Ultimate Disposal of Waste Waters by Deep Well Injection

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INTRODUCTION

The final disposition of difficult-to-treat waste water, e.g., brines and of the residues resulting from the treatment and renovation of waste waters, e.g., sludges, is generally termed "ultimate disposal". The techniques of ultimate disposal include the treatment, handling, or placement of the waste in such a manner that it never comes in contact with human activities while in its noxious form.

Solutions to the ultimate disposal problem include: (1) subsurface storage; (2) conversion of wastes to innocuous end products; (3) storage in lagoons and ponds, or spreading; (4) ocean disposal; and (5) conversion to useful products.

As pointed out by Mr. Herring of the Texas Railroad Commission in his paper entitled "Pollution Control and Oilfield Brine Disposal" presented April, 1971 at the Eighteenth Southwestern Petroleum Short Course, the Commission has tightened up its requirements as evidenced by Statewide Rule 8 (C) commonly known as the Statewide No-Pit Order as well as the new amended Rule 8 (D) which concerns itself not only with offshore drilling but includes lakes, streams and rivers within the State of Texas. As a result of such requirements the injection of brine wastes into subterranean formations while inherently costly, is currently recognized as the most effective means of disposing of this type of waste, with the possible exception of some coastal fields where ocean disposal of the brine is feasible. This paper will be limited to a discussion of deep well injection including injection systems, geological considerations, brine considerations, and costs.

DEEP WELL INJECTION

Deep well disposal requires the injection of liquid wastes into a porous subsurface stratum which contains noncommercial brines. In Texas the stratum is required to have impermeable strata above and below so as to isolate the stratum from usable underground water supplies or mineral resources. Such a requirement does not complicate the problem due to the fact that approximately one-half of the land area in the United States contains these impermeable conditions that sandwich the desired formation.

GEOLOGICAL CONSIDERATIONS

In selecting a subsurface disposal site, the porosity, permeability, and areal extent of the stratum must be evaluated to insure storage of the brine at safe injection pressures over a period of about 15 years. Sedimentary rocks in the unfractured state generally can store large volumes of brine. This group of rocks includes sandstones, limestones, and dolomites. Unconsolidated sands are generally excellent disposal formations. Fractured strata should be avoided since vertical fissures may exist and the injected waters may travel vertically towards usable water supplies. Occasionally hydraulically fractured shales may be used for small volumes, but in general, shales are not considered to be good disposal formations.

The dynamic pressure surface encountered in injection wells can be described by Darcy's Law and is the reverse of that of a conventional artesian well. The greatest pressure in the disposal stratum during injection occurs at the well and decreases inversely and exponentially with distance from the well. Some published data on disposal wells indicate limestone formations taking 6000 GPM with only hydrostatic head necessary while dense sandstone strata have been reported requiring 2000 psi to inject 100 GPM.

The disposal stratum should cover a large area, and generally the thickness of the disposal reservoir can vary from several feet to more than 5000 feet. The permeability of the stratum as well as the thickness of the stratum determines injection capacities.

In many cases the disposal well injectivity is monitored by calculating the well index. This index is the ratio of the flow in GPM to the square root of the wellhead pressure in psig. The well capacity and system head curves for the injection pumps can be estimated from the relationship of the well index to flow. A typical curve is shown in Fig. 1.

The wellhead pressure may be defined as:

$$P_H = (P_R + \Delta P_D - P_C) + \Delta P_F$$

in which

P_H = operating wellhead pressure

P_R = reservoir pressure at bottom of the well

P_C = pressure at the bottom of the well resulting from hydrostatic head

ΔP_D = driving pressure at the bottom of the well

ΔP_F = pressure drop resulting from pipe friction.

This relationship indicates that the driving force in deep well injection is the difference between bottomhole pressure and the reservoir pressure. Frictional pressure loss is generally neglected.

Cores of the injection horizon are necessary in evaluating the porosity and permeability of the stratum, but even more important the core sample is used to determine possible reactions between the rock and the waste water or between the water or fluid in the injection horizon and the injected waste water.

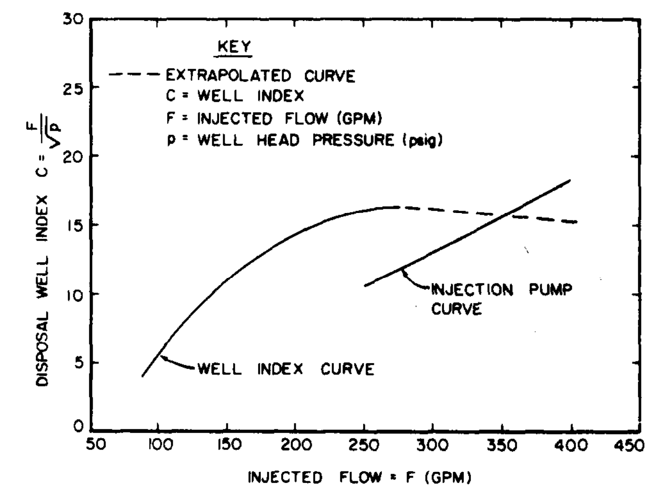

FIGURE 1

BRINE CONSIDERATIONS AND PRETREATMENT

The primary purpose of pretreatment of brine is to minimize corrosion of the injection equipment and to prevent premature blockage of the injection well face. Wells can be plugged by entrained solids, oil and bottom settlings, sulfur, bacteria, algae, and by precipitation of salts after treatment. The amount of pretreatment necessary is, of course, dependent upon the nature of the formation into which the brine is being injected. While a sand formation demands that few clogging materials be present in the treated brine, some formations contain fractures and large pores that are not susceptible to clogging.

The surface installations and arrangements of pretreating units employed in salt-water disposal systems vary with the locale, type of reservoir, characteristics of the injection formation, type of water being treated, and the type of operation, i.e., closed or open system. In some areas cavernous formations are found which offer little or no resistance to the injection of salt water. In such instances the surface equipment is quite simple and probably should include only an oil skimmer. In most cases, however, it will be necessary to stabilize and filter the water prior to injection.

Open system operation usually requires facilities for skimming of oil, aeration, chlorination, mixing of chemicals, coagulation, sedimentation, and filtration. Closed systems will require facilities for trapping oil, feeding chemicals, sedimentation, and filtration with complete exclusion of air throughout the system. Obviously, the closed system operation is somewhat more complex than the open system, especially in the area of using coagulants and bactericides without disrupting the normal operation. Return of the brines to subsurface formations necessitates, then, any changes in chemical equilibria occasioned by pressure reduction or temperature, or change in composition due to loss of dissolved gas must be returned to stable equilibrium conditions. Whereas the closed system attempts to minimize the changes in composition of the water exiting under original equilibrium conditions brought about by reduction in pressure and temperature, the open system attempts to establish new but equally stable conditions. The predominant change in chemical equilibrium is the decomposition of bicarbonates with liberation of carbon dioxide resulting from the pressure reduction.

Some of the undesirable characteristics, and pretreatment processes which may be employed to eliminate or alleviate the effects of these characteristics from the injected fluid prior to subsurface disposal are summarized in Table 1. In practically every location where salt-water injection is practiced, use of nonferrous gathering lines is preferred due to the severe corrosion generally present when brines are conducted through steel lines. Cement, asbestos, wood, coal-tar asphalt impregnated fiber, cast iron, plastic, vitrified clay, and cement-lined pipe all fulfill the requirements of a noncorrosive material, though each type has its distinct shortcomings. The pressure requirement normally dictates the kind of pipe to be used.

All gravity lines should be laid to grade when possible to prevent gas locking. In areas where this is impossible, a vent should be placed on the line to discharge accumulated gas. The vent should be large enough to allow gas to escape without jetting water from the line. Properly designed gathering systems avoid right angle turns wherever possible and provisions should be made to use "go-devils" periodically for scale removal when water is known to contain calcium and magnesium salts.

A schematic drawing of a typical complete sub-

TABLE 1

UNDESIRABLE BRINE CHARACTERISTICS AND POSSIBLE METHODS OF PRETREATMENT

Characteristics	Treatment
A. SUSPENDED MATERIAL	
1. Oils and Floating Material	Oil Separators Skimming Equipment
2. Solids, Colloids, etc.	Coagulation Sedimentation Centrifugation Gravity Sand Filtration Pressure Sand Filtration Diatomite Filtration
3. Biological Forms (slime forming bacteria and algae)	Chlorination and Filtration
B. DISSOLVED SUBSTANCES	
1. Gases	Purging Stripping Vacuum Degasifier
2. Ions (principally those which react to form precipitates)	pH Adjustment Neutralization Precipitation Coagulation and Removal of Precipitate
C. CORROSIVENESS	Neutralization pH Adjustment and Control

surface waste-disposal system is shown in Fig. 2. The oil separator is required since oil tends to plug disposal formation, and oil can be recovered and reused. The usual separator consists of a tank with multiple internal baffles to cause the oil to separate and rise. If a clarifier is then used, heavier material such as dirt, sludge, and suspended solids can be removed by sedimentation. Mechanical equipment such as rakes and skimmers can be used with this equipment. Since not all solids are completely removed by sedimentation, filters are then used to protect sand or sandstone formations from becoming plugged. The filter screens are usually metal and coated with diatomaceous earth. In certain instances sand filters have been used. If wastes contain slime that will promote growth of bacteria, algae, iron bacteria, sulfate-reducing bacteria, or fungi, a suitable bactericide such as quaternary amines, formaldehyde, chlorinated hydrocarbons, chlorine or copper sulfate is added to control their effects. The pH may also be adjusted at this point. The clear water storage tank is normally equipped with a float switch designed to operate the injection pump at given liquid levels. The size and type of injection pump are determined by wellhead pressure, waste water flow, and brine characteristics. Multiplex piston pumps are most commonly used when wellhead pressures greater than 150 psig are required. At lower pressures single-stage centrifugal pumps may be used.

The type of well to be used is of considerable economic interest. There are four types of wells that can be used for injection; (1) a newly drilled well for the specific purpose of injection; (2) an abandoned dry hole that can be converted to an injection well; (3) a poor producing well converted to injection; and (4) an abandoned producing well converted to injection. The last three have the advantage of being previously drilled but the cost of conversion to injection type may be high, so each must be considered separately. The newly drilled hole has the advantage of being able to be placed in the most desirable position. Donaldson in Bureau of Mines Information Circular number 8121 outlines typical injection wells and summarizes findings for 20 separate installations including costs, depths, pressures, and types of formations.

ECONOMICS

The economics of each different type of disposal well must be considered separately. The cost will vary with; (1) the depth of the disposal well to be drilled or renovated; (2) the type of well completion; (3) the amount of coring and testing required, (4) the type of surface equipment required; (5) the pressure required for injection; and (6) the size of the well bore and casing. A review of the current literature, as sparse as it is, indicates that these well costs

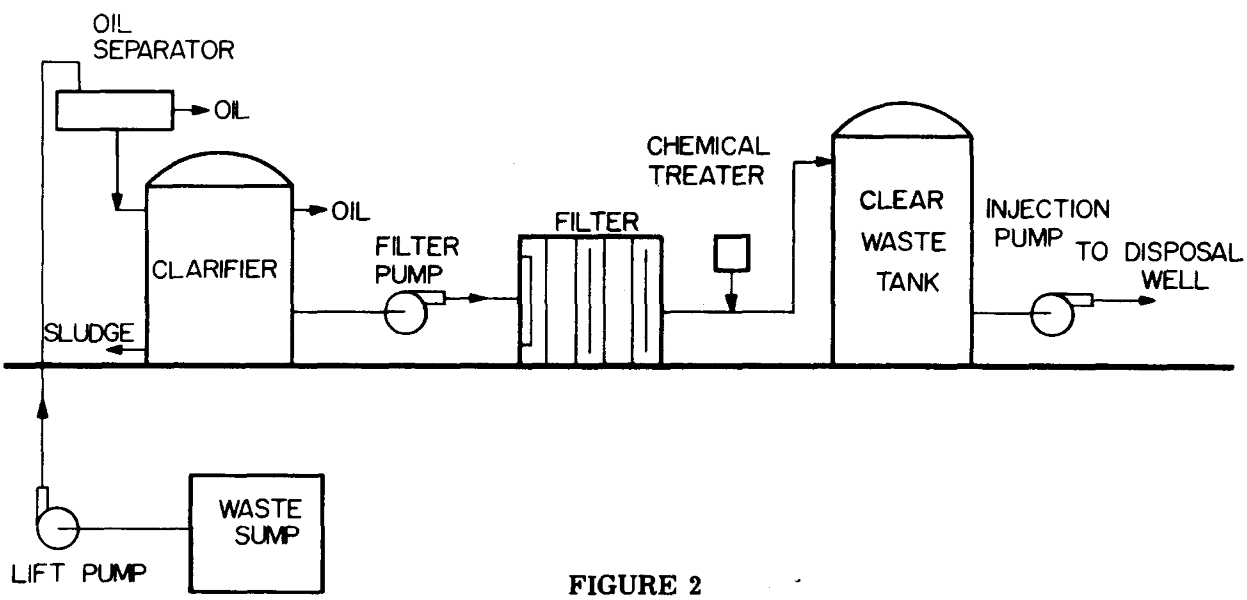

FIGURE 2

can vary from $30,000 when no surface equipment is necessary at depths of 1500 ft, to $1,500,000 at depths of 12,000 to 14,000 ft with complete pretreatment facilities.

The literature reports many cost figures as related to injection wells for industrial wastes but specific data as regards brine injection is almost nonexistent. A comprehensive review of cost data reported in the literature has been correlated for all types of industrial wastes on the basis of operating and capital costs required for a given flow rate.

The capital and operating costs for deep well injection systems are presented in Figs. 3 and 4. Admittedly the costs are only "ball park values" but they do provide some insight into the economics of deep well injection. These costs are presented for different flow rates with parameters of wellhead casing pressures. The capital costs are presented in terms of total capital investment required whereas the operating costs are expressed on an annual basis. In order to evolve the correlations it was necessary to select typical geological, mechanical, and hydraulic systems.

Variables such as depth, effective thickness, porosity, permeability and reservoir pressure were normalized and the diameter of the injection stream was chosen at seven inches. Geological characteristics assumed were based on evaluation of existing data and represent conditions at more than 50 percent of the reported installations. Power costs were assumed to be 0.008 dollars per kilowatt hour, interest rates at six percent and a payout period of 15 years.

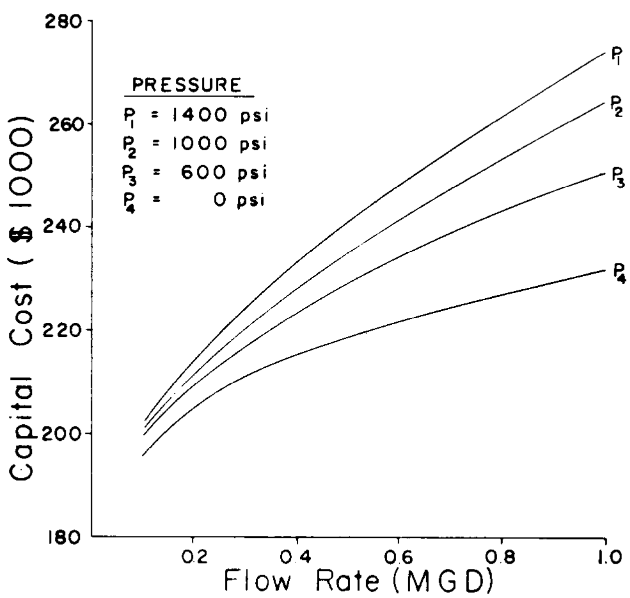

FIGURE 3

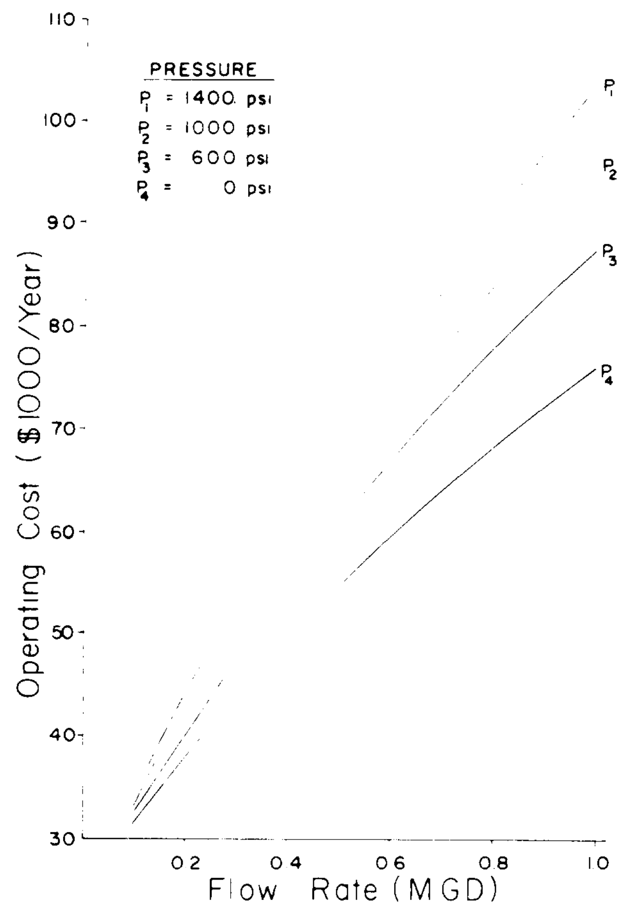

FIGURE 4

The Engineering News and Building Cost Index of September 1971 was used for estimating the capital costs. The curves reflect minimal pretreatment, namely filtration. Any additional treatment must be added to the capital and operating costs as shown.

PROGNOSTICATION

The disposal of brines as currently practiced is not a cheap process; consequently, one must look for alternate means of economically handling the problem. The obvious alternative is to convert the waste by-product into a salable byproduct, thus, economically speaking, eliminating the problem. It has been estimated that if the bromine, iodine, magnesium, and lithium alone were recovered from the oilfield brines in the continental limits of the United States, their market value would be $1.5 billion dollars per year, and if elements such as rubidium, cesium, potassium, and chlorine were also recovered, \$3.0 billion dollars per year would be realized. On the injection well basis this represents the cost of approximately 24,000 new wells per year. Processes already in existence for the removal of dissolved mineral salts from sea water (Office of Saline Water), whose concentrations are much less on the average than oilfield brines, could be and are being adapted for use in the oil fields. Modern techniques such as: (1) removal of calcium by fixed bed ion exchange; (2) precipitation of magnesium ammonium phosphate by ammonia and phosphoric acid; (3) sulfur recovery by the modified Georges Process; (4) magnesium metal production by the Dow or American Magnesium method; and (5) reverse osmosis processes are available for adaptation to mineral recovery in the oilfield brine area. The hypothesis that brine is a by-product of oil production and should be considered as a noxious material of no value is incomprehensible.

The author feels that the prognosis for the solution of the oilfield brine problem is good and the only limitation is the IMAGINATION of those concerned.