Deep-Well Disposal -- Prerequisites, Priorities and Practices

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INTRODUCTION

Thoughout the United States, the increasing emphasis on pollution and the adoption of state water quality standards have caused many municipalities and industries to seek new and better ways for the satisfactory disposal of their wastes. One possibility for disposing of waste is to inject it in a suitable formation underground where it will be completely isolated from formations containing potable water.

The placement of industrial waste in subsurface formations through deep well systems is a relatively new process. Although the oil industry has been disposing of brine in salt-water disposal wells for over 40 years, only since 1950 have deep wells been used to any extent for industrial waste disposal. Approximately 130 waste disposal wells now exist in the United States. Over 80 of these wells have been installed since 1963, indicating the growth of this process in recent years. Undoubtedly the national emphasis on pollution control will cause many companies to look closely at this process for disposing of effluents which cannot be easily and economically treated for surface disposal.

Much has already been written on this process for industrial waste disposal. A survey taken in 1967 gives the data for 110 deep wells in 16 states which were active in industrial waste injection at that time.[1] It also indicated that the chemical, petrochemical and pharmaceutical industries operated 55 per cent of the existing wells and the refineries and natural gas plants operated 20 per cent. Another survey conducted in 1968 by the Interstate Oil Compact Commission lists information on 118 wells in the United States and 13 in Canada.[2]

PREREQUISITES TO SUBSURFACE DISPOSAL

There are many prerequisites required in considering a deep-well disposal system. The legal aspects of the system might be the initial consideration. Some states do not allow this type of disposal. About two-thirds of the states permit construction of the disposal wells subject to certain requirements. Many states have split authority and do not have a single policy and enforcement agency. Only two states, Texas and Ohio, have enacted specific legislation covering the drilling and operation of liquid waste disposal wells. The Ohio law was enacted in June, 1967. The Texas law, Article 7621b, Vernon's Revised Civil Statutes, was enacted in 1961. It designated the Texas Water Development Board as the "permit issuing agency for all injection wells to dispose of wastes, other than wastes arising out of the drilling for or the producing of oil or gas . . . ". In order to obtain a permit for constructing a deep-well disposal system, a variety of information is usually required on the application. Included could be a plat of the proposed well location, surface features, property boundaries and mineral ownership. Approval of mineral owners within a mile radius of injection is usually required. Subsurface geology and hydrology, nature and amounts of waste fluid and well construction information also may be required by the state regulatory agency.[2]

One limitation of this disposal method is that the area selected for injection must be suitable geologically. The geological features desirable for injection wells are porous, sedimentary rock strata, usually sand, sandstone, limestone or dolomite. The formation must be permeable enough to accept large amounts of fluid. In addition, these formations must be contained between impermeable strata above and below to prevent migration of the injected fluid to other horizons. These geological conditions are found in roughly one-half of the land area of the United States, predominately in the central plains states and the coastal areas of the southeast. Therefore, present deep-well disposal systems are concentrated heavily in the north central and Gulf Coast areas. This is due not only to favorable

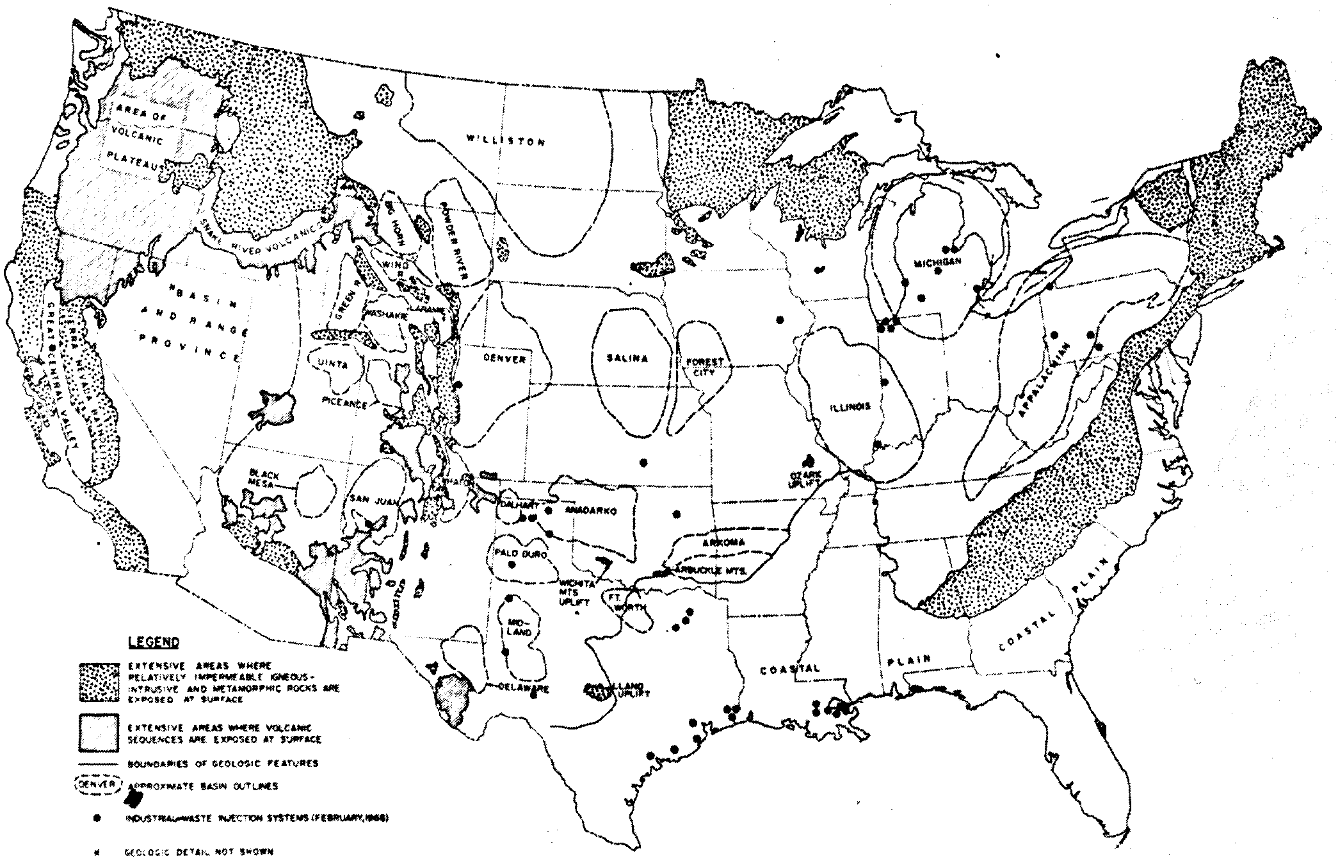


FIGURE 1

Basins and Geologic Features Significant in Deep-Well Disposal Evaluation[6]

geological conditions, but also to heavy industrial concentration and the favorable attitude of states in those areas to the underground injection technique of disposal.[3]

The synclinal basins are particularly favorable sites for waste disposal wells since they contain relatively thick sequences of salt-water-bearing sedimentary rocks and because the subsurface geology of the basins is relatively well known.[4] Figure 1 is a map which shows these basins and other geologic features.[5] Also shown are locations of many of the industrial-waste injection systems. Regions shown in Fig. 1 where a thick volcanic sequence lies at the surface generally are not suitable for disposal well systems since the volcanic rock contains fresh water.

Less is known on the geology of areas other than the basin areas, but they may be generally satisfactory for waste injection systems if they are underlain by sedimentary rocks of sufficient thickness which contain saline water, provided formations used for injection are isolated from fresh water formations by an underlying and overlying impermeable strata. Confining strata that are considered impermeable are unfractured shale, clay, salt, anhydrite, gypsum, marl and bentonite.[6]

Some possible hazards in injecting effluent underground must be considered in the geological and hydrological studies.[7] These include the presence of faults or natural vertical fractures such as shown in Fig. 2. Presence of these in the region of the disposal well could permit migration of the waste to formations of potable water. Another hazard is the presence of an unplugged or improperly plugged well in the vicinity of the disposal operation as shown in Fig. 3. Increase of pressure in the disposal aquifer may cause the formation brine or injected wastes to migrate to the open well and then to a fresh water aquifer. If any of these conditions are suspected, pumping tests should be made as a part of the

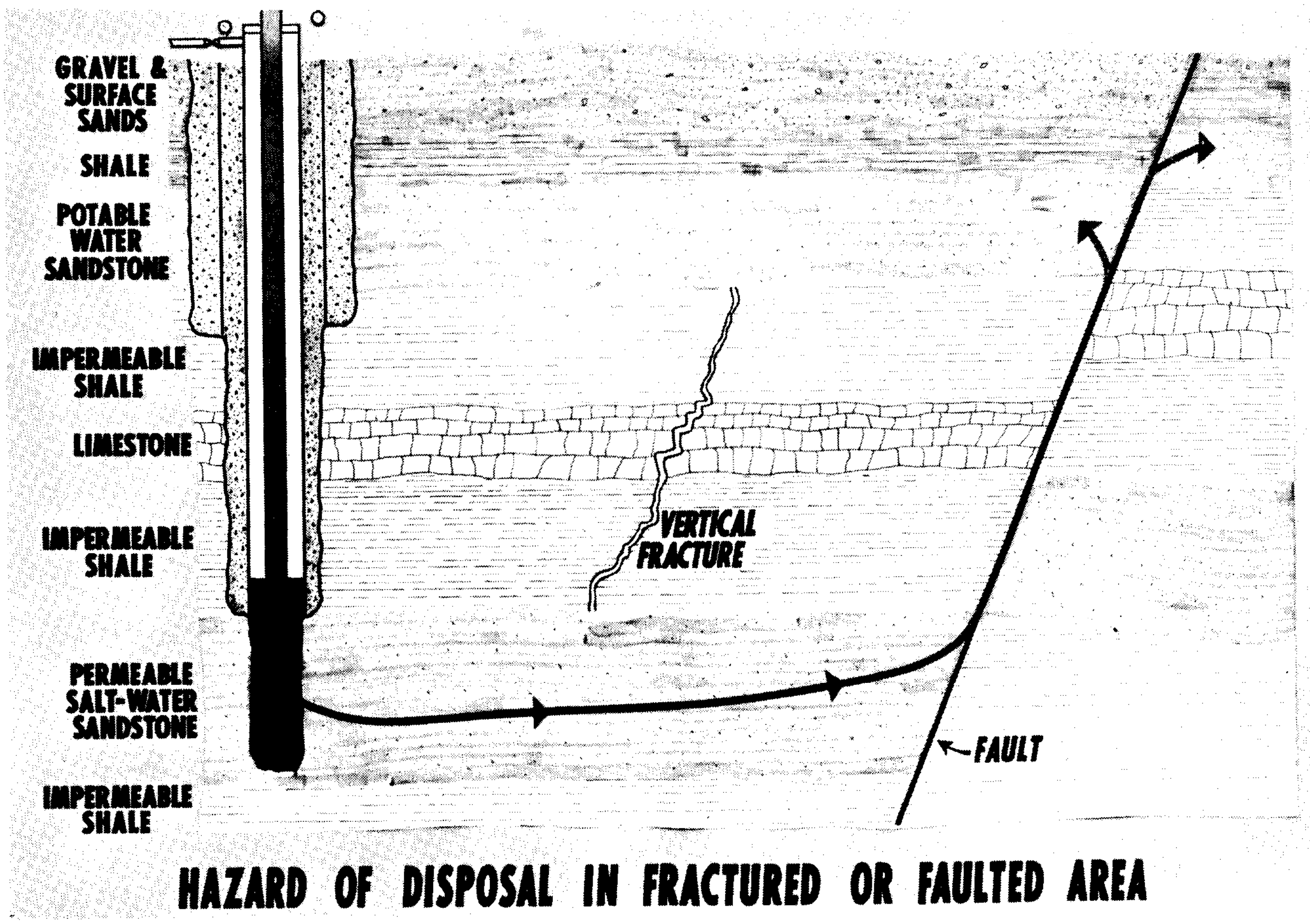


FIGURE 2

feasibility study to determine definite answers.

Although the suitability of the site and geological conditions are very important, there are other factors which may be considered of equal importance in the prerequisites for deep-well disposal. One of these factors is the suitability of the waste effluent for subsurface injection. Involved in this consideration are the characteristics of the waste and its compatibility to the disposal formation and the interstitial fluids. It is necessary that the effluent be free of suspended solids, that it will not form a precipitate with the formation fluid and that it will not react chemically with the formation to form any type of plugging material.

According to Selm and Hulse[8] and MacLeod[9], plugging can be caused by the following reactions:

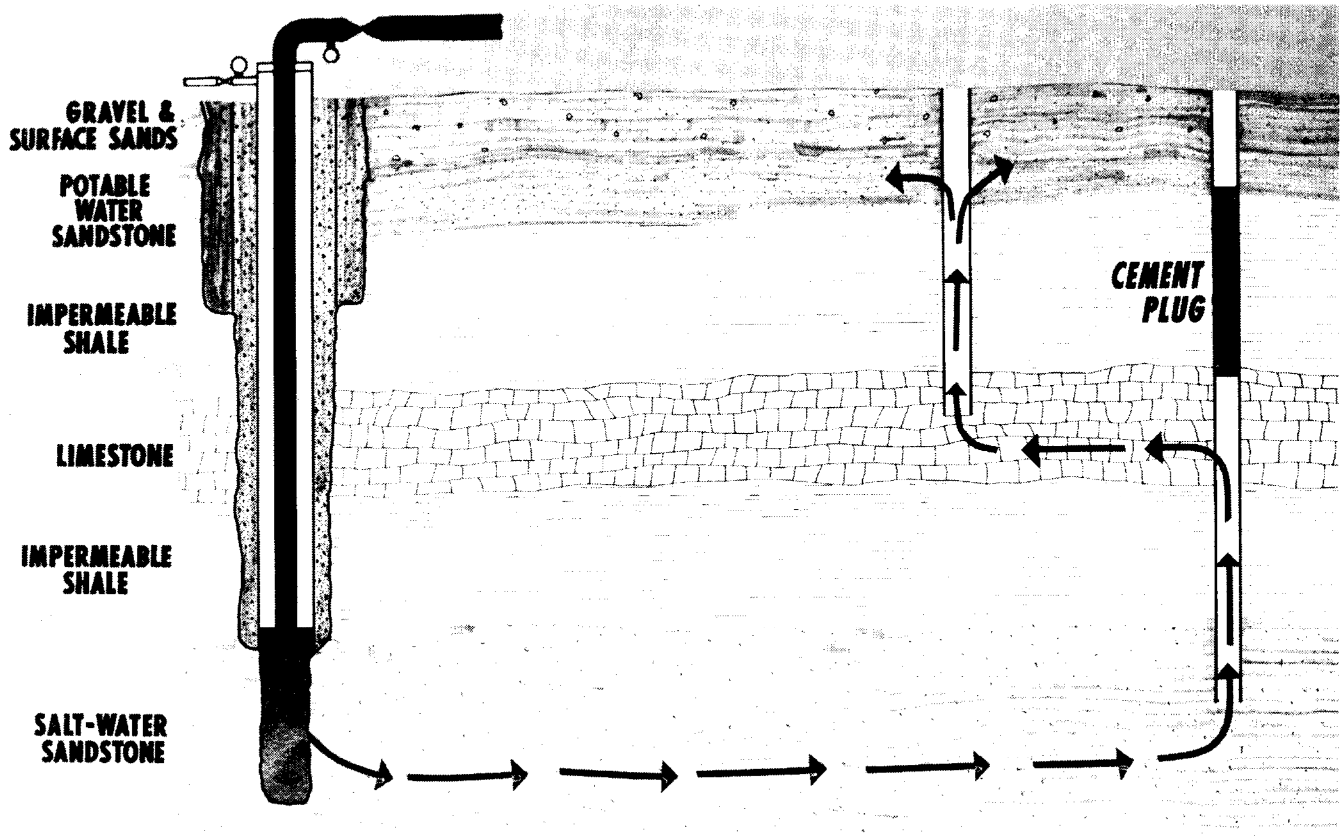
1. Precipitation of alkaline earths, such as calcium, barium, strontium or magnesium, as relatively insoluble carbonates, bicarbonates, sulfates, orthophosphates, fluorides or hydroxides.

2. Precipitation of heavy metals, such as iron, aluminum, cadmium, nickel, copper, zinc, manganese, chromium and others, as insoluble carbonates, bicarbonates, hydroxides, orthophosphates and sulfides.

3. Precipitation of oxidation-reduction reaction products.

4. Polymerization of resin-like materials to insoluble solids under aquifer temperature and pressure.

The porosity of the disposal formation is a gauge of the capacity of the zone from the point of injection. The permeability of the formation controls the injection rate at any given pressure. Considerable material has been written in regard to both the formation capacity and pressure buildup obtained by injection of the waste. These two questions are discussed thoroughly elsewhere, so further elaboration will not be attempted in this paper.[10]



HAZARD OF DISPOSAL WITH ABANDONED BORE HOLE IN AREA

FIGURE 3

Normally a feasibility study is conducted to determine the extent of treatment required for the waste prior to injection. This will usually include some means of separating suspended solids and/or organic oils. A second step usually involves some type of filtration to remove any remaining suspended solids. Tests with a core of the disposal formation will determine the size of solids which can be tolerated in the waste.

The study also should include a chemical analysis of the waste to ascertain the need for chemical treatment prior to injection. An analysis of the formation fluid would be desirable to indicate the reaction expected during injection. Laboratory injection tests performed with cores from the disposal formation can determine expected rates and confirm anticipated reactions.

A look at a feasibility study recently conducted for a large Gulf Coast chemical company will give an excellent summary of the prerequisites required when considering deep-well disposal.

This company has about thirty different chemical units producing a variety of waste effluent. About 90 per cent of the waste can be disposed of in a satisfactory manner. The remaining 10 per cent, amounting to approximately one million gallons per day, requires some means of disposal. The company wished to investigate the use of underground injection for disposal of this waste, so it was necessary to conduct a feasibility study to determine if this method was applicable.

A "wildcat" well had been drilled and abandoned on the company's property adjoining their plant site. The feasibility study was also to determine if this well could be used as a disposal well for the plant waste.

After examination of logs and other data on the well, it was determined that there were 893 feet of injectable sands in the Miocene formation. Samples of the Miocene sand were obtained from a nearby well for use in the study.

Initial tests indicated that the waste effluent was not compatible with the formation brine until the effluent was pretreated to remove the organic portion. Subsequent tests were conducted on test cylinders made of packed Miocene sand by flowing the filtered effluent and formation brine through these cylinders. Results in these tests showed the necessity of removing from the waste effluent all suspended solids larger than 25 microns prior to injection to prevent formation plugging. It was also necessary to buffer the effluent to reduce the pH to 5.5, since clays present in the Miocene formation, such as illites, kaolinites and montmorillonites, are subject to swelling in the pH range above 7.5. Although the 50-hour flow tests used in the study were not long enough to definitely show how the buffering affected the flow rate, one test did indicate that the buffered effluent had less tendency to plug the sand than the effluent with higher pH value.

The study also suggested that the abandoned well could be economically recompleted for use as a disposal well and that the disposal formation would accept the modified waste effluent at the desired rate.

WELL COMPLETION PRIORITIES

There are several priorities to observe in well completion for subsurface disposal. The selection of the proper kind of casing and the correct cement rate a high priority.

The casing used in each well must be of a material which will be compatible with the effluent being injected in the disposal formation. In most cases, only the casing or tubing used for injection will be exposed to the waste effluent and need be given special consideration. The selection must be made in the light of the corrosive nature of the specific waste to be injected. Generally, injection casing can be chosen from special steel alloys, fiberglass, or plastic-lined steel.

Effluents in different areas of the country vary considerably in chemical composition, pH, minor chemical contaminants and their effects on the properties of set cement. In the downhole well design for disposal of these effluents, no single recommendation seems to fit all conditions. Pipe and cement programs may differ considerably in different parts of the United States. Specific emphasis should be placed on tests with the effluent to be absolutely certain of the best and safest recommendation. There appear to be no short cuts in test methods; these generally require long-term laboratory studies under static and/or dynamic conditions. The resistance of one type of cement to a specific fluid may not be valid for another due to trace chemicals having adverse effects on the set cement.

If one could standardize on a single cementing composition for these disposal wells it appears that resins combined with the cement or straight resin should be used to offer the maximum resistance to the more corrosive effluents being disposed of in subsurface reservoirs.

Figure 4 illustrates the casing and cementing program for a disposal well in the Gulf Coast area. This well is used to dispose of 1 per cent sulfuric acid at a depth of 6756-6875 feet. The well was completed as shown with 40 ft of 24-in. pipe driven in the hole and then 2013 ft of 16-in., J-55 steel casing cemented in 22-in. hole as surface pipe. The cement used for this application was Halliburton LIGHT cement with 3 per cent salt, mixed at a weight of 12.5 pounds per gallon. The LIGHT cement is a blend of 65 per cent portland cement, 35 per cent fly ash and 6 per cent bentonite. It was selected for this well because it possesses good sulfate resistance. This cement was "tailed in" with Class "H" cement containing 2 per cent calcium chloride, mixed at a weight of 15.5 pounds per gallon. This was used to provide a heavier slurry around the lower portion of the casing.

In like manner, the intermediate string of 10-3/4 in., J-55 steel casing was cemented from 3850 ft to surface in a 14-3/4 in. hole using the same cement combination as that used in the surface pipe cementing. The long string of casing was 7-5/8 in., J-55 casing. This was cemented from 6900 ft TD to surface in a two-stage cementing operation. The first stage was cemented with a Pozmix cement mixed at a weight of 14.1 lb/gal. This is a cement containing 50 per cent portland cement and 50 per cent pozzolans by volume. The second stage was composed of the LIGHT cement mixed at a weight of 12.3 lb/gal. This stage was cemented to surface.

A 4-1/2 in., J-55 casing with plastic coating was installed with a permanent-type packer in the 7-5/8 in. casing. Injection was made through perforations in the casing to the disposal formation.

Another Gulf Coast waste disposal well in a chemical plant was completed to dispose of

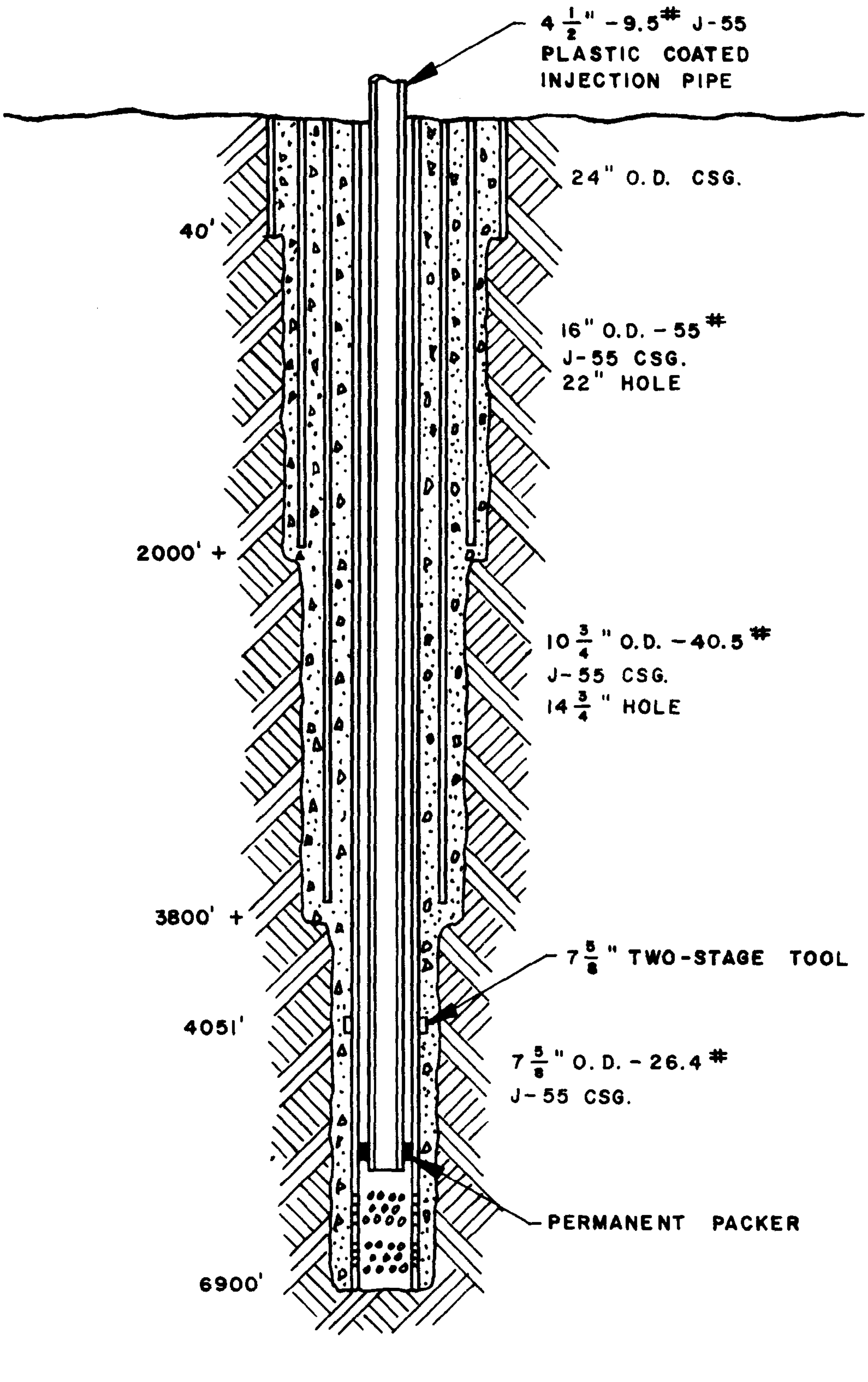


FIGURE 4

Casing And Cementing Program—Gulf Coast Well a chemical waste containing acetic acid and chlorinated derivatives. The corrosive nature of this waste prohibited the use of ordinary steel casing. A baked epoxy fiberglass tubing joined to a section of special Hastelloy "C" welded casing was extended through the disposal sand for the injection tubing. The entire tubing-casing annulus was then cemented to surface using a blend of Special Incor cement and pozzolan. This material was also used to cement the long string. This particular material was selected when laboratory tests showed this composition to be virtually unreactive with no significant loss in compressive strength after submersion in this corrosive waste for over 90 days at 160°F.

This well was completed by perforating, backwashing with gas and gravel packing for sand control. After two years of disposal, this well was still performing satisfactorily at an injection rate of 7000 BPD and a pressure of 200 psi.

In a western state a well for disposal of muriatic acid was cemented using Hydromite, a blend of a special gypsum cement and a powdered resin. The Hydromite was retarded to give one-hour pumping time for placement of the 3-1/2 in. fiberglass pipe in a 5-1/2 in. hole. The Hydromite obtained a compressive strength of over 1000 psi in 24 hours and had good acid-resistance qualities. This same material was also used in cementing a well for disposal of hydrochloric acid.

Two disposal wells in the Gary, Indiana area were completed in the Mount Simon formation for disposal of steel "pickle liquor". For each of these installations, resin cement was used for cementing the pipe to surface. General completion practice for the deeper disposal wells in the Mount Simon formation is to run surface casing, intermediate casing and a long string with all casing cemented to the surface. To date, most cementing has been accomplished with either resin cement or a pozzolan-cement blend. Current trends are to tailor the cement for each specific effluent to insure maximum compatibility. The importance of giving top priority to the casing selection and the cementing material choice cannot be overemphasized.

DISPOSAL PRACTICES

Industrial waste disposal wells now in operation range from 300 to 12,000 feet in depth with the most typical depths from 1000-4000 feet. Surface equipment includes pumps, valving, and piping constructed of material which will not be affected by the corrosive waste being handled. Pumps can be either centrifugal or positive displacement, depending on the injection pressure required. In many cases an oil separator, a waste settling tank, a clarifier, equalizer basins, filters or lagoons are necessary for the pre-treatment of the waste prior to injection.

A Bureau of Mines publication gives an excellent resumé of 15 industrial disposal well installations, showing the nature of the waste, surface equipment and well completion and geology.[11] Other papers discuss deep-well disposal of steel mill wastes, wastes from refineries and chemical plant waste.[12,13,14]

Liquid waste injection operations are similar in many respects, yet each plant must provide the proper surface equipment and well completion required by the waste effluent being produced.

Solid waste disposal underground has been successfully accomplished in shale formations. The waste is injected into the shale following the initiation of fractures in the shale by hydraulic pressure application.[15] The design of wells for this type disposal is similar to the design for liquid disposal. However, stronger casing should be used in anticipation of higher pressures in the injection process. A different type of perforation should be used to help orient the fracture horizontally.

This type system has been successfully used to dispose of radioactive waste by mixing the waste with a cement slurry and pumping the mixture into the hydraulically fractured disposal formation. Over the past seven years in one area, approximately one million gallons of radioactive waste have been injected underground through 10 slots in the casing in a total of 17 injections.

Another advisable practice in deep-well disposal operations is the use of a monitoring well located in the vicinity of the disposal well. A monitoring well is usually completed through all known fresh water sands with the casing cemented to the surface. The casing may be perforated to allow sampling of the deepest fresh water strata. Periodic sampling and analysis of the water from this well would reveal any possible contaminants from the injected waste.

Experience has shown that if the necessary prerequisites are observed when planning a deep-well disposal system, and the completion priorities are followed, the chances for a successful, practical operation are very good.

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