SUBSURFACE DISPOSAL OF INDUSTRIAL WASTES IN THE UNITED STATES

By Erle C. Donaldson

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SUBSURFACE DISPOSAL OF INDUSTRIAL WASTES IN THE UNITED STATES

by

Erle C. Donaldson[1]

ABSTRACT

A study of subsurface waste disposal in the United States shows that in eight States a wide variety of industrial wastes are being injected into formations ranging in age from Precambrian to Recent. More than 30 wells ranging in depth from 300 to 12,000 feet are used for waste disposal into subsurface formations which include unconsolidated sand, sandstone, vugular limestone, and fractured gneiss.

INTRODUCTION

Contamination of natural waters is a critical national problem that in recent years has gained increased recognition from industries, local and Federal Government, and the public. This complex problem involves individual interests as well as the welfare and comfort of the general population. Generally, contamination of surface waters by industrial and municipal wastes is more severe in areas of dense population where potable water requirements are high. Contamination from organic waste is of primary concern; however, inorganic wastes are also of major concern.

Since 1950 an increasing number of companies have disposed of toxic organic and inorganic industrial wastes into subsurface formations. Subsurface waste disposal was selected in some instances because the waste was odoriferous or highly toxic. In many cases subsurface disposal was the most economical method for disposing of high-density inorganic waste such as brines and of organic wastes such as phenols that are not amenable to surface treatment. This method was selected in preference to disposal in streams where the water supply was inadequate to furnish dilution for the toxic liquid wastes.

Subsurface injection is the most economical solution for many difficult disposal problems, but it is not the solution to every waste problem. Some

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areas are devoid of formations suitable for injection of waste; the initial investment may be too great, or necessary preinjection treatment of the waste may be too expensive.

A company considering subsurface waste disposal usually consults a geologist or drilling contractor familiar with the local geology to decide on a potential waste-disposal zone. A well is drilled, and cores of the potential disposal formation are secured and tested for pore size, porosity, permeability, and reactivity with the waste. If the tests prove satisfactory, the well is completed according to State regulations, the physical conditions of the formation, and the corrosive properties of the waste. Injectivity tests to determine the surface pressure required for injection at various rates are usually made by the driller after completing and cleaning the well. Acidizing and fracturing are carried out if the injectivity tests indicate a need for increased permeability in the vicinity of the well bore for injection at moderate surface pressures.

ACKNOWLEDGMENT

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Data for the report were obtained from interviews at industrial plants, communications with industrial organizations, and a search of the literature. The assistance and helpful suggestions of the Health or Departments of the various States are gratefully acknowledged, as are personnel of the U.S. Army Chemical Corps and of the following industrial organizations: American Airlines Co., American Cyanamid Co., Anaconda Co., Dow Chemical Co., E. I. Du Pont de Nemours & Co., Food Machinery Corp., Ford Motor Co., Frontier Chemical Co., Jones & Laughlin Steel Corp., Motorola, Inc., Olin Mathieson Corp., Potash Company of America, Shamrock Oil Co., Shell Chemical Co., Shell Oil Co., Tennessee Gas Transmission Co., and Upjohn Co.

SURFACE EQUIPMENT USED IN WASTE DISPOSAL

Figure 1 shows a typical system for subsurface disposal of liquid waste. Essential units in the system are sump, separator, clarifier, filter, chemical treater, surge tank, and pump. However, the amount and type of equipment necessary to prepare a waste mixture for injection depend upon the amount and size of suspended solids in the waste, the pore size of the formation matrix, the chemical compatibility of the waste and formation water, and the corrosiveness of the waste. The removal of suspended solids was unnecessary where the disposal formation was limestone or dolomite containing interconnected vugs and fractures. At a few plants excess equipment was installed in anticipation of difficulties that did not develop.

Sump

Some type of storage is incorporated in the design of all systems for collecting and mixing the several waste streams. Commonly a cement sump tank

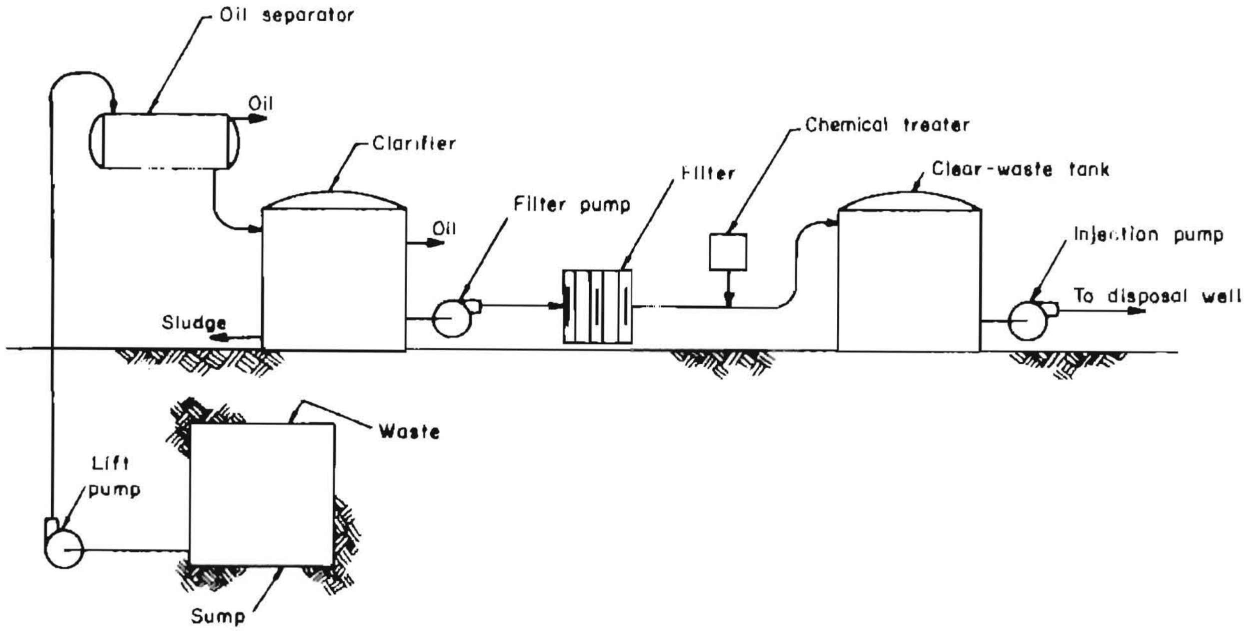

FIGURE 1. - Typical Subsurface Waste-Disposal System.

is constructed in the basement of a building which houses other equipment, or the sump may be an open 30,000- to 50,000-gallon steel tank. An oil layer or, in a closed steel tank, an inert gas blanket may be used to prevent contact of the waste with the air. Large, shallow, open ponds provide sufficient detention time to permit natural sedimentation of particulate matter from the waste during passage from the inlet to the outlet. The ponds commonly are equipped with either cascade, spray, or forced-draft aerators to oxidize iron and manganese salts to insoluble forms that precipitate in the aeration pond (4).[2]

Oil Separator

When oil is present in the waste it is removed before injection because it tends to plug the disposal formation. Petroleum refineries recover the oil from liquid wastes and return it to the refinery for reprocessing.

Separation of oil from the aqueous waste is carried out by passing the waste through a settling tank equipped with internal baffles. Usually the oil-separating tanks used in waste-treating systems are designed to remove most of the entrained oil, but are not large enough to allow enough detention time for settling suspended solids. Therefore, the waste passes to a clarifier or sedimentation tank designed to remove the suspended solids.

Clarifier

Aqueous chemical wastes usually contain fairly large amounts of particulate matter such as polymeric flocs, dirt, oil, and grease that can plug the

[2] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

disposal formation. If the waste is allowed to flow slowly through ponds or tanks, most of the suspended particles gradually settle. The sedimentation process can be accelerated by adding a flocculating agent such as aluminum sulfate, ferric sulfate, or sodium aluminate. These agents form gelatinous precipitates that entrap suspended particles and promote faster settling. The pH of the waste must be adjusted to the value best suited to the formation of the gelatinous precipitate.

Some installations use a clarifier equipped with a mechanical stirrer, sludge rake, and surface skimmer instead of a pond for coagulation and sedimentation of the suspended particles. In such systems the sludge and oil are removed continuously and the clarified effluent is pumped to a filter system.

Filter

Coagulation and sedimentation do not completely separate the solids from the liquid waste. Therefore, in areas where sand and sandstone formations susceptible to plugging are used for waste disposal, surface filtration is included as a part of the waste-treating system.

Filters with a series of metal screens coated with diatomaceous earth and cartridge filters generally are used by the chemical process industries for conditioning wastes for disposal underground. Usually two diatomaceous earth filters are installed to process the waste. One is in service while the other one is being cleaned and coated. A final polishing filtration is obtained by flowing the waste through a cartridge filter.

The cartridge filter unit has replaceable cartridges and a welded-steel shell with a quick-opening cover for accessibility. The unit is designed so that all of the waste must flow through the filter cartridges.

Dual filtration is used to condition waste for disposal into sandstone formations with small pore sizes. Where vugular limestone formations are used for waste injection, filtration usually is not necessary. Instead the waste generally is run into a sump from which it is pumped through a clarifier and then injected. In a few systems the clarifier is eliminated and the waste is injected directly from the sump without surface treatment of any kind.

Sand filters designed for pressure and gravity flow are used extensively by the petroleum industry in brine-conditioning systems (3).

Chemical Treater

When the waste contains microorganisms, a small reciprocating-piston pump is used to inject a metered amount of a suitable bactericide.

Five general types of microorganisms can interfere with subsurface injection system (1, 2).

1. Slime Formers. These bacteria grow in large colonies, producing a colorless slime. The individual cells are enveloped in a polysaccharide

material that gives the colocy the slimy texture. These bacteria can produce colonies either in pipelines or on the wellbores. As the colonies grow larger, parts of the colony are carried by the flow of waste to the face of the formation where they plug the pores of the formation.

2. Algae. Algae, most prevalent during the summer months, depend on carbon dioxide and sunlight for growth. Algae consume carbon dioxide causing a shift in the carbonate-bicarbonate equilibrium, which results in the precipitation of insoluble carbonates.

3. Iron Bacteria (Crenotrix and Leptotrix Groups). These bacteria consume soluble iron salts and excrete insoluble iron salts. They not only produce scale but also promote corrosion because of the demand for iron ions. Also, they deposit a ferric hydroxide slime on the exposed surfaces of the casing and tubing that can be displaced to the bottom of the disposal well and cause plugging of the formations.

4. Sulfate-Reducing Bacteria (Sporovibrio Desulfuricans). Sulfate-reducing bacteria ingest sulfate anions and excrete hydrogen sulfide. The hydrogen sulfide corrodes metal parts and reacts with soluble iron salts in the formation to deposit insoluble sulfides.

5. Fungi. These appear as molds on the surface of the waste and along the edges of the reservoir exposed to the atmosphere. When they enter the system they cause plugging.

Quaternary amines, formaldehyde, chlorinated hydrocarbons, chlorine and copper sulfate are used to control the growth of microorganisms.

Clear-Waste Tank

An unlined steel tank with 50,000 to 100,000 gallons' capacity is generally used to hold clarified waste before injection. The tank is equipped with a float switch designed to start and stop the injection pump at predetermined liquid levels.

Injection Pump

Selection of the injection pump is governed primarily by required wellhead pressure, volume of liquid to be injected, and corrosiveness of the waste. Some subsurface installations dispose of 500 gpm of waste under the hydrostatic pressure of the waste column and require no injection pump.

Single-stage centrifugal pumps are used in systems that require wellhead pressures up to approximately 150 psi. Multistaging imparts some of the characteristics of a positive displacement pump, and these pumps are used in some systems requiring wellhead pressures greater than 150 psi.

The multiplex piston pump is most commonly used for waste injection in systems requiring wellhead pressures greater than the capacity of a single-stage centrifugal pump. Usually two or more multiplex pumps are connected in parallel to a common discharge manifold equipped with a pressure relief valve and a pulsation dampener. Reciprocating-piston pumps deliver a constant volume of fluid at widely varying pressures; however, the close tolerances in machined parts are a source of maintenance difficulties.

DISPOSAL WELLS

Where the manufacturing process is dependent upon the uninterrupted operation of a waste-disposal well, some companies have provided a standby well. When two disposal wells are used, the waste stream is split either by separate injection pumps or by valves from a common manifold equipped to permit simultaneous or alternate flow to the wells. Several chemical companies engaged in subsurface waste disposal use monitor wells to detect possible casing leaks in the disposal well. The wells are drilled about 1,000 feet from the disposal well and are completed in the deepest fresh water aquifer. Generally monitor wells are pumped and sampled once a month to test the quality of water from the lowest fresh water aquifer.

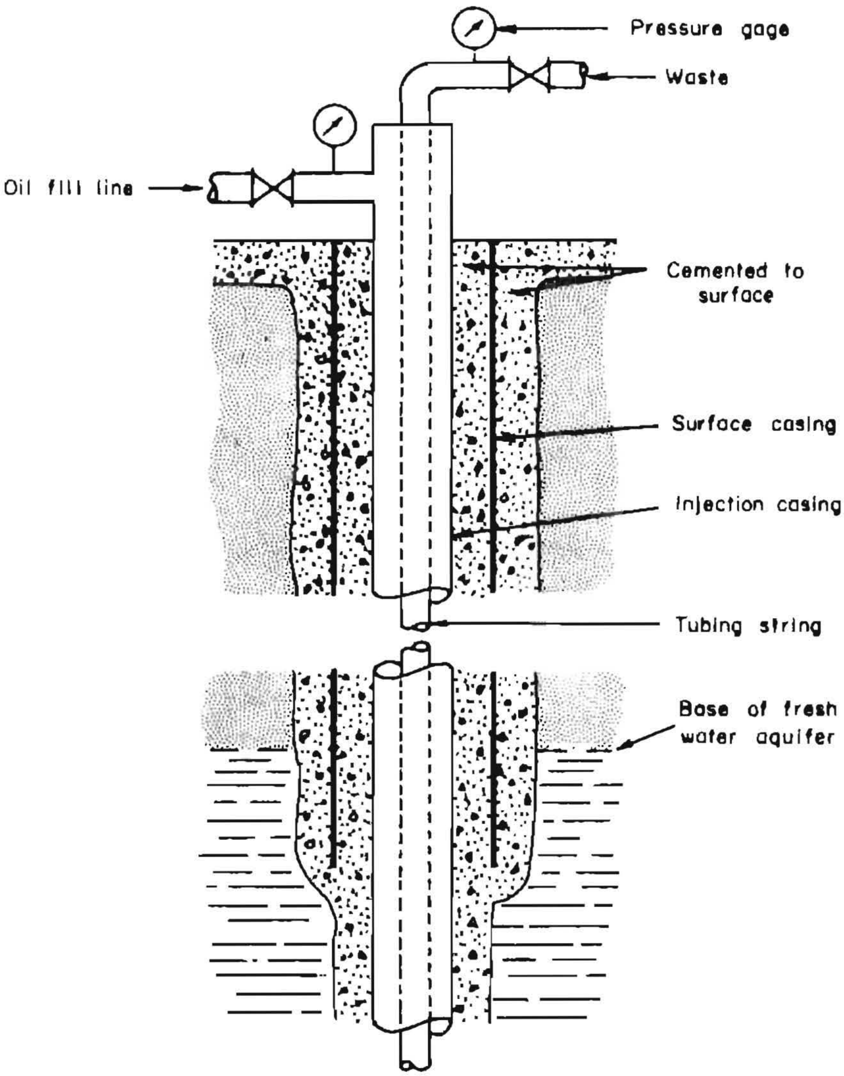

FIGURE 2. - Waste-Disposal Well: Fresh Water Protection.

<u>Protection for Fresh Water Aquifers</u>

For the average chemical waste-disposal well, a 15-inch-diameter hole is drilled about 200 feet below the deepest fresh water aquifer, where 10-1/2-inch-OD casing is set and cemented to the surface. After the cement has set, the hole is drilled with a 9-inch-diameter bit to the bottom of the potential disposal formations. After the disposal zone is selected, 7-inch-OD casing is set at the total depth of the hole and cement is circulated to the surface in the annulus between the injection casing and 9-inch hole. This method effectively seals off fresh water aquifers from the well and offers positive protection for valuable fresh water resources.

The drill and well casing sizes mentioned above are those generally used in chemical industry disposal wells. Figure 2 is a schematic drawing of a typical disposal well.

Completion Methods

Several completion procedures can be followed, depending on the disposal formation and accepted practices within the area.

Cased-Hole Completion

Casing may be set and cemented through the disposal formation and then perforated with shot or jet opposite the most permeable sections (Fig. 3A).

Cased-hole completions are used in consolidated formations and in unconsolidated formations where the wellbores tend to cave and restrict the flow of fluids into the formation.

Open-Hole Completion

Where an open-hole completion is used in a well the injection casing is set to the top of the disposal formation and cement is circulated to the surface. The cement plug at the bottom of the well is then drilled out and drilling is continued into the formation to a desired depth, as illustrated in figure 3B.

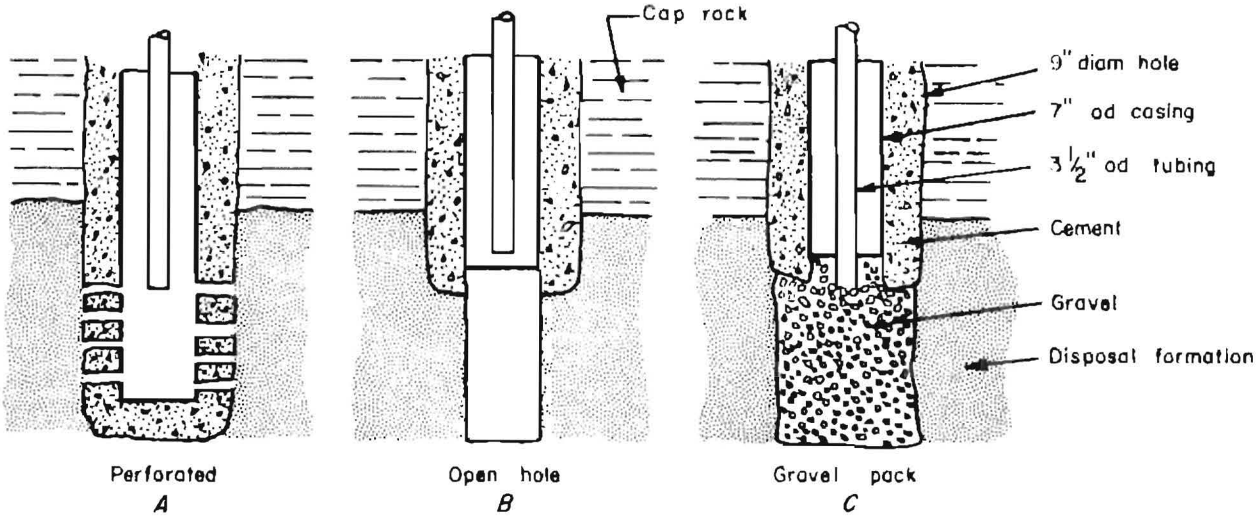

FIGURE 3. - Disposal-Well Completion Methods.

Open-hole completions are used where the formation is composed of consolidated material such as sandstone or vugular limestone.

Gravel Pack

Unconsolidated sand formations may be gravel-packed to prevent sand cavings from filling the bottom section of the injection casing and thus restricting the outward flow of fluids. Where the well is to be gravel-packed, the cement plug at the bottom of the injection casing is drilled out, a large-diameter hole is reamed below the end of the casing, and the cavity is filled with gravel as illustrated in figure 3C. Another way in which gravel packing is accomplished is to place either a perforated liner or a screen in the well so that it extends below the casing; then gravel is introduced through the annular space and placed around the liner with the aid of a circulating fluid.

Tubing

Disposal wells are equipped with tubing when corrosive waste is to be injected. Tubing that is internally coated with plastic or cement commonly is used. Epoxy resin tubing is used to protect the injection string in wells disposing of wastes containing hydrochloric acid. Because of the relatively small diameters of tubing, more pressure is required to inject liquids at high rates through tubing than through casing.

Usually the annular space between the tubing and casing is filled either with fresh water containing a corrosion inhibitor or with oil to prevent corrosive wastes from entering the annulus at the bottom of the well. Monitoring the fluid pressure in the annulus provides a means of detecting leaks in the tubing or casing.

Stimulation and Reconditioning

When the well is completed, drilling mud is washed from the face of the formation by pumping water into the tubing and allowing it to circulate to the surface through the annulus between the tubing and casing. If the well was completed for open-hole disposal of waste into the formation, the drilling mud is removed from the face of the formation by either reaming, scraping, or backwashing.

Acidizing and hydraulic fracturing of the formation are used to increase the injectivity of the newly completed wells and to stimulate old wells that have become plugged with suspended solids. Acidizing increases the effective permeability of the formation in the vicinity of the wellbore by dissolving soluble constituents such as carbonate salts.

Hydraulic fracturing produces a series of fractures extending outward from the wellbore that are propped open by either injected sand or other selected propping agents. Fracturing serves to reduce fluid injection pressures.

ECONOMICS

The costs of waste-disposal installations ranged from $30,000, where no surface equipment was required for treatment of the waste and the well was 1,800 feet deep to $1,400,000 for a complete system, including a well 12,000 feet deep, a treating plant with a clarifier, dual filters, and four piston-type, positive displacement pumps.

Costs vary primarily with (1) depth of disposal well, (2) type of well completion; (3) amount of coring and testing; (4) type and amount of surface equipment required to remove solids and enhance compatibility; (5) pressure required for injection of the liquid wastes, and (6) size of the wellbore and casing.

A general estimate of capital costs to be anticipated for an injection well under favorable conditions of well location, drilling, and preinjection treatment of the waste is tabulated:

Well specifications:
- Depth of well..................3,000 feet
- Surface casing, 200 feet.......10-1/2-inch OD
- Injection casing, 3,000 feet...7-inch OD
- Tubing, 3,000 feet.............2-3/8-inch OD
- Completion method.............Casing perforations at disposal zone

Drilling costs: Drilling of hole, drilling mud, coring, cementing, perforating, logging, drill stem test, and well stimulation.........	$30,000
Materials: Surface casing, injection casing, tubing, and wellhead....	20,000
Testing: Analysis of waste, core, and brine; injectivity surveys.....	5,000
Engineering and consulting...	15,000
Surface equipment..	125,000
Monitor well - 1,000 feet deep...	5,000
Total..	$200,000

DISCUSSION OF INDIVIDUAL PLANTS

The data secured by visits to industrial plants are discussed in detail in this section. A summary of operating conditions is presented in table 1. Some data pertaining to subsurface disposal plants were secured from the literature and from communication with industrial organizations.

TABLE 1. - Summary of disposal systems

Company	Type of waste	Injection rate, gpm	Injection pressure, psi	Subsurface depth of wells, feet	Formation age, type, and name	Total cost of system	Date started	Problems, solution, and remarks
Company A..	Brine and chlorinated hydrocarbons.	200	500	12,045	Precambrian fractured gneiss (unnamed).	$1,419,000	March 1962	Microorganisms in waste.
Company B..	Clear 4-percent solution sodium sulfate.	300	45	295	Sandstone.........	([1])	June 1951	None.
Company C..	Basic waste, pH 10±.......	70	1,000	6,160	Cambrian sandstone (Mount Simon).	250,000	November 1960	Inadequate filtration. Larger filter planned.
Company D..	Magnesium and calcium hydroxides.	200	Vacuum	400	Permian salt bed (Hutchinson).	([1])	([1])	None.
Do......	Manufacturing waste, pH may change from 1 to 9 in 8 hours.	400	Vacuum	4,150	Ordovician vugular limestone (Arbuckle).	700,000	December 1957	Corrosion and water hammer. Heavier tubing planned.
Company E..	Lachrymator waste from acrolein and glycerine units.	700	150-170	1,960	Pleistocene unconsolidated sand.	135,000	1956	Sand incursion increased injection pressure. Well is back-washed every 4 months.
Company F..	Aqueous solution--phenols mercaptans, and sulfides.	215	30- 90	1,795	do.	30,000	September 1959	Sand incursion. Periodic backwashing.
Company G..	Phenols, mercaptans, sulfides, and brine.	100	40-100	1,980	do.	([1])	March 1960	Do.
Company H..	Phenols and chlorinated hydrocarbons.	200	450	4,000	Devonian vugular limestone (Dundee).	([1])	1950	None.
Do......	Brine.....................	200	150	4,000	do.	([1])	1931	Do.
Do......	Phenols, mercaptans, and sulfides.	50	-	4,000	do.	([1])	1950	Do.
Do......	Spent caustic scrubber liquor, pH 9.	50	950	4,000	do.	([1])	1955	Do.
Company I..	Coke oven phenols and quench water.	50	300	563	Silurian sandstone (Sylvania).	25,000	August 1956	High wellhead pressure. Acidizing and fracturing.
Company J	Organic waste............	60	500	1,472	Devonian sandy limestone (Dundee). Traverse, Dundee and Monroe	400,000	1954	None.
Company K..	Sulfuric acid waste.	400	Vacuum	1,830	Permian sandstone (Yeso).	562,000	January 1960	Microorganisms decreased injectivity. Formaldehyde.
Company L..	Detergents, solvents, and salts.	254	280	1,807	Ordovician vugular limestone (Arbuckle).	300,000	February 1960	Mechanical failure of surface equipment.
Company M..	38-percent hydrochloric acid solution.	14	-	1,110	Unconsolidated sand (Glorieta).	([1])	April 1962	None.
Company N..	Stripping steam condensate and cooling tower blowdown.	50	10- 20	1,110	do.	([1])	1959	Do.
Do......	Aqueous petroleum refinery effluent.	400	50- 70	1,110	do.	([1])	1958	Do.
Company O..	Phenols and brine........	75	400	7,650	Eocene sand and clay (Frio).	([1])	1958	High injection pressure--periodic acidizing.

[1] Information not available.

COMPANY A

A waste brine and waste from the manufacture of the insecticides chlordane, aldrin, and dieldrin originally were disposed of by seepage and evaporation from large reservoirs; however, a more reliable method of waste disposal was desired. Subsurface disposal offered the best solution to the problem, and drilling was started on a disposal well in March 1961. Routine injection of the accumulated waste began in March 1962.

Source and Nature of Waste

An analysis of the waste was not available; however, it is known to be slightly basic (pH 8) and to contain ammonia, nitrates, chlorides, chlorates, chlorinated hydrocarbons, and organic phosphorous compounds.

Microorganisms identified as Paracolan aeroginoids and Bacillus subtilis grow in colonies of colorless slime in the waste reservoir and present a problem of removal before injection.

Surface Equipment

The waste effluent streams (approximately 350 to 450 gallons per minute) are discharged into a 9-acre asphalt-lined waste reservoir. Aerating towers at the reservoir aid in reducing the water content of the waste effluent. Two single-stage centrifugal pumps move the waste from the reservoir about 200 feet to the injection treating plant.

The waste first flows into a 12,000-gallon concrete sedimentation tank from which it flows by gravity into a 30,000-gallon clarifier equipped with a skimmer and sludge rake. The clarifier was originally installed to aid in preinjection treatment of the waste with flocculating agents; however, because the floc that formed would neither settle nor float this process was abandoned. The clarifier is now used as an extra detention tank.

The waste is pumped from the detention tank to one of two leaf filters, each of which has filter surface area of 450 square feet. Chemically treated diatomaceous earth is used along with asbestos for precoating the filters. Engineering consultants recommended filtration to less than 20 ppm of suspended material of 0.5-micron particle size. This is both expensive and difficult to accomplish; however, it is essential for removal of a high percentage of microorganism. A bactericide injected after filtration accomplishes complete bacterial control.

The company is planning to install the necessary equipment to bypass the reservoir and to inject the waste directly, thus eliminating the need for filtration and bactericides. The process waste streams are sterile as they leave the plant. Accumulated waste in the reservoir will be disposed of by concentration through solar evaporation and by intermittent subsurface injection.

In addition to the bactericide, sodium sulfite is added to the waste after filtration to act as an oxygen scavenger to protect the well from corrosion by dissolved oxygen acquired by exposure to the atmosphere.

After filtration and treatment, the waste is pumped into a 50,000-gallon clear tank equipped with a float switch that activates one or more, as required, of the four injection pumps.

Four reciprocating, positive-displacement pumps discharge into a common fluid manifold equipped with a pulsation dampener as a precaution against water hammer. Each pump is powered by a 130-hp electric motor and is rated at 95 gpm and 2,000 psi. A pressure relief valve is set at 1,500 psi. Normal operating wellhead pressure fluctuates from 500 psi at 200 gpm to 820 psi at 400 gpm.

Well Completion and Geology

The disposal well was drilled to a total depth of 12,045 feet and cased with 5-1/2-inch casing cemented at 11,975 feet leaving 70 feet of open hole in the Precambrian rock exposed for injection. Formations penetrated by the disposal well are shown in table 2.

TABLE 2. - Log of company A Disposal Well

Approximate depth, feet	Period	Formation name	Description
0- 460	Pleistocene	Unnamed	Sand and gravel--fresh water.
460- 550	Tertiary	Arapaho	Gray shales.
550- 1,250	Cretaceous	Laramie	Sandstone and shale.
1,250- 1,480	do.	Fox Hills	Sandstone.
1,480- 7,710	do.	Pierre	Shale.
7,710- 8,078	do.	Niobrara	Do.
8,078- 8,120	do.	Carlile	Do.
8,120- 8,345	do.	Greenhorn	Do.
8,345- 8,485	do.	Graneroes	Sandstone.
8,485- 8,633	do.	"J"	Sandstone--low permeability.
8,633- 8,730	Lower Cretaceous	Dakota	Sandstone--5-percent porosity; 4-millidarcy permeability.
8,730- 8,786	do.	Lakota	Sandstone.
8,786- 8,972	Jurassic	Morrison	Shale.
8,972- 9,582	Triassic	Lykins	Sandstone.
9,582- 9,772	Permian	Lyons	Sandstone--3-percent porosity; 1-millidarcy permeability.
9,772-11,880	Pennsylvanian	Fountain	Siltstones and thin zones of limestone--3-percent porosity; 4-millidarcy permeability.
11,880-11,895	Cambrian	Regolith	Shale.
11,895-11,850	do.	Unnamed	Quartz conglomerate.
11,950-12,045	Precambrian	do.	Fractured rock.

A string of 13-3/8-inch-OD casing was set at 2,000 feet in a 24-inch hole and cemented to the surface to protect fresh water aquifers above 1,480 feet. Near the base of the Fountain formation, 11,330 feet deep, drilling became difficult because of prolonged periods of lost circulation and, therefore, a string of 8-5/8-inch-OD casing was set and cemented at 8,980 feet. Drilling then proceeded to a Precambrian gneiss that was cored and found to be highly fractured. This fractured zone offered the best potential for a disposal reservoir; therefore, a 5-1/2-inch-OD casing was set and cemented in place from the bottom of the 8-5/8-inch-OD casing to the top of the Precambrian gneiss at a total depth of 11,975 feet.

COMPANY B

Source and Nature of Waste

The company prepares an aluminum oxide petroleum catalyst from sodium silicate, sulfuric acid, and aluminum hydroxide. Effluent from the plant is about 300 gpm of 4-percent sodium sulfate solution to be disposed of by subsurface injection.

Surface Equipment

Waste streams from the plant are piped into a 50,000-gallon tank where a float switch actuates two single-stage centrifugal pumps to inject waste alternately into one of two disposal wells. The flow rate (300 gpm) and injection pressure (45 psig) are monitored continuously with automatic recording devices. The waste is a clear solution and does not require either filtration or other preinjection treatment.

Well Completion and Geology

The first waste-disposal well was completed in June 1951 in a sandstone formation at a depth of 295 feet. Subsurface water withdrawn from the well contained a high concentration of salts and hydrogen sulfide. Because the subsurface water had a higher concentration of salts than the plant waste stream, the sandstone formation was the logical place to inject the waste.

In 1953 a well was drilled in search of fresh water that could be used in the plant. A second well about 1,000 feet north of the first well was drilled to a depth of 655 feet without finding water suitable for use by the plant. Consequently, this well was cased to 256 feet and used as an alternate disposal well.

COMPANY C

Source and Nature of Waste

Some of the waste consists of sodium hydroxide, phosphorous trichloride, methyldichlorophosphine, ethanol, and ammonium chloride. The pH of the waste stream never is below 10, and the concentration of suspended solids ranges from 0.1 to 0.2 percent. The waste streams are highly toxic; therefore, extra care is exercised in disposing of plant wastes.

Surface Equipment

The waste is accumulated and mixed in a 13,000-gallon tank. The waste is filtered, first by a leaf filter and then by a cartridge filter, before it flows into a clear-waste tank. The clear-waste tank is equipped with a float valve that actuates the injection pump. The filtration unit is undersized and requires constant attention to clean the leaves and to dispose of the dry cake. A new automatic filter of greater capacity is being considered for this installation. Because of difficulties with the filter, suspended solids have entered the well on several occasions but thus far have not adversely affected the injectivity of the well.

The injection pump is a 23-stage centrifugal pump that develops 1,400 psi at a flow rate of 112 gpm. A buildup of calcium carbonate on the impellers of the pump stopped its operation until the pump could be cleaned and returned to service. Later a second pump was installed in the system for alternate use.

Well Completion and Geology

In January 1960, the State Health Department officially granted approval for the subsurface waste-disposal system and, a month later, drilling was started. The drilling was exploratory to some extent because adequate geological data were not available. Drilling was completed to a depth of 6,160 feet in May 1960, and disposal of waste was started in November 1960. Operation has been interrupted only once, to clean the injection pump impellers and to install an auxiliary injection pump.

Surface casing 10-3/4 inches in diameter was set at a depth of 498 feet and cemented to the surface. A 9-inch hole was then drilled to a depth of 5,450 feet where a string of 7-inch-OD seamless casing was set and cemented. Drilling was resumed to complete the well with 710 feet of 9-inch open hole below in the Mount Simon formation.

The top of the casing was fitted with wellhead equipment designed for 3,000-psi working pressure and to support a string of injection tubing if required for future operation. Thus far, the waste has been injected directly through the 7-inch casing into the formation.

Water from the Mount Simon formation has a pH of 4.9 and contains about 2.2 percent calcium, 0.9 percent iron, and 0.3 percent magnesium. Because of the high pH of the injected waste and to avoid possible precipitation, a buffer zone was created in the reservoir by injecting 200,000 gallons of low pH water ahead of the waste. Thus far there has been no indication of plugging.

The Mount Simon formation is a clean sandstone with fine to coarse grains and several fractured zones. The 640-foot Eau Clair formation overlying the Mount Simon is a dense impermeable shale that prevents migration and protects the fresh water aquifers from contamination.

COMPANY D

Source and Nature of Waste

Separate streams of waste from this plant are injected into two separate wells. One stream composed of about 200 gpm of magnesium hydroxide and sodium chloride solution is injected into a shallow well 400 feet deep. The other stream, 200 to 400 gpm of liquid waste which is injected into a deeper well, varies widely in composition. It contains caustic, salts, impure bromine, chlorinated organics, and excess acids. The pH of this waste ranges from 1 to 9 during short periods because of the variable amounts of the several components.

Surface Equipment

During normal operation, waste from the several plant streams enters the sump where some of the suspended solids are removed as it flows over two weirs. The flow of waste from a sump to the well is governed by two automatic throttling valves and a liquid level control. When the liquid level in the sump reaches a preset minimum, the control closes both valves to prevent air from entering the well. A 6-inch steel-jacketed polyethylene pipe is used to deliver waste from the control valve to the wellhead. The pipe is steel jacketed to protect it from the detrimental effect of water hammer. While the disposal well is shut down for repair, the waste is accumulated in an asphalt-lined detention pond capable of holding 8 days' normal waste effluent. For longer shutdown periods, the units producing the acid waste solution are shut down and the neutral solutions are handled by the shallow well.

All storm sewers drain into a surface drainage ditch which empties into the waste disposal well through a flow control valve.

Well Completion and Geology

The 400-foot-deep well was drilled in 1952 because the health authorities objected to solar evaporation of inorganic waste solution from 35 lagoons on the plant site; the health authorities suggested that a disposal well be used. The shallow well was adequate for disposal of waste until 1957 when the size of the inorganic plant was doubled and the organic division plant was constructed. Because the waste contained varying amounts of organics as well as hydrochloric acid, permission was secured from the State authorities to dispose of the combined inorganic and organic plant waste by injection into the Arbuckle formation, thus freeing the shallow well for disposal of mining tailings and for emergency use.

Alternating layers of shale and limestone overlie the Arbuckle formation in this area and furnish an excellent cap for protection of fresh water aquifers above the disposal zone.

During 1957 the combined volume of chemical waste amounting to 275 gpm was injected into the first disposal well drilled into the Arbuckle formation. This well was equipped with 2-1/2-inch-OD fiber glass-epoxy plastic tubing.

The first installation of 4,150 feet of 3-1/2-inch tubing was completed in December 1957, and the annulus of the well was charged with diesel fuel. Before the well was placed in routine operation, a loss of annulus pressure and oil charge indicated a break in the tubing; it was found that the lower 3,000 feet of tubing had parted from the string. After the necessary repair, the well was put in service and operated continuously from December 1957 to January 1959 at an average flow rate of 275 gpm, a wellhead vacuum of 28 inches of mercury, and 35-psi pressure in the annulus. During this period of operation the average temperature at the wellhead was 120° F. Increasing waste loads made it desirable to install larger tubing (4-1/2-inch OD) in the well in February 1959.

After the tubing was changed, the well was returned to disposal service in February 1959 at flow rates of approximately 400 gpm; principally acid materials were injected. In July, after only 5 months of continuous operation, the tubing string parted about 1,400 feet below the surface. Inspection of the tubing revealed chemical attack and erosion of the exposed coupling threads. The couplings were protected with neoprene gaskets, and the tubing was returned to service. By the spring of 1961, the casing in the well had corroded and a large section had collapsed. The well was plugged with cement, and a second well was drilled 150 feet east of the first one.

The second disposal well was completed with 10-3/4-inch-OD surface casing set at 395 feet and cemented to protect fresh water sands. Internally plastic-coated 7-inch casing was set at 4,122 feet and cemented. Regular cement was pumped in first, followed by a special acid-resistant cement placed around the bottom 600 feet of casing. Four and one-half-inch-OD fiber glass-epoxy resin tubing was set at 3,994 feet with two Teflon disks at 3,974 feet to help prevent diffusion of waste fluids into the annulus. The annulus was loaded with diesel oil above the disks to furnish further protection. A total of 48 feet of the casing was perforated with four, 1/2-inch-diameter holes per foot at locations of greatest porosity as determined by drilling samples and well logs.

No loss of drilling mud occurred while drilling, indicating no abnormally large communication to the No. 1 disposal well. However, communication with the disposal cavity of No. 1 well in the Arbuckle formation will probably occur because of acidic solution of the formation. The initial input rates for neutral water were low; consequently, the well was stimulated with a treatment of muriatic acid.

Operation of the well started in June 1961 with a caustic waste solution flowing at a rate of 300 gpm, at a wellhead vacuum of 27 inches of mercury, and with an annulus pressure of 38 psi. The well operated for 2 days with flow rates continually decreasing until the tubing vacuum was lost and flow could not be maintained. The well was again acidized and returned to service with an input rate greater than 300 gpm. The waste was purposely maintained very acidic for 1 week, after which the full disposal stream was allowed to enter the sump. Subsequently the well has not failed to take fluid.

Once a week 50 gallons of diesel oil is pumped into the annulus of the well to remove the bottom portion of oil that may have become contaminated during this period of operation.

Flow rates fluctuate from a minimum process rate of 210 gpm to a rate in excess of the capacity of the well (450 gpm) during periods of heavy rainfall. At rates less than 350 gpm, vaporization of the waste solution occurs in the tubing of the well and results in a vapor block that acts like the instantaneous closing of a valve to produce water hammer. This has ruptured the tubing four times since the well was placed in routine service. Company engineers believe that the rupture does not occur suddenly, but results from gradual fatigue of the tubing by a combination of corrosion and excess wall pressure.

Recently, 3-inch tubing was inserted inside of the 4-1/2-inch tubing to create a greater friction head and reduce the vacuum. The modification changed the normal operating vacuum from 27 inches of mercury to 25 inches of mercury and restricted the flow to 270 gpm, which was too low for normal operation.

The company now is considering the use of a specially made tubing having greater tensile strength to withstand the water hammer. Also, they may drill another well for disposing of caustic and neutral waste solutions.

COMPANY E

The company currently is disposing of 700 gpm of waste into two disposal wells that are bottomed 300 feet apart; the wellhead pressures range from 120 to 200 psi. The first well originally was intended as a test well to determine the feasibility of underground disposal and to gain experience in subsurface waste disposal. Immediately after completion of the well in 1956, it was deliberately abused during a test period by the injection of wastes containing as high as 2,000 ppm of suspended solids, primarily calcium carbonate. Plugging gradually took place and the well had to be acidized to reestablish injectivity. Other process wastes differing widely in pH and containing dissolved and suspended organics were injected during subsequent tests. Inhibited hydrochloric acid was always effective in restoring normal injectivity--about 400 gpm at 120 psi.

The success of disposal well No. 1 was one of the main factors leading to construction of a plant and subsequent completion and use of well No. 2.

<u>Source and Nature of Waste</u>

Acrolein used in the manufacture of glycerine is a very reactive compound and a severe lachrymator. It was used during World War I as a tear gas. The waste contains some acrolein in addition to some derivatives of acrolein; therefore, it cannot be discharged into a natural watercourse.

In addition to lachrymators, the process waste for well No. 2 contains a large amount of diatomaceous earth, aluminum hydroxide, water, and toxic organic wastes.

Chemical treatment to decrease the toxicity of the waste was considered but found to be uneconomical for the overall operation. Before the advent of the disposal well for subsurface disposal of this waste, a process for destruction of the waste by bacteria was developed, but it proved to be a costly, complicated, and sensitive operation. The disposal plant would have been larger than the manufacturing plant, and a surge in operation could easily upset the delicate bacterial balance and cause production interruptions. Construction of the manufacturing plant was delayed until the success of well No. 1 solved the difficult disposal problem that accompanied the new chemical process.

Surface Equipment

The waste is first collected in a 95,000-gallon surface tank that serves as a process-waste surge tank to retain any waste which momentarily would exceed the capacity of the disposal system. The waste is pumped from the tank to one of two vacuum filters, each having 1,000 square feet of surface area, where the nontoxic solids are removed. The filtrate is pumped to another 95,000-gallon tank where it is blended with other waste streams to make a total waste stream of 700 gpm. Before entering the injection pumps, the waste is filtered through two cartridge filters, each designed to retain particles greater than 25 microns. The cartridge filters have proved to be expensive because they must be changed frequently and will be replaced by a circular screen filter using an asbestos fiber and polyester fabric.

The injection pumps are two-stage centrifugal pumps rated at 750 gpm at 207 psig. Corrosion of the impellers and casing of the pumps led to the use of type 316 stainless steel construction.

The No. 1 well disposal system is equipped with an oil separator to remove oil ahead of a mixing tank where automatic pH control of the waste was maintained by the addition of caustic. The process that produced the waste for No. 1 well has been shut down and the equipment has been placed in standby; this well now handles half the waste previously handled by well No. 2.

The wells are acidized weekly with 30 percent hydrochloric acid to improve injectivity and to dispose of acid produced in the plant as a waste. Production of this waste acid is scheduled to stop in the near future, thereafter acidizing will become less frequent. Acidizing may be replaced entirely by backwashing, which is more effective in increasing the injectivity of the well. A mobile air compressor takes suction from plant air supply at 100 psig and compresses it to 500 psig for backwashing. The return water and sand are discharged into a shallow pit.

Well Completion and Geology

Disposal well No. 1 was completed in 1956 and well No. 2 was completed in September 1959. The acrolein process was started in June 1960 and has used the subsurface disposal system successfully since then.

Waste-disposal well No. 1 was drilled and completed with 16-inch-OD surface casing set at a depth of 120 feet. Drilling proceeded and a protective string of 10-3/4-inch-OD casing was set at a depth of 1,960 feet. An injection string of 6-5/8-inch-ID casing was run to a point near the bottom.

Well No. 2 also was equipped with 120 feet of 16-inch-OD surface casing. Then a string of 10-3/4-inch casing was set at a depth of 1,800 feet. Finally an injection string of 6-5/8-inch-ID casing was set at the total depth, cemented, and perforated opposite the interval from 1,773 to 1,788 feet.

The disposal formation is an unconsolidated sand of Pleistocene age. Average values of porosity and permeability are 29 percent and 1 darcy respectively. The natural formation water in this disposal zone contains approximately 5 weight-percent NaCl.

COMPANY F

Source and Nature of Waste

The waste injected underground at the refinery is a sour aqueous mixture with the following composition: Suspended solids, 20 ppm; mercaptans, 38 ppm; phenols, 225 ppm; and sulfides, 2,000 ppm.

The most undesirable constituents of the waste are the phenols because of the objectionable taste that a few parts per million impart to drinking water. River water downstream from the refinery is used for drinking water, soft drink preparation, and breweries.

The refinery also produces a caustic waste that must be discarded at sea from a barge. It was suggested that this caustic waste could be added to the sour water from the catalytic cracking unit for disposal by injection; however, a compatibility test revealed that a gel was formed on mixing the two solutions. No attempt was made to explain or examine the gel since the test indicated that serious difficulties could be expected if the caustic were injected.

Surface Equipment

The waste streams from the distillation columns enter an oil separator, and the liquid effluent stream is injected by a single-stage centrifugal pump into the annular space between tubing and casing in the disposal well.

Facilities were included for the injection of supply water in the event of a power failure or maintenance shutdown to prevent incursion of sand into the lower portion of the well. Because of a remote possibility that the water may contain bacteria harmful to the disposal system, a bactericide is injected along with the water. A plantwide power failure occurred in October 1961, and about 30 minutes elapsed before supply water could be turned into the disposal well. Apparently this was sufficient time for a large amount of sand to accumulate in the perforated section of the casing. When normal injection was resumed, it was found that injection pressure had increased to the maximum allowable (90 psig) and backwashing was necessary. Some difficulty was experienced, and the backwashing was not as efficient as anticipated. When the well was placed in service again, the injection pressure for the normal waste flow rate of 200 gpm was 50 psig instead of 35 psig. The pressure gradually increased to a point in December where backwashing became necessary once more. Before backwashing, however, a wire line was run in the tubing and it was found that the lower section of the tubing was restricted by a deposit of iron sulfide. Without attempting to clean out the iron sulfide, the well was backwashed and approximately 30 cubic yards of sand was removed. When replaced in service, the injection pressure had been reduced to 30 psig at a flow rate of 215 gpm.

On January 10, 1962, abnormally cold temperatures occurred in the area for which the plant was not prepared. This caused operating difficulties that resulted in a shutdown of waste injection. On this occasion supply water had frozen in the pipes and could not be used. When operations were resumed, the injection pressure for a flow rate of 260 gpm had increased to 60 psig and by March 12, 1962, it had gradually increased to 80 psig. Attempts to clean the well by alternately closing and opening the pump discharge gate valve in rapid succession did not improve the injectivity, and it will soon be necessary to backwash the well again. Before backwashing, the tubing will be pulled and the accumulated iron sulfide will be cleared from the plugged section.

Well Completion and Geology

The waste-disposal well was completed in September 1959 with 10-3/4-inch surface casing cemented at a depth of 40 feet, and 7-5/8-inch-OD casing set and cemented into the disposal formation at a depth of 1,795 feet. A string of 2-3/8-inch tubing inside the casing is used exclusively for backwashing with air injection at a pressure of 500 psig. The waste is injected through the annulus between the tubing and casing.

COMPANY G

Source and Nature of Waste

Waste from a catalytic cracker containing phenols, mercaptans, and sulfides is mixed with a brine solution emitted from the crude-oil desalting unit and injected underground.

Before construction of the disposal well, the phenols were removed by acidifying the waste stream and skimming the resultant acid solution for removal of the phenols. However, because the phenols could not be completely removed by this method, the company drilled a disposal well at the refinery during the spring of 1960.

Surface Equipment

Brine flowing from the desalter at a rate of 70 gpm and at a pressure of 125 psig is mixed with a waste stream of 30 gpm from the catalytic cracker. The waste stream from the desalter is connected into the system on the discharge side of a triplex, piston-type, positive-displacement pump that pumps the waste from the catalytic cracker into the disposal well. The desalting line is arranged with a bypass to a separator for use when the injection pressure of the well exceeds the line pressure of this stream. When the bypass is in use, the triplex pump injects the offensive phenolic stream at higher pressures until the well can be backwashed to increase injectivity.

This disposal operation has been difficult because the well required backwashing twice a week. The well is backwashed by introducing air into the annulus at 500 psig to force water and sand to the surface through the 2-inch tubing. Only 1 cubic yard of sand is lifted to the surface during a 12-hour period of backwashing, possibly because the pressure drop in the tubing is too great. The company plans in the near future to reverse the procedure; the tubing string will be pulled and the airlift valves will be changed for reverse flow to permit more sand to be removed through the annulus. After a typical backwash operation the injection pressure is 40 psig for a total flow of 100 gpm; however, after a few days operation the injection pressure increases to above 100 psig.

In January 1962, the sand recovered from backwashing was analyzed to determine if the rapid loss of injectivity might be attributed to plugging by aluminum oxide catalyst which was too fine to be removed by the system filter. However, the aluminum present in the sample could not be identified as the aluminum oxide catalyst. The 5.2 percent aluminum that was reported as aluminum oxide could be a natural component of the sand formation; however, an analysis of the sand was not made before injection was started.

Well Completion and Geology

The disposal well was completed with 10-3/4-inch surface casing cemented at a depth of 90 feet; 7-5/8-inch casing at 1,980 feet; and a 2-inch tubing string extending to a point near the total depth, with airlift valves at 880 and 1,380 feet.

The well was completed in March 1960 at a total depth of 1,980 feet with shot perforations in the 7-5/8-inch casing from 1,960 to 1,968 feet. At this depth the sand was so fine and unconsolidated that it quickly filled the well casing to the level of the highest perforation; therefore, additional perforations were shot in the interval from 1,944 to 1,954 feet.

COMPANY H

Source and Nature of Waste

A 10-percent sodium chloride solution containing 100 to 400 ppm of phenols and intermittent slugs of chlorinated phenols is injected into one well. Aqueous solutions containing calcium and magnesium chloride, which are wastes from the salt-mining operations, are injected into three wells.

The company is also using two disposal wells for wastes from an oil refinery. A phenol-sulfide waste stream from the catalytic cracking unit is injected into one well. A second well is used for injecting spent caustic scrubber liquor that is a sodium hydroxide solution containing mercaptans and sulfides.

Surface Equipment

The phenol and salt disposal well was equipped with a 16-stage centrifugal pump mounted vertically at the wellhead. This type of pump was selected in preference to a piston-type positive displacement pump because of the lower initial cost, greater delivery volume, and lower maintenance. Flow rates and pressure at the wellhead are approximately 200 gpm and 450 psi, respectively. Soon after injection was started the well became plugged by organic material entrained in the system. The well was acidized, and two settling basins providing a total storage volume of 288,000 gallons were installed with a theoretical detention time of 24 hours at a flow rate of 200 gpm. A tarry organic gum settles out of the waste. Provisions are made for pH control before injection by adding either an acid or a base as required to form a neutral waste. Generally, treatment at the settling basin is not necessary because personnel at the processing plants treat the waste for pH control. Occasionally the plant treatment is upset, and then the basin pH adjustment system is used. Reduction of pH decreases the corrosiveness of acid wastes and tends to decrease plugging by the basic wastes.

A single-stage centrifugal pump delivers 200 gpm of calcium and magnesium chloride waste to each of three disposal wells at a line pressure of 150 psi.

Well Completion and Geology

All of the waste-injection wells penetrate about 200 feet into the Dundee formation; the top of which lies 3,800 feet below the surface. The injection strings of casing are set on the bottom, cemented, and perforated opposite permeable zones that range from 1 to 5 feet thick. All fresh water zones are cemented off.

COMPANY I

When the State Water Resources Commission objected to the discharge of liquid wastes containing phenols into a river in 1956, the company considered biological treatment of the waste in a large trickling filter. However, after comparing the operating cost with that of subsurface disposal wells, a preliminary geological investigation was made of possible disposal formations. The Sylvania sandstone at the shallow depth of 483 feet appeared suitable for waste disposal. It was estimated that a disposal well and surface equipment for the subsurface disposal system would cost $25,000, which was less than the cost of a trickling filter system.

Source and Nature of Waste

A hard metallurgical coke for blast furnaces is prepared in coke ovens. Crude benzene is extracted from the coal gas by washing with a light oil which also removes about 95 percent of the naphthalene. Ammonia, removed by scrubbing with water, is reacted with phosphoric acid to make ammonium phosphate.

The light hydrocarbons from the gas are used as fuel, and the phenols are mixed with coke quench water to form a waste containing about 0.2 percent phenols. The tar is sold to a local company for manufacturing coal tar products.

Surface Equipment

Quench water and the waste stream containing the phenols are collected in a 30,000-gallon sump from which the waste is pumped through leaf-type filters precoated with diatomaceous earth. The waste then is given a final filtration through a cartridge filter before it is pumped into a 900-gallon clear-waste tank. A liquid level controller governs the operation of a steam-drive, duplex, injection pump having a rated capacity of 100 gpm at 450 psig.

Analysis of the water from the Sylvania sand showed that it was not potable. Although some precipitation occurred when the underground water was mixed with the waste, the situation was not serious and could be overcome by acidification of the waste. Therefore, approximately 150 gallons per day of 28 percent hydrochloric acid was added to the waste to reduce the pH below 8.3 and prevent precipitation of salts. After about 4 months, acidification of waste was discontinued as being unnecessary.

Well Completion and Geology

The disposal well is relatively shallow compared with others in use. A 9-inch hole was drilled to a depth of 483 feet and 7-inch-OD casing was run and cemented to the surface. When the cement was set, a 6-inch hole was drilled to a depth of 563 feet, forming an open-hole disposal zone 80 feet into the Sylvania sandstone. Waste is injected through 2-inch tubing set 489 feet deep.

Acidizing and fracturing were necessary during 1957, 1958, and 1960 because of injection pressure increase. The injection pressure was observed to gradually increase from 200 psig following acidizing to the limit of the injection pump (450 psig). However, the frequency of acidizing seemed to decrease after each treatment; the period between the first and second treatment was 1 year; between the second and third 2 years elapsed; and thus far there is no indication that stimulation of the well will be necessary this year because the injection pressure has been holding constant at 330 psig for approximately 6 months.

COMPANY J

Source and Nature of Waste

The waste from batch organic chemical reactions containing a high concentration of acetic acid is injected into the Traverse formation.

Although the exact chemical composition of the injected waste is unknown, it varies with the type and quantity of batch organic reactions carried out in the organic chemical manufacturing plant. The pH of this waste ranges only from 4 to 4.5 because of the presence of acetic acid used in cleaning reactors.

Surface Equipment

The waste streams from the organic preparation department are collected in an underground sump and pumped to a mixing tank now used as an equalizer basin. Waste flows to a steel clarifier tank where sediment is removed. The clarifier is equipped with a cement spillway or overflow lip that is coated with epoxy resin to resist the severe attack from the acidic waste. On one occasion the waste from an unknown organic preparation formed a gum on the bottom of the clarifier. The gum was not noticed until the bottom rake became jammed and broken. Necessary repairs of the clarifier, general cleaning, and replacement of high-pressure valves were performed.

After leaving the clarifier, the waste flows into a holding tank from which it is pumped through a leaf-type filter by a single-stage centrifugal pump. After filtration the waste is pumped into the clear-waste tank where a float switch operates two triplex injection pumps on an on-off basis.

Very little material is being removed by the filter because of the number and efficiency of settling tanks in the system. Filtration may not be necessary, and plans are being made to inject unfiltered waste into one of the wells to test its performance.

Two small centrifugal pumps are used as pressure booster pumps to feed waste to the triplex injection pumps. The triplex injection pumps are equipped with alloy heads and ceramic pistons as a precaution against corrosion. Each triplex pump is rated at a delivery rate of 50 gpm at 1,010 psi.

It has been determined that either one pump will deliver 40 gpm at 150 psig into two wells or two pumps will deliver 60 gpm at 500 psi into one well. The manifold arrangement of two pumps and two wells allows several combinations.

When the subsurface disposal system was placed in routine operation in 1954, the company considered that acetic acid in the waste might corrode the well casing. For several years waste was neutralized with lime. In 1956 the injection pressure increased from a normal of about 400 psi to 1,000 psi, indicating plugging of the formation. When lime neutralization was stopped, the injection pressure gradually decreased to the normal operating level. Possibly some of the lime escaped filtration and caused the plugging. The waste is no longer neutralized and, except for high-pressure valves on the discharge manifold of the injection pumps, no indication of adverse effects from corrosion by the acetic acid waste has been noticed. The valves now show signs of leakage. Expense of replacing the high-pressure valves is offset by labor saving. Previously two operators worked on a 24-hour basis, whereas one daytime operator is now employed and a roaming operator checks the system periodically at night. The expense of purchasing lime has been eliminated.

Well Completion and Geology

Two disposal wells, drilled 1,000 feet apart, were completed for disposal into porous zones in the Traverse, Dundee, and Monroe formations. Surface casing, 10-3/4 inches in diameter, was set at about 390 feet and cemented to the surface. Seven-inch casing was set at the top of the sandy Traverse limestone at about 1,272 feet with open hole extending through the Traverse and Dundee and 42 feet into the Monroe formation at an average total depth of 1,472 feet. The top of the vugular Dundee limestone was drilled at 1,377 feet, and the top of the Monroe was at 1,430 feet.

Chemical waste is injected through 2-inch tubing set a few feet below the 7-inch casing. A blanket of nitrogen is maintained in the annulus between the tubing and casing to exclude oxygen. The pressure is monitored at the surface by a continuous pressure recorder.

COMPANY K

Source and Nature of Waste

The company processes uranium sandstone ore by leaching with sulfuric acid, followed by an ion exchange process to recover the uranium. The major constituents of the waste solution from this process are the chloride and sulfate salts of sodium, calcium, iron, and magnesium. Table 3 lists the detailed analysis of the waste. The effluent is a low-level radioactive fluid containing small amounts of natural uranium, radium 226, and thorium 230. The gross alpha emission of the waste is 3.42×10^{-4} µc/ml. Determination of the neutralizing capacity of the disposal formation toward this waste from core samples indicated that 1 cubic foot of the sandstone will neutralize 390 gallons of waste from pH 2.8 to 7.0. Neutralization of the waste causes precipitation of thorium 230, calcium sulfate, and ferric hydroxide. However, no difficulties directly attributed to precipitation from the waste have been encountered since routine injection of the filtered waste was started in January 1960.

TABLE 3. - Chemical and radioactivity analysis of the injection water and formation water of company K

Analysis	Injection water	Yeso formation water
Chemical, ppm:		
Sodium	1,206	414
Calcium	677	592
Iron	439	17
Magnesium	411	157
Manganese	378	-
Sulfate	8,332	2,270
Chloride	1,725	304
Nitrate	130	-
pH	2.8	7.3
Radioactivity, µc/ml:		
Gross alpha emission	3.42×10^{-4}	8.6×10^{-8}
Thorium 230	2.57×10^{-4}	-
Natural uranium	1.73×10^{-6}	2.2×10^{-10}
Radium 226	5.63×10^{-7}	6.4×10^{-10}

Surface Equipment

The concentrated waste leaving the uranium mill is discharged into a pond that has approximately 25,000 square yards of surface area. The pond acts as a sedimentation basin having a very long detention time where precipitates and tailing solids from the mill are accumulated. Solar evaporation of the water from the pond is not sufficient for adequate disposal of the liquid portion. A much larger pond would be necessary for effective disposal, but evaporation and enlargement of the pond were considered undesirable. Therefore, the company turned to subsurface injection of the waste.

To maintain entrained solids at a minimum, a decanter consisting of a 4- by 120-foot wooden box is erected in the tailing pond adjacent to the filtering and pumping station. The decanted water is pumped to one of two leaf filters that are used alternately for removal of suspended solids. Diatomaceous earth is added to the waste as an aid to filtration; in addition, the filter feed is treated continuously with 20 ppm of sodium polyphosphate to retard precipitation of calcium sulfate and with 4 ppm of copper sulfate to control the growth of microorganisms. The filtered waste is discharged into a 300-gallon surge tank from which it is pumped through a 12-inch rubber-lined pipeline 1.4 miles long to the disposal well. The hydrostatic head of the waste offers sufficient pressure for injection of as much as 600 gpm; the average quantity of waste being injected continuously is 400 gpm.

Corrosion of equipment has been the major source of operational difficulties. The original sump pumps were made of rubber-lined carbon steel; however, the rubber lining was soon destroyed by suspended solids, and metallic parts in contact with the fluid were corroded. The sump pumps were replaced with pumps made of type 316 stainless steel, and the well delivery pump was changed from rubber-lined carbon steel to stainless steel.

The rubber lining of the 12-inch-OD delivery pipe was damaged at a flange connection. Fluid entering the annulus between the rubber lining and pipe corroded the pipe to the extent that it became necessary to replace the damaged section. When the corroded section of the delivery pipe was replaced in October 1961, a 1/8-inch-thick layer of microorganisms coating the rubber lining was discovered. The presence of the microorganisms explained a slow decrease in well injectivity that had been observed over 12 months. Treatment with 3 barrels of formaldehyde to kill the microorganisms was followed by continuous injection of 100 ppm of formaldehyde. The formaldehyde treatment will be continued until a more economical bactericide is found.

A disposal well was drilled in 1959 to a total depth of 1,830 feet and completed in 560 feet of sandstone of the Yeso formation. Formations penetrated by the well are shown:

Depth, feet	Age	Formation	Description
0- 350	Triassic	Chinle	Shales and siltstones.
350- 460	Permian	San Andres	Limestone.
460- 580	do.	Glorieta	Sand--fresh water.
580-1,300	do.	Yeso-San Ysidro	Sand, anhydrite, and limestone.
1,300-1,480	do.	Yeso-Meseta Blanca	Fine sandstone, porosity 17 percent, permeability 105 md.
1,480-1,830	do.	Abo	Siltsones and claystones.

Well Completion and Geology

The disposal well was drilled and reamed to a diameter of 17 inches and depth of 730 feet, and 13-3/8-inch-OD casing was set and cemented to the surface to seal off the fresh water aquifers. Plastic-coated 8-5/8-inch-OD injection casing was set at 1,830 feet in an 11-inch hole. The injection casing had to be cemented in two stages because the first-stage cement filled the annulus only to 900 feet from the bottom because of the loss of cement into the disposal formation. Casing was perforated above the 900-foot level, and cement was squeezed through the perforations. After cementing, the injection casing was perforated and the formation was fractured at potential disposal zones below the San Andres fresh water aquifer, as determined by well log data. The hole was then cleaned out to a depth of 1,796 feet and injection tests indicated that fracturing had increased the injectivity by eight times over that predicted from core analysis.

The plastic lining of the 8-5/8-inch casing was damaged during completion, which exposed zones for severe corrosion. An attempt was made to fabricate a liner from 7-inch-OD acrylonitrile-butadiene-styrene plastic pipe; however, the plastic pipe ruptured under pressure from cementing operations and had to be removed. A type 316 stainless steel, 6-5/8-inch-OD schedule 10 liner was cemented to a depth of 905 feet.

A well was drilled to 625 feet into the San Andres fresh water aquifer for monitoring purposes. This well is 300 feet down the hydraulic gradient of the San Andres formation from the disposal well. Fresh water samples from the monitoring well are analyzed periodically for chemical content and radioactivity. In addition, three springs, three ponds, and several municipal wells in the area are analyzed bimonthly.

COMPANY L

Source and Nature of Waste

The waste is a complex mixture of detergents, paint and varnish removers, hydrocarbon solvents used for oil sludge cleaning, phenols, cresols, and rinse water from electroplating tanks. The only test conducted periodically is pH determination; pH has been found to range from 5.0 to 9.0 in 1 day.

Surface Equipment

The waste-collecting sump is a 20,000-gallon tank buried 15 feet underground. All liquid waste from the maintenance area flows by gravity through drain lines into this tank. Two lobe pumps (rated at 200 gpm each) are used to pump the waste from the underground sump to the clarifier on the surface. Originally, two duplex stainless steel centrifugal pumps were used, but they were replaced because excessive bearing and shaft wear caused frequent shutdown. However, the lobe pumps have not given trouble-free operation. In January 1962, an accident in the maintenance area caused a surge of a caustic cleaning solvent that was sufficiently high to dissolve the buna-N rubber sleeves that cover the pump lobes, causing a maintenance shutdown.

The clarifier is a 30,000-gallon automatic skimmer. Oil that floats to the top of the aqueous waste is skimmed and drained into a tank by gravity flow. A scraper at the bottom of the tank removes accumulated sludge. The insoluble oil and sludge are hauled away. Although the clarifier is rated for 670 gpm with a detention time of 47 minutes, it did not prove adequate for this system because oil and sludge appear in the equalizer basin, indicating that a longer detention time is necessary to treat this waste.

From the clarifier, the waste flows by gravity into a 200,000-gallon equalizer basin. This tank is equipped with a manually operated skimmer and bottom rake to remove the oil and sludge that overflow from the clarifier. The sludge is skimmed twice a week. The equalizer allows time for mixing the many components of the waste and thus provides a more uniform waste for disposal. It also serves as a detention reservoir for the injection pumps. A float switch is provided to shut off the injection pumps at a minimum liquid level. The equalizer basin is constructed with a cement bottom and carbon steel sides. A leak-proof seal between the cement bottom and steel sides is difficult to maintain.

The injection pumps are set in a basement approximately 10 feet below the surface to receive waste by gravity feed from the equalizer basin. Two triplex, piston-type, positive displacement pumps rated for 150 gpm at 600 psig are driven by 60-hp electric motors. The pumps are equipped with 3-inch ceramic pistons and aluminum-bronze fluid ends. Positive displacement pumps were selected because of their characteristic of delivering a constant volume under varying pressures. Pressure fluctuations and eventual plugging of the formation were anticipated in the original design; however, 4 months after startup the operating pressure leveled out at 280 psig and has not changed except for a few fluctuations of ±40 psig.

Well Completion and Geology

The top of the Arbuckle limestone formation occurs in this area at 1,729 feet below the surface and extends to the top of the granite at 3,036 feet. Seven-inch-OD casing was cemented to a depth of 1,807 feet to insure a good seal into the top of the Arbuckle formation. A string of 2-1/2-inch-OD tubing was run to a point near the bottom of the disposal well.

A monitoring well drilled to the deepest layer of fresh water at 180 feet is sampled weekly. Thus far, no contamination of the fresh well-water has occurred.

COMPANY M

When the company was visited in March 1962, some drilling tools had been lost in the well and fishing operations were in progress. The estimated date of completion of the disposal well (March 12) had been postponed.

Source and Nature of Waste

The waste to be injected into the Glorieta formation is a 38-percent solution of hydrochloric acid produced as a byproduct from the manufacture of potassium sulfate. Potassium chloride is treated with sulfuric acid to make the desired potassium sulfate and waste hydrogen chloride, which is absorbed in water. At present the hydrochloric acid waste is discharged into a pond behind the plant, which results in undesirable odor in the area from atmospheric pollution by hydrogen chloride.

The volume of waste produced in this process is approximately 20,000 gallons per day.

Surface Equipment

The pumps that will be in contact with the acidic waste are rubber-lined centrifugal pumps; all surface pipes are made of polyvinyl chloride.

Well Completion and Geology

The bottom 150 feet of the disposal well tubing will be slotted 3-1/2-inch polyvinyl chloride pipe; the upper portion will be epoxy resin type. The bottom 200 feet of the well was reamed and packed with gravel to avoid incursion of sand into the slotted section of pipe attached to the bottom of the well casing.

The Glorieta formation, which is used for waste disposal, is a fine unconsolidated sand at a depth ranging from 1,110 to 1,270 feet. Overlying the Glorieta at a depth of 465 feet is an impermeable zone of gypsum mixed with shale which forms a barrier against the migration of waste materials from the Glorieta to the fresh water aquifer.

COMPANY N

Source and Nature of Waste

The company is operating three disposal wells. The first well is used for disposal of the aqueous waste from a natural gasoline-processing plant. This waste comes from cooling tower blowdown and stripping steam condensate and is produced at an average rate of 50 gpm. The waste contains varying amounts of chromates, sulfates, sulfides, and oil.

The refinery uses two wells to dispose of the entire aqueous effluent waste from the petroleum refinery amounting to 400 gpm. Spent sulfuric acid from the alkylation unit is neutralized and added to the waste stream, which consists of stripping steam condensate, cooling tower blowdown, desalter waste brine, and spent caustic from the caustic scrubbers.

Surface Equipment

The waste from the gasoline plant enters a closed, baffled, oil separator where oil is removed. A small centrifugal pump operating at a discharge pressure of 10 to 20 psig delivers the waste to the well, which is drilled into the Glorieta formation.

The waste mixture from the petroleum refinery is first pumped through a 3,200-gallon separator to remove most of the oil and then into a 100,000-gallon clarifier tank to remove residual oil and sludge. The oil is pumped to the refinery, and the sludge is discharged to a surface pit. The clarified aqueous waste is collected in a pond from which it is pumped into two disposal wells. The discharge pressures of the injection pumps range from 50 to 70 psig. These two wells, completed in the fall of 1958, and the gasoline plant disposal well, completed in the summer of 1959, have operated continuously without difficulties.

Well Completion and Geology

The well casings are cemented from the surface to the top of the Glorieta formation, 1,110 feet deep. The wells are gravel packed at the base to avoid difficulties from sand incursion.

COMPANY O

Source and Nature of Waste

Before the manufacture of phenols could be undertaken by the company a method was required for the permanent disposal of waste byproducts containing derivatives of phenol. Biological treatment was considered first. However, the anticipated volume of waste byproducts from this process was too great to be handled effectively by biological treatment. Subsurface disposal was selected as the best solution to this waste problem and, because no other method was available for the disposal of the phenol waste stream, the manufacturing process was totally dependent on the successful operation of the disposal well.

The phenol process waste contained varying amounts of phenol derivatives and a flocculant type of polymeric waste. No analysis of this waste stream was available. The suspended solids are flocculant, stable, organic polymers formed in the phenol reactors. A brine waste stream containing 15 percent sodium chloride is added to the phenol waste, making a total of 35 gpm of waste that is injected underground. The brine is added to the organic waste as a precaution against swelling of bentonite clay which is present in the disposal formation.

Surface Equipment

A concentrated brine waste stream is run together with the phenol process waste into an open pit sump. The waste is then pumped to a 40,000-gallon tank for clarification and pH adjustment.

A unique method was developed for clarifying the waste mixture. It was improvised because of circumstances that arose during operation. Originally the 40,000-gallon tank was used only to serve as a reservoir of waste for injection in the event that the manufacturing process was stopped. Uninterrupted injection was desired to avoid the possibility of sand incursion into the perforated section of the well.

When the tank was inspected after an extended period of operation, an oil layer was discovered on the surface of the waste and a method for its removal, involving a minimum expenditure of capital, was devised. A pipe was connected to a ball joint welded to the side of the tank, and a pulley was attached to facilitate manual positioning of the pipe to conform with the surface of the waste. The oil film was thus drained into the pipe and conducted out of the tank through the ball joint. To provide a calm surface for removal of the oil film by the drain pipe, the waste influent pipe was changed from a position above the surface to midpoint in the tank. The effluent pipe, however, was located 2 feet directly below the influent pipe, and short circuiting of the two streams occurred. This condition will be corrected in the near future by repositioning the influent pipe. No provisions were made to remove sludge that may form on the bottom of the tank. The 5 gallons of oil that is skimmed from the surface of the waste each day is burned.

After pH adjustment and clarification, the waste is filtered first through a leaf-type filter coated with diatomaceous earth as a filter aid and then through a cartridge filter for a final polishing filtration before injection. Although the waste is filtered in two stages, using leaf and cartridge filters, these steps are not entirely effective and a decrease in injectivity occurs gradually. Usually there is a vacuum at the wellhead immediately following acid treatment; the pressure increases to 400 psig within 4 months of operation. Consequently, the well usually is acidized at 4-month intervals. One injection pump is a two-stage centrifugal pump rated at 75 gpm and 400 psig.

Well Completion and Geology

The disposal well was completed with 50 feet of 24-inch surface casing cemented to the surface. Then a string of 10-3/4-inch casing was set at a depth of 3,000 feet and cemented to the surface to protect a fresh water zone exposed at 2,690 feet. A string of 7-inch-OD injection casing was set at a total depth of 7,650 feet and is cemented to the surface. The 7-inch casing was first perforated in four zones extending from 7,226 to 7,533 feet in the Frio formation.

As soon as the well was completed, a hot (180° F) unfiltered waste stream was injected to determine if the formation would accept the waste under these severe conditions. Within a few hours, injection was completely blocked, and acidizing with a mixture of hydrochloric and hydrofluoric acids did not improve injectivity. The casing was reperforated in the interval opposite 7,152 and 7,218 feet, and the well was placed in service receiving a filtered waste.

The Frio formation is a fine-grained sand containing calcium carbonate as a cementing material. Because of the quantity and type of clay content, the formation requires salinity adjustment as a precaution against swelling. The Catahoula formation, composed of bentonitic clays and thin lenses of sand, overlies the Frio.

CONCLUSIONS

General conclusions drawn from the experience of chemical industries using subsurface waste-disposal systems follow.

1. Each waste disposal problem must be evaluated separately.

2. Selection of surface equipment for preinjection treatment of the waste is contingent on the type of formation available for waste disposal. Precipitate-producing reactions must be avoided, and suspended solids, must be removed from the waste. Coagulation, sedimentation, and filtration are used extensively for preinjection treatment of wastes destined for formations having low permeability measurements. Vugular limestone formations accept waste containing high loads of particulate matter, and preinjection treatment is omitted. The design of the surface treating plant should be as simple as possible, and a thorough chemical and physical analysis of the disposal formation and waste will result in optimum design.

3. A buffer zone of water compatible with the injected waste can be created within the formation by pumping a large volume (250,000 gallons or more) of fresh water into the formation before injection of the waste is started. The buffer zone does not eliminate the need for removing suspended solids.

4. Corrosion of well casing is a serious problem that can lead to loss of an injection well. Careful design and the use of plastic well tubing, together with maintenance of either diesel oil or an inert gas such as nitrogen in the annulus between the tubing and casing, are effective means for dealing with corrosive wastes. Surface equipment must be protected by using special alloys or rubber-lined equipment.

5. Sand incursion into the bottom of the well can be avoided by packing gravel in a reamed cavity at the bottom of the well. Gravel packing the bottom of the well has a secondary beneficial effect; it decreases the required surface pressure for a given injection rate because it increases the effective borehole diameter.

6. The use of a waste reservoir exposed to the atmosphere should be avoided because such a reservoir offers ideal conditions for the growth of

aerobic microorganisms. The bacteria make coagulation, sedimentation, filtration, and chemical treatment difficult and expensive. A pit for emergency detention of the waste is recommended, but as soon as the well can be placed in operation the accumulated waste should be injected into the underground formation. The waste to be injected should be as sterile as possible.

7. Single and multistage centrifugal pumps are best suited for waste-injection systems because they offer more flexibility in operation than do piston-type multiplex pumps. Maintenance cost for a centrifugal pump is lower, packing gland leakage is minimal, and centrifugal pumps offer greater safety in handling dangerous wastes.

8. Pressure injection wells should be equipped with pressure desurgers to avoid the detrimental effects of water hammer which can destroy the well tubing and pump manifold.

9. When the entire manufacturing complex is dependent on uninterrupted disposal of the wastes, it is best to have a second disposal well in standby that can be used if maintenance work on the disposed well becomes necessary.

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