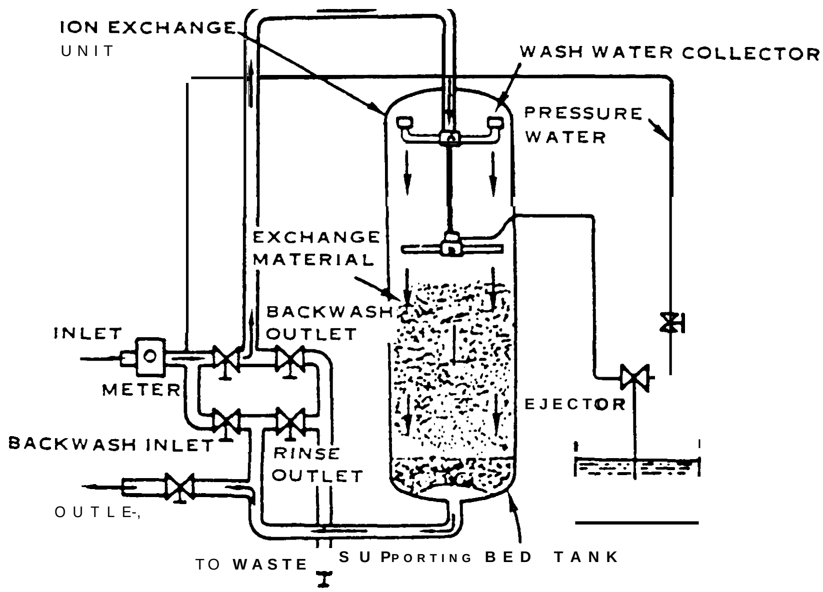
A. Evaporation pond



B. Sludge drying bed

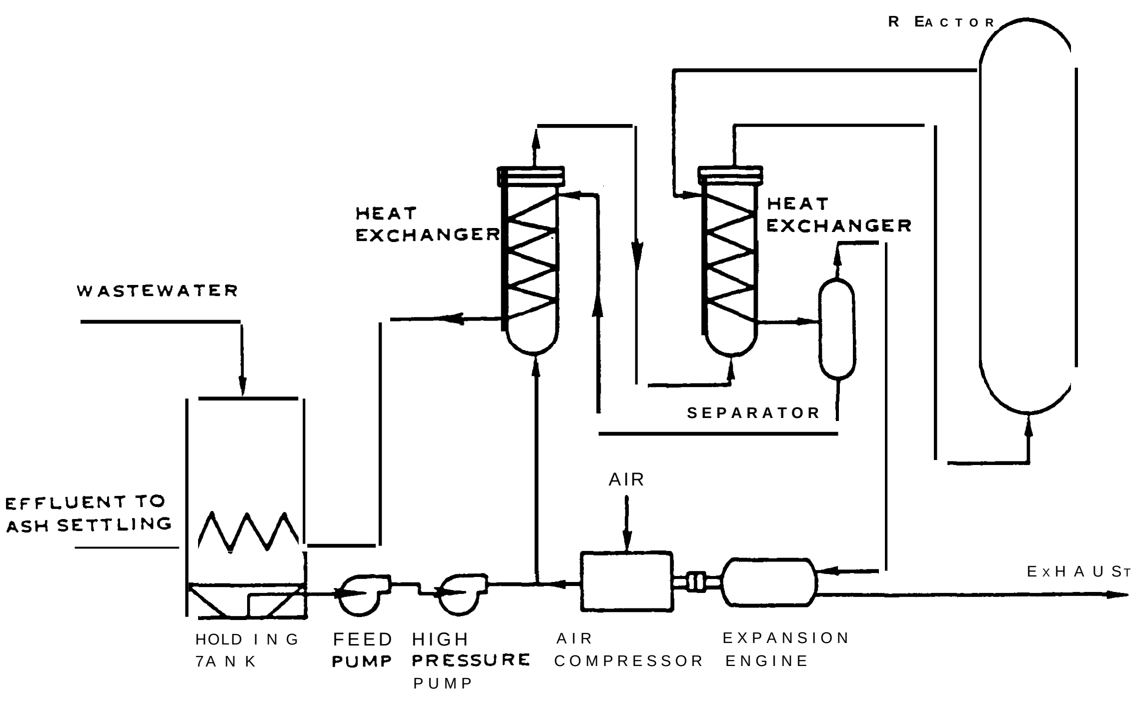
SOURCE: *Assessment of Oil Shale Retort Wastewater Treatment and Control Technology*, Hamilton Standard Division of United Technologies, July 1978, pp. 5-10 and 4-11.

Figure D-12.—A Regenerable Ion Exchange System



SOURCE *Assessment of 011 Shale Retort Wastewater Treatment and Control Technology,* Hamilton Standard Divlsion of United Technologies. July 1978, p 5-14

Figure D-1 3.— Wet Air Oxidation



SOURCE. *Assessment of 0il Shale Retort Wastewater Treatment and Control Technology,* **Hamilton Standard Division of United Technologies, July 1978, p 5-14**

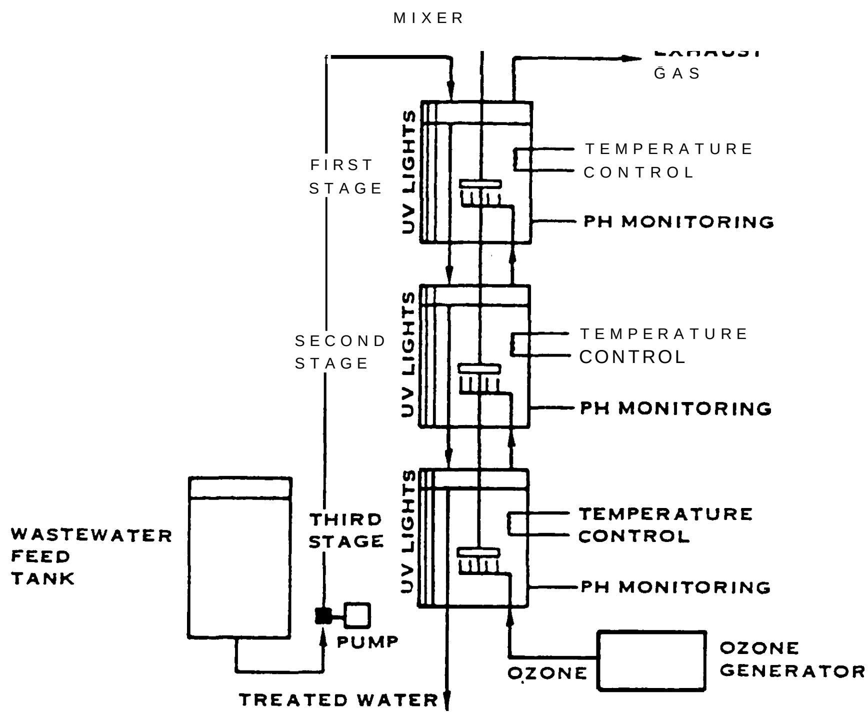
pletely or at least decomposing them into forms that are more easily treated. In particular, the process can be used to increase the biodegradable properties of compounds that are normally refractory (resistant) to biological oxidation. The method is very effective but is costly because the highly corrosive environment within the equipment requires expensive materials and construction methods.

- **Photolytic oxidation** processes (figure D-14) use light to oxidize organic contaminants. They can be used in conjunction with chemical oxidizers. One technique that works well in many industrial situations is the combination of ultraviolet light and ozone gas. The process has the disadvantage of requiring relatively long residence times.
- **Electrolytic oxidation** is similar to electrodialysis except that it can be used to oxidize or reduce dissolved contaminants to their gaseous forms. **A** typical system is shown in figure D-15. The method is costly to operate, and is generally reserved for removing very valuable or very hazardous substances, It has been used with industrial wastewaters to remove, for example, chromic acid and cyanide. In oil shale plants, it could be employed for removing hazardous organics.
- **Chemical oxidation** relies on contacting wastewater with oxidizing chemicals. **As** mentioned previously, chemical oxidation can be combined with other oxidizing systems. The example of ozone combined with ultraviolet light was mentioned above. The chemical combination of ozone and hydrogen peroxide has been found to work well with refinery wastes, which are similar to the expected wastes from oil shale processing. Potassium permanganate has been tested with oil shale streams.

Biological Methods

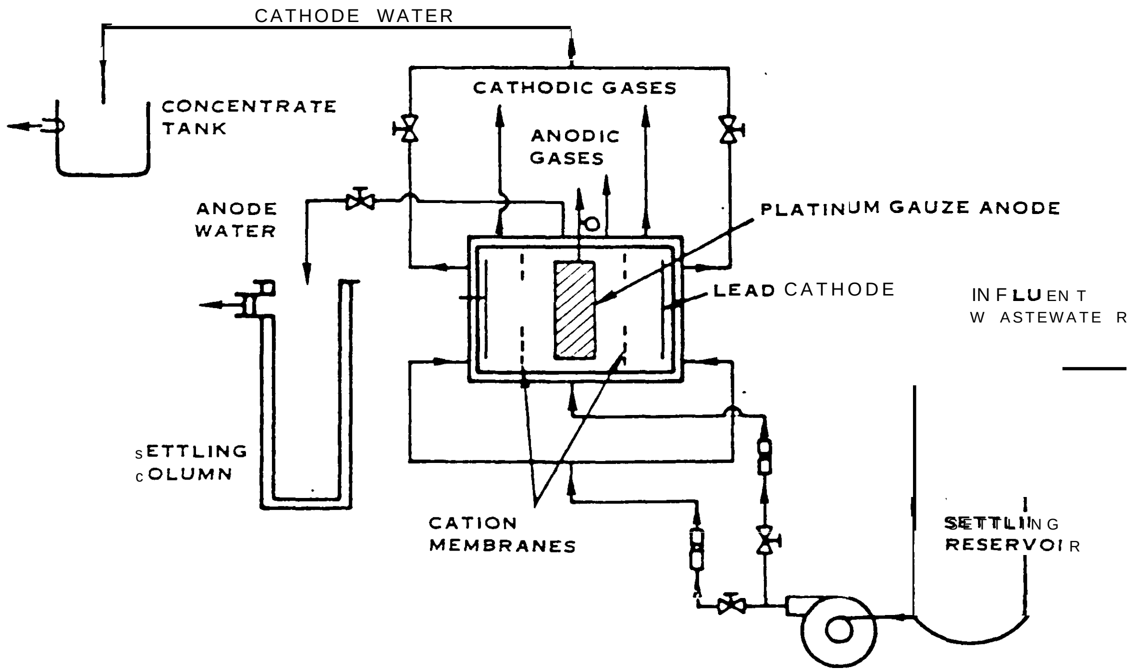
- **Anaerobic and aerobic digestion.-The principal** anaerobic system is the anaerobic digester, which is a closed, heated vessel in which the microbial population is maintained under an atmosphere of its own waste gases. Such systems have a long history of application in treatment of municipal wastes. **A** typical digester is

Figure D-14.— Photolytic Oxidation



SOURCE: *Assessment of Oil Shale Retort Wastewater Treatment and Control Technology*, Hamilton Standard Division of United Technologies, July 1978, p. 5-15.

Figure D-15.— Electrolytic Oxidation

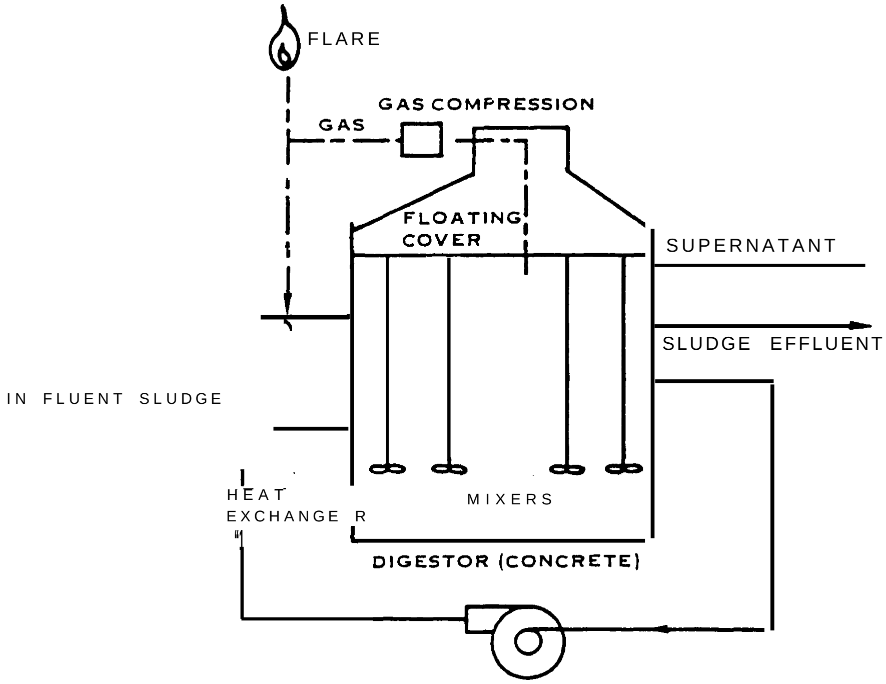


SOURCE *Assessment of* Oil *Shale Retort Wastewater Treatment and Control Technology,* **Hamilton Standard Division of United Technologies.** July 1978, p 5-15

shown in figure D-16. The illustration shows a flare stack for disposal of the digester gas. It is also possible to use the gas for many industrial purposes. In municipal systems, the gas is used as fuel for the compressors that maintain the atmosphere within the unit. Some of the common aerobic biological systems, in which digestion takes place in an oxygen-rich atmosphere, are described below,

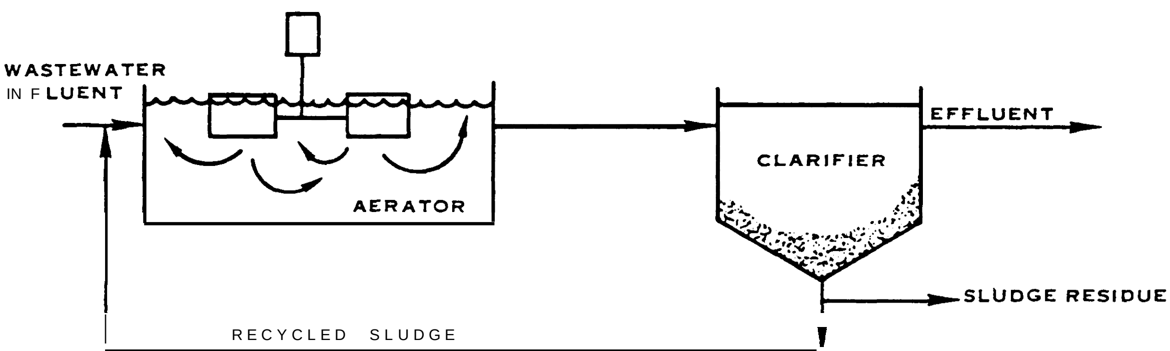
1. Activated sludge processes treat waste streams that contain 1 percent or less of suspended solids. In this process, flocculated biological growths are continuously circulated in contact with organic wastewater in the presence of oxygen. Organic compounds that can be decomposed include polysaccharides, proteins, fats, alcohols, aldehydes, fatty acids, alkanes, alkenes, cycloalkanes, and aromatics. The process is widely used for industrial wastes and is even more common in municipal treatment plants, It is relatively inexpensive to fabricate and operate, and is usually cost effective for a variety of organic contaminants. Its major disadvantages are complex control procedures and high maintenance and power requirements. A typical activated sludge system is shown in figure D-1 7,
2. Trickling filters are also commonly used for municipal wastewater treatment. One system is shown in figure D-18. In this process, the microbial population lives on the fixed elements of the filtering medium, and the wastewater trickles past them. Stones were a common medium in the past; plastic is more common today. Extra nutrients are often added to the entering waste stream to accelerate the biodegradation process. The process requires relatively little land area and can achieve high throughputs with the proper adjustments of acidity, nutrients, and trace chemicals. It does not work well if the waste is chemically unstable or if it contains suspended solids.
3, Aerated lagoons are similar to activated sludge processes except that the micro-organisms are not circulated. The lagoons are essentially stabilization ponds that are equipped with mechanical agitators and aerators to provide the microbial population with uniform conditions and with the oxygen that they need to grow. About 60 to 90 per-

Figure D-16.—An Anaerobic Digestor



SOURCE: *Assessment of Oil Shale Retort Wastewater Treatment and Control Technology,* Hamilton Standard Division of United Technologies, July 1978, pp. 2-12 to 2-24.

Figure D-17.—The Activated Sludge Process

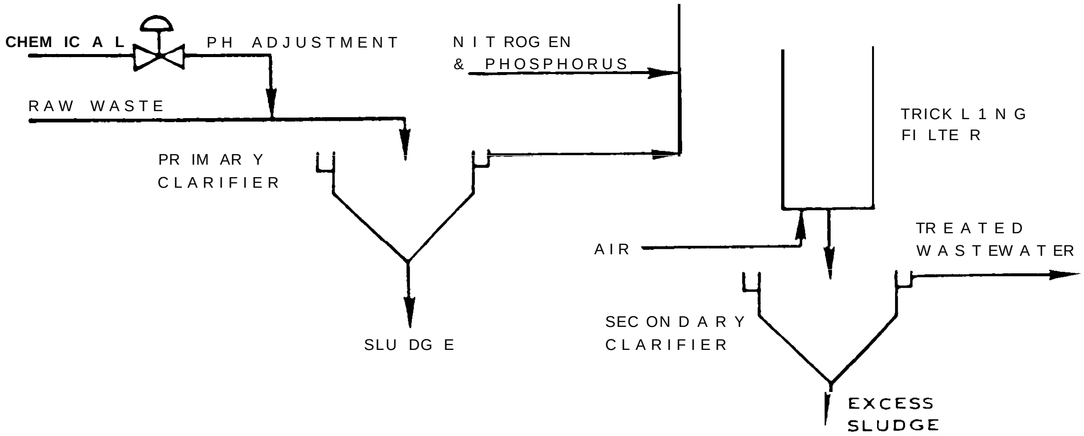


SOURCE: *Assessment of Oil Shale Retort Wastewater Treatment and Control Technology,* Hamilton Standard Division of United Technologies, July 1978, p. 5-17

cent of organic matter can be removed by this process. A typical arrangement is shown in figure D-19.

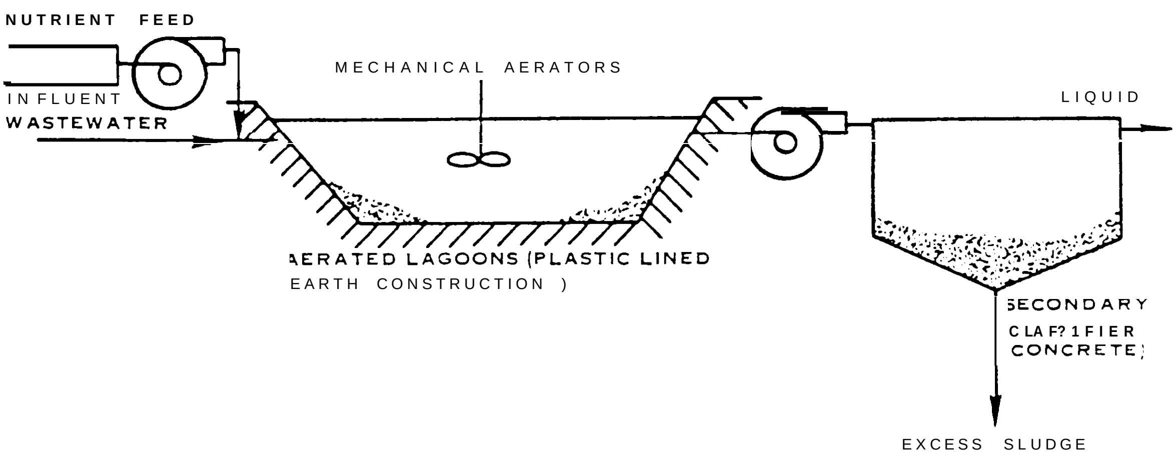
4. *Rotating biological contactors (RBCs)* are a combination of activated sludge and trickling filter processes. One system is shown in figure D-20. The micro-organisms are attached to a large number of disks that are rotated through a pool of the wastewater. Thus, a thin film of wastewater is simultaneously exposed to the microbial colony and to the air. Biodegradation occurs very rapidly. A unique advantage of RBCs is that different strains of micro-organisms can be established on each of the disks, One strain could be established on an upstream disk to remove the organic compounds that might be harmful to another strain on a downstream disk. This could not be done in other biological systems in which all micro-organisms are exposed to essentially the same environment.

Figure D-18.—Trickling. Filter Waste Treatment



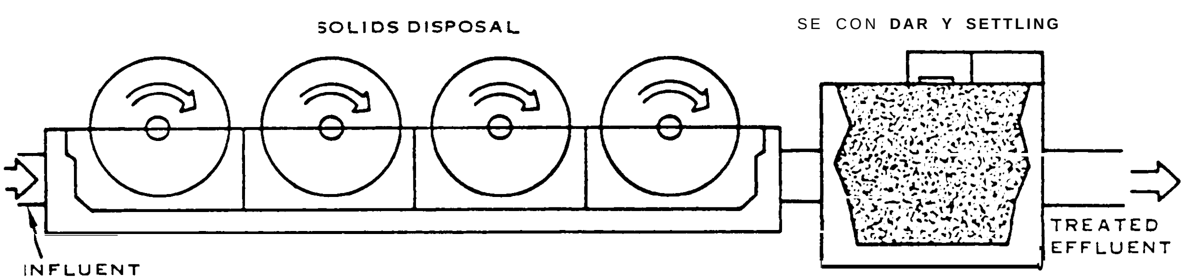
SOURCE ***Assessment of Oil Shale Retort Waste water Treatment and Contro/ Technology,*** Hamilton Standard Division of United Technologies, July 1978 p 5-17

Figure D-19.—Aerated-Lagoon Waste Treatment



SOURCE ***Assessment of Oil Shale Retort Wastewater Treatment and Control Technology.*** Hamilton Standard Division of United Technologies, July 1978 p 5-17

Figure D-20.— Rotating Biological Contractor



SOURCE ***Assessment of*** Oil Shale Retort ***Wastewater Treatment and Control Technology,*** Hamilton Standard Division of United Technologies. July 1978, P 518

Status of Point Source Water Pollution Control Methods

The removal efficiencies, reliabilities, adaptabilities, and cost features of some point source control technologies are summarized in table D-1.

Removal Efficiency

All of the systems could perform adequately for first-stage oil and grease removal, and meeting discharge standards should be possible if a biological oxidation unit is used for final cleaning. If not, single-stage cleaning in a coalescing filter would be sufficient. For dissolved gases, any of the stripping techniques should be adequate alone, and a biological oxidation unit could be used for final removal of any residual NH_3. For removal of organic compounds, carbon adsorption would be suitable if used in conjunction with pretreatment and post-treatment systems. Photolytic methods should also work, but they are not well demonstrated. Any filtration method would reduce suspended solids to acceptable levels. For dissolved inorganic, clarification would generally have low removal efficiency but could be suitable for removing metals. Distillation would be very effective for salt removal. Ion exchange or reverse osmosis would also work well, but their limited capacities might restrict their use to final removal of low-level contaminants. For sludges, sludge drying beds and evaporation basins would be very effective in the semiarid oil shale region. The alternate processes would be much less effective.

Table D-1 .–Relative Ranking of the Water Treatment Methods

Contaminant	Technology	Removal efficiency, %	Relative reliability	Relative adaptability	Relative cost
Oil and grease	Dissolved air flotation	90	Very high	Very high	Medium
	Coalescing filter	99	High	High	Medium
	Clarification	80	Very high	Very high	High
Dissolved gases	Air stripping	80	High	High	Medium
	Steam stripping	95	Very high	High	Medium
	Flue gas stripping		High	Medium	Medium
	Biological oxidation	High	Medium	Medium	Low
Dissolved organics	Activated sludge	95 BOD/40 COD	High	Medium	Low
	Trickling filter	85 BOD	High	Medium	Low
	Aerated lagoon	80 BOD	Medium	Medium	Low
	Rotating contactor	90 BOD/20-50 COD	High	Medium	Low
	Anaerobic digestion	60-95 BOD	High	Medium	Medium
	Wet air oxidation	64 BOD/74 COD	Medium	High	Very high
	Photolytic oxidation	99 BOD	Medium	Very high	Very high
	Carbon adsorption	99 BOD	Medium	High	Medium
	Chemical oxidation	90 BOD/90 COD	Very high	Very high	High
	Electrolytic oxidation	95 BOD/61 COD	Medium	Very high	High
Suspended solids	Clarification	50	High	High	Medium
	Pressure filtration	95	High	High	Medium
	Multimedia filtration	95	Very high	High	Low
Dissolved solids	Clarification	Low except for metals	High	Medium	Medium
	Distillation	99	Medium	Low	Very high
	Reverse osmosis	60-95	Medium	Medium	Medium
	Ion exchange	High	High	Low	High
	Electrodialysis	10-40	Medium	Medium	Very high
Sludges	Thickening	Product 6-8% solids	Very high	High	Medium
	Anaerobic digestion	Low	High	Medium	Medium
	Vacuum filtration	Product 20-35% solids	High	High	High
	Sludge drying beds	Product 90% solids	Medium	Low	Medium
	Evaporation basins	Product 95% solids	Very high	Low	Low
	Filter press	Product 35% solids	Very high	High	High
	Aerobic digestion	Low	Low	Low	High

BOD = biological oxygen demand COD = chemical oxygen demand

Adapted from: Assessment of Oil Shale *Retort Wastewater Treatment Control Technology,* Hamilton Standard Division of United Technologies, July 1978, pp 2-12 to 2-24

Reliability

For oil and grease removal, the coalescing filter has the only potentially severe reliability problem because it tends to clog. For dissolved gases, all of the stripping techniques should be sufficiently reliable, Biological oxidation is considered less reliable because of the need for carefully controlled inlet conditions. For organics removal, chemical oxidation should be the most reliable; the biological systems (activated sludge, trickling filters, rotating contractors, and anaerobic digestion) should also be satisfactory. All systems for removal of suspended solids should be highly reliable, For dissolved solids, clarification and ion exchange are highly reliable. Distillation is downgraded because of its potential for corrosion; reverse osmosis because of potential fouling problems; and electrodialysis because it has a relatively short history of successful applications. For handling sludge, thickening, anaerobic digestion, and all of the filtration techniques should be highly reliable,

Adaptability

Few treatment techniques have been extensively tested with oil shale waste streams, and most will be adapted directly from other industries. Physical and chemical conditions in which a device will be expected to operate may differ significantly from those for which it was originally developed and in which it is normally operated. For example, a method suitable for petroleum refineries may not work well in the oil shale industry where it will be exposed to shale fines, organometallic complexes, or other contaminants peculiar to oil shale wastewaters. Although a system cannot be fully evaluated until it has been tested under commercial operating conditions, indications of the expected performance can be obtained by examining how easily the technique has been adapted to other new industries significantly different from the one for which it was developed.

As shown in table D-1, all of the systems for oil and grease removal are highly adaptable. For dissolved gases, air stripping and steam stripping are highly adaptable; flue gas stripping is downgraded because suitable gases may not be available. Biological systems are downgraded because they may have problems with the high NH_3 concentrations in some oil shale wastewaters. They could probably be used only with some pretreatment system. For dissolved organics, the oxidation systems and carbon adsorption are very adaptable, the biological systems less so because of potentially toxic substances and because they are sensitive to inlet conditions. All methods for removing suspended solids are highly adaptable. However, problems may be encountered with the removal of dissolved solids because of possible interference from high salt loadings or membrane clogging. The only significant problem with distillation is its need for cooling water, which may not be readily available at oil shale sites. For sludge handling, thickeners and filters are highly adaptable. Sludge drying beds and evaporation ponds should have no technical adaptability problems, but they are downgraded because evaporation would mean a loss of the contained moisture, which could be recovered with filtration systems. Aerobic digestion is downgraded because some of the components of oil shale sludges may resist biological degradation.

cost

Costs in table D-1 are based on experience with similar systems in other industries. As indicated, systems with moderate capital and operating costs are available for all of the major contaminants, and many of the lower cost options also have reasonable removal efficiencies, reliability, and adaptability. The only potentially serious problem is in removal of dissolved solids, where the medium-cost systems (reverse osmosis and clarification) have questionable removal efficiencies.

Integrated Wastewater Treatment Systems

Generally, no one device is able to remove all the contaminants from a process stream, Furthermore, certain process streams may be combined before treatment or at different stages of treatment to take advantage of scale economies.

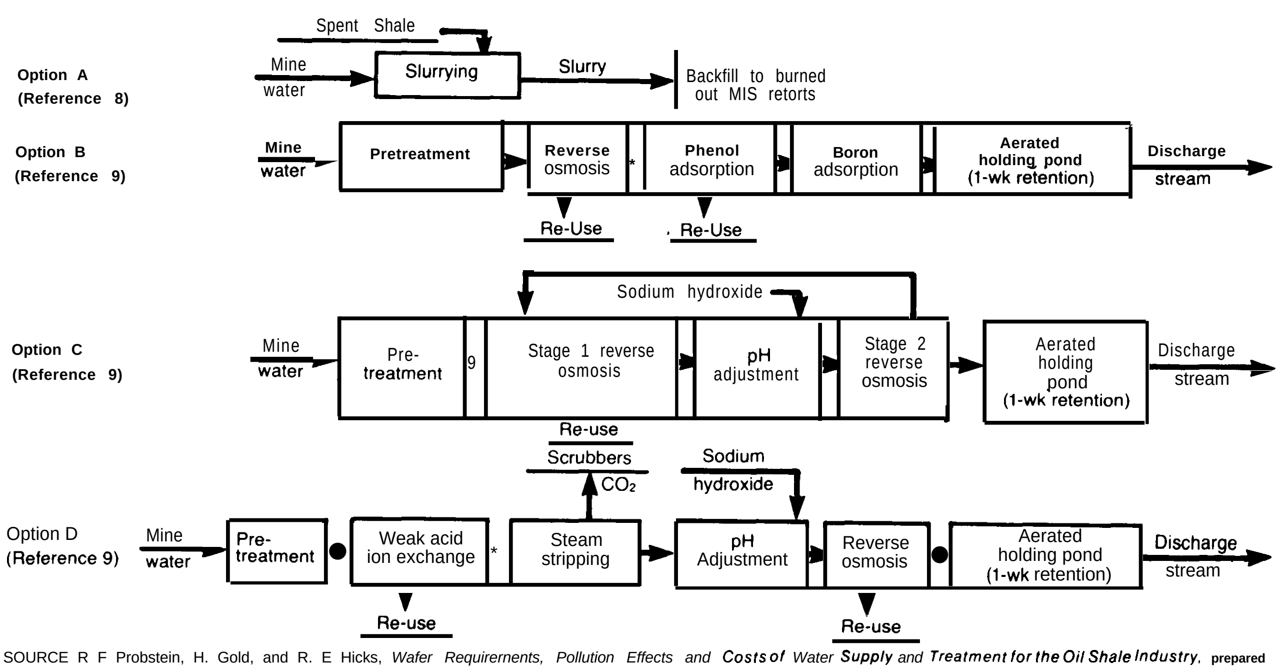
Treatment systems that have been proposed for oil shale wastewater streams are shown in figure D-21 for mine drainage water, figure D-22 for gas condensate, and figure D-23 for retort condensate. These systems and their component units are discussed below.

Excess Mine Drainage Water

This water can be used without treatment as a slurry medium for backfilling burnt out in situ retorts,' but sufficient ground water may not be available over the lifetime of the plant for this control option. Additional water might have to be imported from other sites. Another disposal option is reinfection, but for this purpose the water should be free of suspended solids and contain no constituents that would react adversely with the water in the receiving strata.[5 6 7] While mine drainage water could easily be treated to meet these requirements, reinfection is a costly disposal option, because deep wells would be required to avoid contamination of aquifers that discharge to the surface, and an extensive piping network would be needed. It has been suggested that the reinfection option be used only for very objectionable and relatively untreatable wastes and that underground disposal of the relatively clean mine drainage water would be wasteful in a region where water is scarce.[17 18]

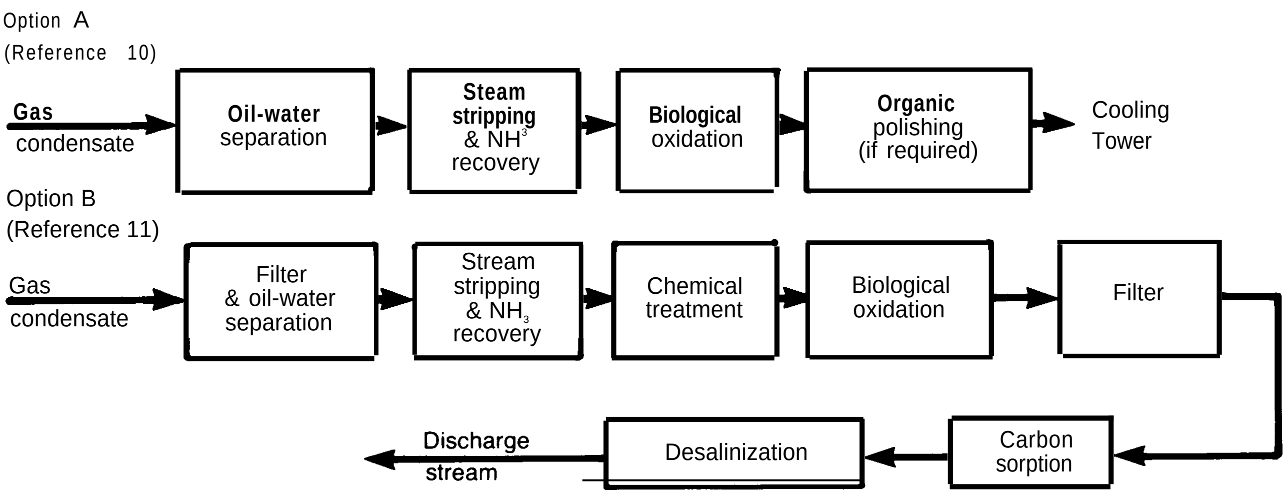
For the option of discharge to a river, dissolved solids would have to be reduced to less than 500 mg/l, which can easily be achieved by a membrane process such as reverse osmosis, as shown in figure D-21. Treatment is not expected to be difficult, but conclusive test data are not yet available.[19] Discharge permits will probably also specify a phenol concentration of no more than 0.001 mg/1 and a boron concentration of less than 0.75 mg/1. Specific ion absorbents are available for these substances and can be used, as suggested in option A of figure D-21. Alternatively, a second-stage reverse osmosis step may prove more economical, as suggested in option C of figure D-21. A single-stage, high-pH reverse osmosis step may also prove adequate, particularly if some of the

Figure D-21 .—Possible Treatment Options for Excess Mine Drainage



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

Figure D-22.— Possible Treatment Options for Gas Condensates



SOURCE R F Probstetn H Gold and R E Hicks, *Wafer RequirementsReaufrernenfs, PollutionEffectsandCostsof Wafer SupplyandTreatmentfortheOil Shale Industry,* prepared for OTA by Water Purification Associates, October '1979

dissolved salts are first removed by chemical pretreatment in a weak acid ion exchange degasifier as shown in option D of figure D-21,

An aerated holding pond would be used in any of the options to dissipate any NH_3 and phenol that are not removed in the treatment units. The pond would also serve as an equalization basin for blending in waters that can bypass the treatment train. The size of the bypass stream will vary with the quality of the drainage water, the effectiveness of the aeration pond, and the criteria of the discharge permit.

Gas Condensate

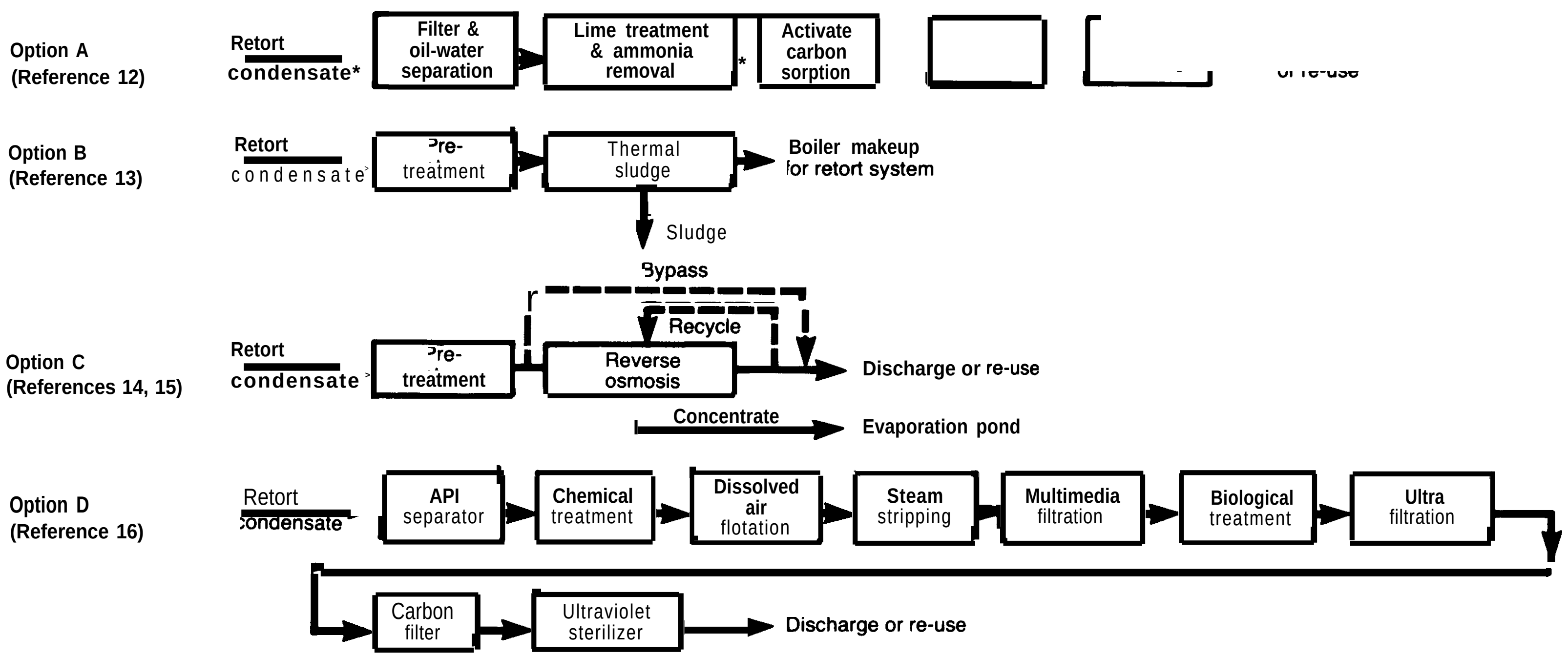
This stream requires treatment for removal of dissolved gases and organics. Dissolved NH_3 will largely be combined with CO_2 in the form of ammonium bicarbonate. Both gases can easily be removed by steam stripping. Stripping has been tested in the laboratory with both a synthetic ammonium bicarbonate solution and an actual gas condensate.[20 21] It was found that the small amount of oil present in the condensate was rapidly removed in the stripping operation, but even if an oil-water separator is required before the stripper (as suggested in figure D-22) separation difficulties due to emulsification are not expected.

Organic control by biological oxidation has not yet been demonstrated on an actual gas condensate stream, The organic mix is different from that of retort condensates and may prove to be more or less amenable to biodegradation. Other processes such as resin adsorption, carbon adsorption, and wet air oxidation are available for organics control and may prove adequate in combination. Preliminary laboratory investigations on retort condensates suggest that no single process (except possibly wet air oxidation) will be capable of controlling all the organics present.

The use of a cooling tower as part of the treatment systems (as shown in option A of figure D-22) would have two advantages. First, experience with similar wastewaters has shown that some degradation of organics occurs in a properly operated cooling tower circuit.[22] Second, the volume of blowdown water leaving the cooling tower is one-half to one-tenth that of the makeup water, depending on the number of concentration cycles used. Final organic polishing, if necessary, can therefore be done on a smaller, more concentrated stream. Because the wastewater stream will previously have been subjected to high-temperature steam stripping, air pollution by volatilization of organics in the cooling tower is not expected to be a problem. This assumes that any organics created in the biological oxidation step will be either nonvolatile or nontoxic.

Although salts are not a major contaminant in the gas condensate stream, desalination by reverse osmosis could be used to remove inorganic and organics. In option B of figure D-22, a desalination step is included to provide a very clean discharge stream. An effluent stream could also be

Figure D-23.—Possible Treatment Options for Retort Condensates



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

taken from any intermediate stage of the treatment system to provide water for various reuse options.

Retort Condensate

The retort condensate stream presents the most formidable treatment challenge. As discussed in chapter 8, this stream is created when water and oil vapors condense within in situ retorts, and some aboveground retorts if they are operated at a low top temperature. The condensate will be contaminated with oil, dissolved gases, inorganic salts, and organic substances, all of which will have to be removed.

In the conventional treatment scheme of option A in figure D-23, oil and suspended solids are first separated from the water. Oil-water separation by API units may not be adequate because of emulsions, and some emulsion-breaking technique will probably be required. The techniques that would be appropriate for oil shale wastewaters have not yet been determined.

The addition of lime will facilitate NH_3 removal and will also remove calcium, magnesium, and carbonate ions. NH_3 is easily removed by steam stripping, but unlike the gas condensate, the retort condensate contains strong acid anions that will "fix" the NH_3 as ammonium ions, which cannot be directly stripped. Lime addition will elevate the pH and convert ammonium to NH_3.[23] The pH elevation is also needed to prevent scaling and fouling of the steam stripping column by carbonate precipitates.

Removal of organic substances from retort condensates has not been adequately demonstrated. Activated carbon adsorption (option A in figure D-23) would remove only about half of the organics and would be expensive, given the high organic concentrations found in retort condensates.[24 25] Biological treatment (option D) has been suggested for control of organics, but complete removal by biological processing may not be achievable. The two major problems with biological treatment are the presence of resistant (biorefractory) and toxic materials. It is expected that as much as half of the organic matter in retort water will be biorefractory and that adequate removal may not be possible even with novel process modifications such as the addition of powdered activated carbon to the biological unit. Laboratory tests have shown that the addition of powdered activated carbon to the aeration basin in an air-activated sludge biological system improves organics removal by only about 10 percent, indicating that much of the biorefractory organic matter is not adsorbed on carbon. Polymeric resins have been shown to facilitate removal of organics from retort condensates,[26] but it **is not** known whether the ones removed are those that are resistant to biological and activated carbon treatment.

The inhibition of biological action by toxic substances is also expected to be a problem, The toxics may be either organic or inorganic, and can be expected to be different in the condensates from different retorts. Their characteristics and concentrations may even change with time if retorting conditions are not constant—a normal situation in MIS processes. Even with all of its potential disadvantages, biological oxidation could prove more economical and more effective than other processes (such as wet air oxidation) when combined with appropriate pretreatment and polishing steps.

Wet air oxidation removes a much wider variety of organics but it is also more expensive. In this process, organic material in water is oxidized by air at about 500° F (260° C). The water is pressurized to prevent boiling. The reaction takes about 30 minutes and a pressure vessel is required that is large enough to contain the water for this length of time. The cost of wet oxidation is not strongly dependent on the concentration of the waste, and unlike biological treatment it can be cost effective for very concentrated wastes. Wet air oxidation also has several technical advantages, Because it relies on chemical oxidation, the organic material that is to be destroyed does not have to be biodegradable. In fact, biorefractory materials are often converted to biodegradable substances, and a biological process could be effectively used as a polishing step. No data have been published on the performance of a wet air oxidation process with oil shale retort condensates, but an investigation has been initiated.[27]

Reverse osmosis membranes (option C in figure D-23) are also available for organics control,[28] but recent tests have shown that considerable pretreatment will be required to provide a feed that will not plug or foul the membranes, [29] In fact, a pretreatment system similar to the treatment train of option A in figure D-23 may be required for very dirty condensates. If this is done, then it is not clear that a final reverse osmosis step will be required to provide an effluent suitable for some of the low-quality reuse options. Nevertheless, reverse osmosis is of interest because it also provides a means for control for some of the inorganic contaminants for which lime softening is not adequate. Ion exchange demineralization after organics removal is an alternative to reverse osmosis, but its costs escalate rapidly with increasing salt concentrations in the feed.

It is apparent that even if the retort condensate is to be treated to only the low-quality levels required by some re-use options, an elaborate treatment system similar to that shown as option D in figure D-23 will be required. Even here additional treatment steps may be required. API separators may not be adequate, and an ultrafiltration step upstream of the steam stripper may be needed to remove emulsified oil and large organic molecules. As discussed above, biological oxidation and carbon adsorption will not adequately control the remaining organics, and resin adsorption or wet air oxidation steps may be required. An additional processing step to remove inorganic may also be required for some re-use options.

In view of the difficulty in treating the retort condensate (option B in figure D-23) in which the treated water is used to raise steam for retorting is the most attractive. Volatilized organics will be incinerated in the retort, and other substances can be removed in a concentrated sludge for disposition at a hazardous-waste disposal site. A stripping pretreatment step may be needed to avoid accumulating NH_3 and CO_2 in the thermal sludge device. No information has been published on the feasibility of a thermal-sludge steam raising process fed with retort condensates. Scaling and fouling may be problems unless appropriate pretreatment steps are used.

Other Wastewater Streams

The two other major streams are the coker and hydrotreater condensates from the shale oil upgrading section. Compositions of these streams are not known, but they should be somewhat similar to the gas condensate. The exception is the concentration of dissolved gas because, in the absence of CO_2, the NH_3 will probably react with H_2S to form ammonium hydrogen sulfide. Different steam stripping conditions will be required in that more stages or more steam will be needed to remove H_2S. Modifications should not be extreme because, unlike in the retort condensate, there should be no NH_3-fixing inorganic anions present. The treatment systems can be expected to be similar to any of the options shown in figure D-22.

Blowdown streams, regenerant streams, concentrates, and sludge products from water treatment processes must also be handled. If a thermal sludge process is included in any water treatment train, it could be used to reduce the reverse osmosis concentrates and ion exchange regenerant streams to a disposable sludge. If not, vapor compression evaporators may be used. These have been successfully demonstrated on a commercial-scale at, for example, electric power generating stations. Because cooling towers will probably be operated with few cycles of concentration, blowdown streams should not have high salt concentrations, and should be suitable for dust control and shale disposal operations.

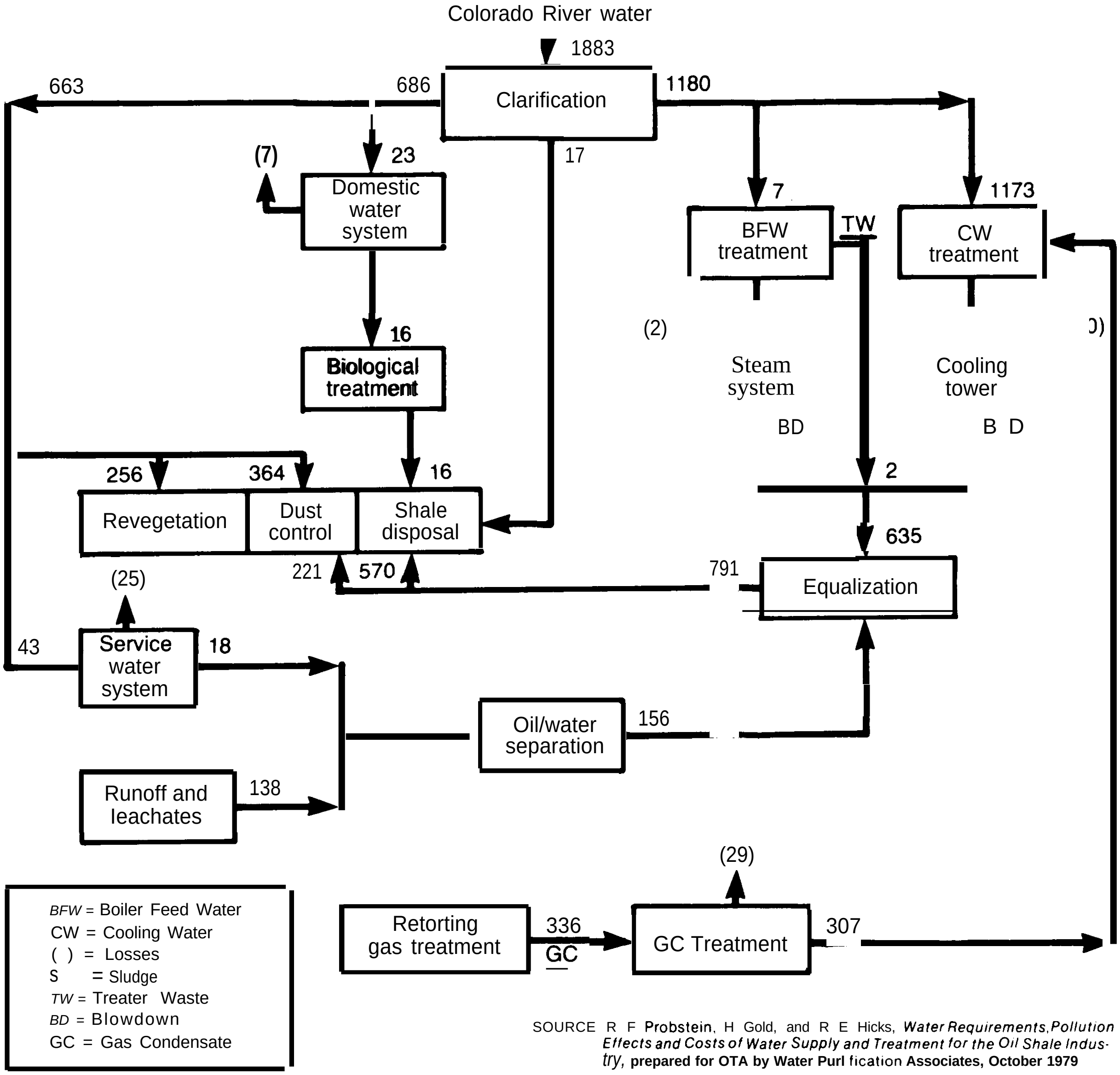
Water Management Plans for Oil Shale Facilities

Complete water management plans must consider supply, treatment, waste recovery and removal, and ultimate disposition. Figures D-24 through D-26 are flow sheets that show how water would be used, treated, and disposed of in three typical oil shale facilities. The flows into, within, and out of the plants are indicated in gallons per minute.

Figure D-24 is a water management plan for an aboveground direct facility that uses Paraho retorts. The major sources of water are the Colorado River, contaminated runoff from the facility site and its associated disposal area, and gas condensates from the retorting section. No upgrading facilities are included, so there are no upgrading condensates. The total water inflow is 2,357 gal/rein, of which about 40 percent is lost to the atmosphere through evaporation within the facility. The rest is eventually used for dust control and in the solid waste disposal area for spent shale moistening, compaction, and revegetation. The principal components of this water are treated river water, sanitary wastes, blowdowns, runoff, service water, and condensates.

Figure **1)-25** is a plan for an aboveground indirect plant that uses TOSCO II retorts. Because the retorts are indirectly heated, and because upgrading facilities are included, water requirements are substantially higher than for the Paraho plant. The total inflow is 7,386 gal/rein from the Colorado River, from surface runoff, and from gas condensates and upgrading condensates.

Figure D-24.— Major Streams in a 50-000-bbl/d Aboveground Direct (Paraho) Oil Shale Plant (gal/rein)



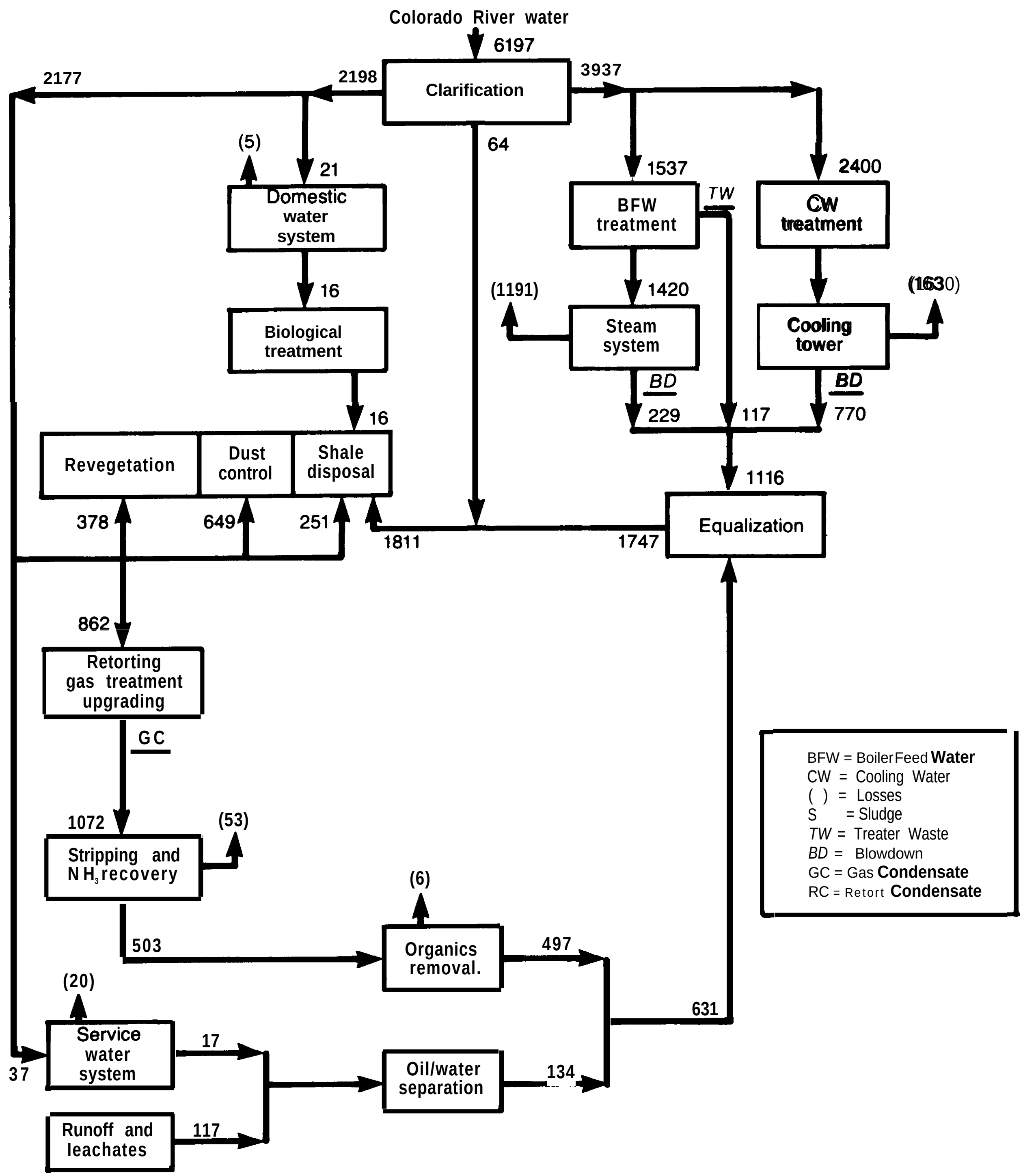
SOURCE R F Probstein, H Gold, and R E Hicks, *Water Requirements, Pollution Effects and Costs of Water Supply and Treatment for the Oil Shale Industry*, prepared for OTA by Water Purl fication Associates, October 1979

About 40 percent of the water is lost through evaporation. The rest is eventually used for dust control, or finds its way to the spent shale pile.

Figure D-26 is a plan for an MIS facility that is located in a ground water area, Excess mine drainage water is produced, and over 70 percent of it is reinfected. The rest is used in the plant, together with retort condensates, gas condensates, and surface runoff, The plant uses a thermal sludge system to process the retort condensate and to generate steam for injection into the in situ retorts. The system produces no liquid effluent. The total net inflow is about 5,059 gal/rein, of which 34 percent is lost through evaporation and 34 percent is converted to steam for the retorts. The rest is used to control dust and for disposal of the mined raw shale.

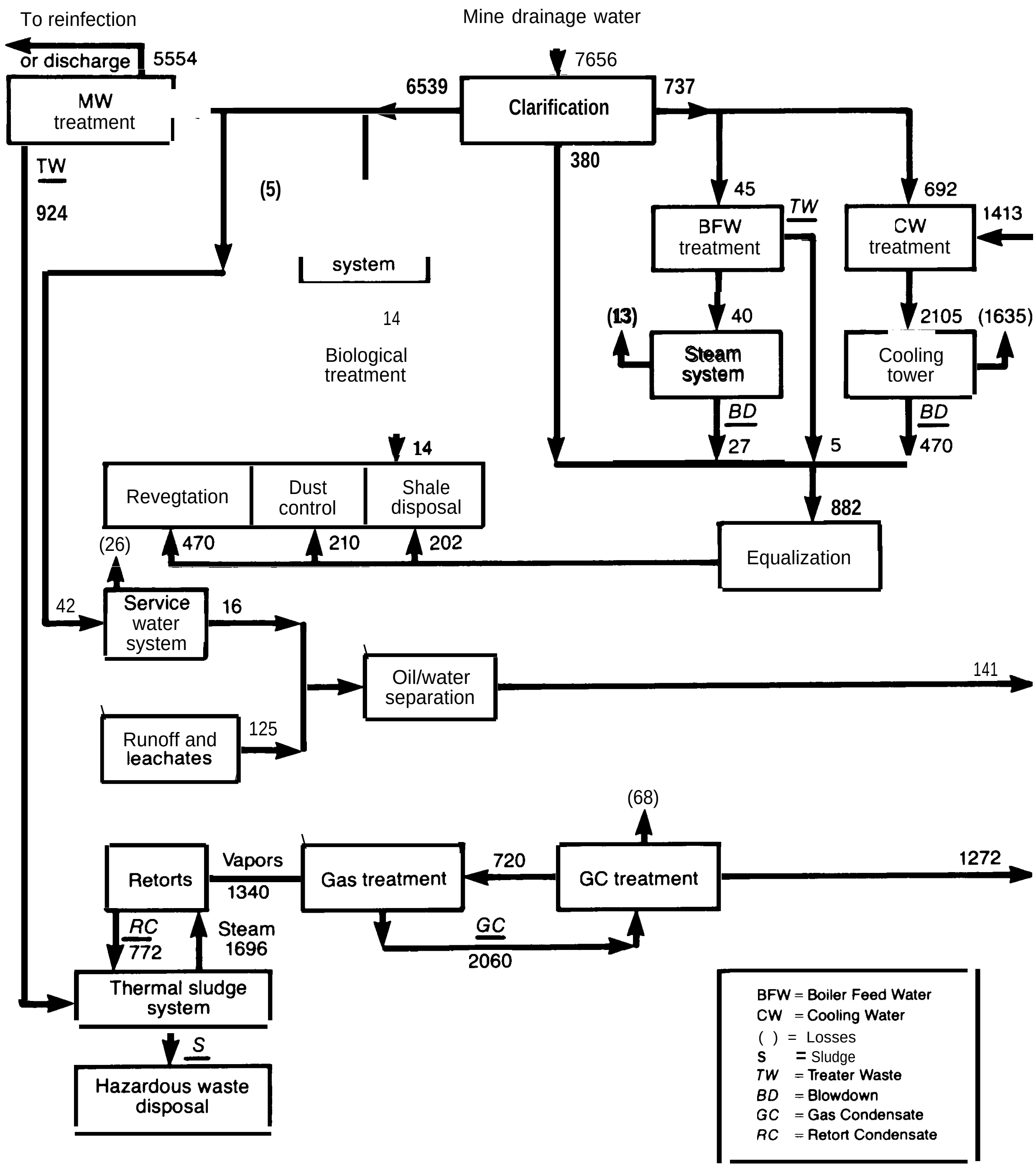
In summary, the aboveground direct plant will dispose of about 604 gal/min of treated wastewater and treated condensates in the spent shale disposal pile. An additional 22 I gal/rein of treated wastewater will be used for dust control. The

Figure D-25.—Major Streams in a 50,000-bbl/d Aboveground Indirect (TOSCO II) Oil Shale Plant (gal/rein)



SOURCE: R. F. Probstein, 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.

Figure D-26.— Major Streams in a 50,000-bbl/d MIS Oil Shale Plant (gal/rein)



SOURCE: R.F. Probstein, 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 aboveground indirect plant will add about 1,827 gal/rein of treated wastewater and concentrates to the disposal pile. The MIS plant will use about 686 gal/rein of treated wastewater for raw shale disposal and 210 gal/rein for dust control An additional 5,554 gal/rein of treated mine drainage water will be reinfected into the source aquifer. Thus, the methods for wastewater management and disposal are recycling after treatment, followed by disposal through evaporation, in dust control, and in solid waste disposal areas. Excess treated mine drainage water will be reinfected.

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