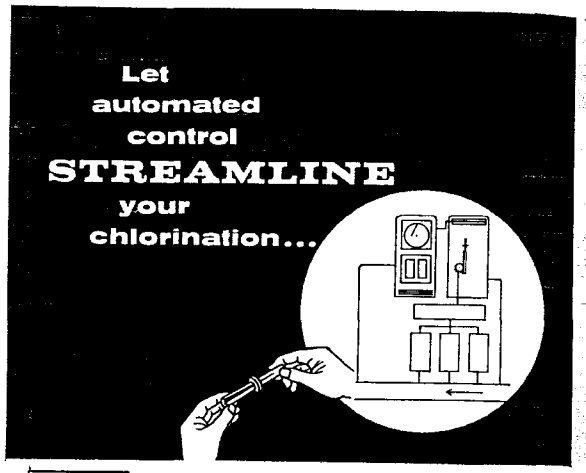


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FEBRUARY 1962

DEEP WELL DISPOSAL OF INDUSTRIAL WASTEWATER

Charles W. Querio and Thomas J. Powers

The disposal of wastewater in subsurface formations was developed in the 1930's by oil producers as an oil recovery and brine disposal method. The method has not been widely publicized as a means of solving other water pollution problems, although several industries have used it successfully.

The deep-well method is worthy of study when concentrated, toxic, or odoriferous wastes are produced in an area of limited stream flows or strict regulations.

Fundamentally the method is the storage of unusable water in the pores of a formation which already contains unusable waters. The cardinal principle which must be observed is that there must be no pollution of usable ground water.

The Dow Chemical Company has been successful in using subsurface disposal for over 10 yr. The chemical wastes which have been and are being disposed of include: (*a*) saturated sodium chloride solution; (*b*) concentrated calcium-magnesium liquors; (*c*) wastes liquors containing phenols, chloro-phenols, bis-phemols, and methocel; and (*d*) weak caustic wash waters from petrochemical processes. These wastes are being returned to limestone and sandstone formations at depths greater than 3,000 ft.

Charles W. Querio is Assistant Superintendent of the Well Department for The Dow Chemical Company, Midland, Mich.; Thomas J. Powers is Consulting Director of Dow Industrial Service, Cleveland, Ohio.

The paper was presented at the 34th Annual Meeting of the Water Pollution Control Federation in Milwaukee, Wis., Oct. 8–12, 1961.

"Deep well" means a well in a formation far below and isolated from fresh water strata. To achieve this, the depth of the wells may vary from 900 to 12,000 ft below the surface. Shallow structures above 900 ft have been used, but only after careful examination since they cannot tolerate high injection pressures without rupturing the formation. Rupturing may open fracture planes extending vertically into usable fresh-water zones.

Knowledge of the geology of the area will aid in determining the depths that must be reached to insure impermeable cap rocks or formations.

To use the method, then, an industry must be located over a porous, permeable formation with an impermeable cap which seals it from fresh water aquifers. The successful application of the method requires a thorough understanding of the principles involved.

Planning for a subsurface disposal system should include:

1. Determination of the amount of total wastewater and maximum rate at which it must be handled by the system.
2. Selection of a disposal formation.
3. Determination of the facts as to whether wastewater is going to require surface treatment before injection.
4. Receipt of the necessary permits from state regulatory agencies.

The amount of waste is a matter of process and plant efficiency. Every effort should be made to reduce the waste volume to a minimum because of the obvious advantages leading to greater chances for successful and economic disposal.

Selection of Disposal Area

Selection of a disposal formation requires geologic and hydrologic study of formations in the area. A feasibility survey based on known information about wells drilled in the area will aid in a decision to continue study. The next step is to drill a test well. In unproven formations the test well is the only way to determine the true potential. The major financial risk involved is the drilling cost, testing, and possibly plugging costs if the potential is not successful. Comprehensive testing will provide the data necessary to justify further well completions and subsequent disposal.

Surface treatment of waste is controlled by the quality of fluid that the formation requires. Suspended solids which might plug the pores or porosity of the formation may have to be reduced or removed. The wastewater may have to be stabilized to prevent its chemical reaction with the fluid or matrix of the formation.

State agencies can be helpful in providing proper information about well drilling and completion practices as outlined by the laws.

The disposal formation and its ability to handle the wastewater provides the main key to the success of subsurface disposal. The following are some of the elements which must be understood for successful application: (*a*) porosity; (*b*) permeability; (*c*) reservoir pressure; (*d*) formation characteristics, including individual well behavior and reservoir behavior; (*e*) areal subsurface geology; and (*f*) well construction and completion.

Porosity

Porosity is probably the best-known and understood physical characteristic of a formation. It is used to determine the storage capacity of the reservoir and is usually expressed on a percentage basis. Two types of porosity are recognized by reservoir engineers: (*a*) absolute and (*b*) effective.

Absolute porosity is the percentage of void space with respect to the bulk volume regardless of the interconnection of pore voids (Equation 1). A media may have a high absolute porosity and yet have no conductivity to fluids because the pores are not interconnected. Clay is an outstanding example of high porosity and very low conductivity. Lavas and other igneous rocks with vesicular porosity also fall into this group.

$$\text{Absolute porosity} = \frac{\text{bulk volume} - \text{grain volume}}{\text{bulk volume}} \times 100 \quad (1)$$

Effective porosity is the percentage of interconnected void space with respect to the bulk volume (Equation 2). It is an indication of conductivity to a fluid but not a quantitative measure of it.

$$\text{Effective porosity} = \frac{\text{interconnect pore volume}}{\text{bulk volume}} \times 100 \quad (2)$$

Several satisfactory methods for determining porosities of rocks, in the laboratory, have been developed. These methods originally used small cuttings of the formation rock. Today most formations being tested are cored using a diamond core bit which gives the technician a better sample of rock for evaluation.

Another method available for determining the formation porosity is provided by electrical well logging. Downhole electrical techniques have been improved and developed to the point where a careful analysis of resistivity, neutron, and sonic logs can provide values for fluid saturation, porosity, and indications of permeability.

Permeability

Permeability is a measure of the ease with which a fluid may flow through a

porous medium. If the pores of the medium were not interconnected, there would be no permeability. Darcy, working with flow-through sand filters, was responsible for development of the basic theory for flow of fluids through porous media. His conclusions have been found to apply to viscous flow through any porous medium. Darcy's Law can be stated as:

$$v = -\frac{K}{\mu}\frac{dp}{dl} \quad \ldots\ldots (3)$$

where

v = apparent velocity,
K = permeability (proportionality constant),
μ = viscosity of flowing fluid, and
$\frac{dp}{dl}$ = pressure drop per unit length.

The minus sign indicates that dp and dl are measured in opposite directions.

K or permeability for a given system is essentially independent of the type of fluid flowing.

For the condition where a non-compressible fluid is flowing the solution for the differential would be:

$$Q = \frac{KA(P_1 - P_2)}{\mu L} \quad \ldots\ldots (4)$$

where

Q = flow rate,
K = permeability,
A = cross-section area,
$P_1 - P_2$ = pressure gradient,
μ = fluid viscosity, and
L = length.

Permeability is generally expressed in terms of darcys. One darcy is equal to one cubic centimeter per second flowing across a cross-sectional area of one square centimeter, under a pressure differential of one atmosphere per centimeter of length and with a viscosity of one centipoise. Because one darcy is a high permeability for most porous media, permeabilities are reported in millidarcies.

Laboratory methods using small cuttings as obtained in rotary or cable tool drillings have been developed to measure permeability. The diamond core bit provides excellent samples for permeability determinations.

Downhole electrical surveys can give indications of formation permeability.

Another method which can yield gross quantitative permeability is the combined use of the caliper log and spinner (permeability) survey. The caliper log is run to define the well bore size. The spinner (a current meter) traverses the open hole while

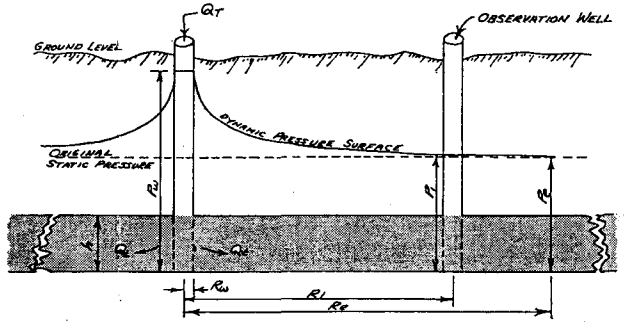


FIGURE 1.—Radial flow in an artesian well.

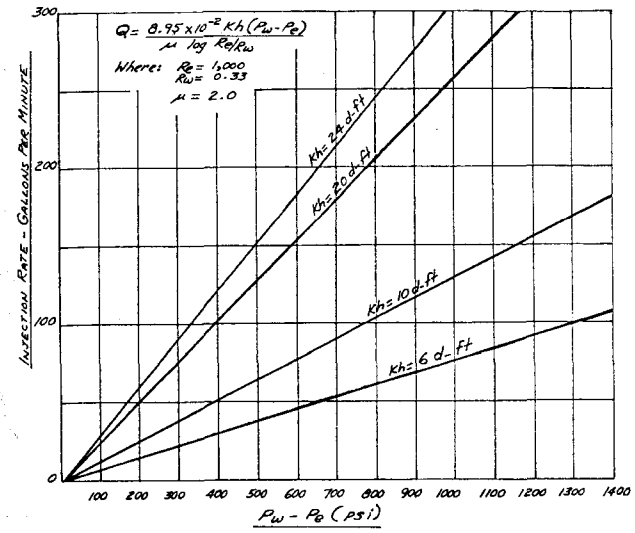


FIGURE 2.—Relationship between injection rate and differential at various formation capacities.

fluid at a constant rate is being injected into the well. As the fluid leaves the well bore and enters the formation the velocity (if hole remains constant) in the main bore will decrease. The change in spinner rate and size of hole can be used to calculate the quantity of fluid that is entering the formation at various points.

Good porosity and high permeability (formation capacity) are two of the four essential requirements of a good disposal formation. The other important ingredients are low reservoir pressure and large areal extent.

Individual Well Behavior

The reservoirs used for subsurface disposal are artesian in nature. That is, the connate fluids within the formation have primary pressures which cause them to rise in the well bore to a point somewhere above the top of the formation structure. In some, this pressure is sufficient to raise the fluid several thousands of feet and produce flowing wells. Figure 1 shows a well finished in an artesian formation. As illustrated fluid is being injected into a formation which is h thick. The original or undisturbed static pressure (dashed line) was well above the formation top. The heavy solid line represents the dynamic pressure level as it was affected by injection.

Assuming flow in the formation is radial and that the static pressure surface P_e is not changed at a distance R_e, Darcy's differential form can be used to develop the following equation:

$$Q = \frac{8.95 \times 10^{-2} Kh\,(P_w - P_e)}{\mu \log R_e/R_w} \quad \ldots\ldots (5)$$

where

Q = flow in gpm,
K = permeability in darcys,
h = depth in ft (permeable section),
μ = viscosity in centipoises,
R_e and R_w = distance in ft, and
P_e and P_w = static pressure surface in lb/sq in.

This equation is for equilibrium conditions and single phase flow of incompressible fluids.

Analysis of this equation reveals the importance of permeability, formation thickness, fluid viscosity, and reservoir pressure. The product Kh represents formation capacity. Injection rate Q is directly proportional to this factor. Figure 2 relates injection rate to formation capacity at various pressure differentials. It is also apparent that as fluid viscosity increases, the rate of injection will decrease.

The injection pressure at a disposal well will vary directly with the reservoir pressure.

$$P_I = P_w - P_h - P_f \quad \ldots\ldots (6)$$

where

P_I = injection pressure in lb/sq in.,
P_w = bottom-hole pressure, original, in lb/sq in.,
P_h = pressure due to column of fluid in hole in lb/sq in., and
P_f = pressure drop due to friction in lb/sq in.

When a waste fluid can be injected under a vacuum, operating expenses and initial capital expenditures will be less than if high injection pressures are required.

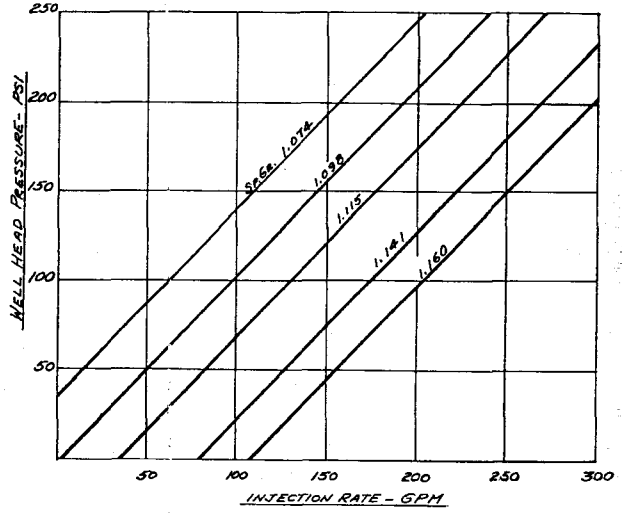


FIGURE 3.—Relationship between well head injection pressures and injection rates for various fluid specific gravities.

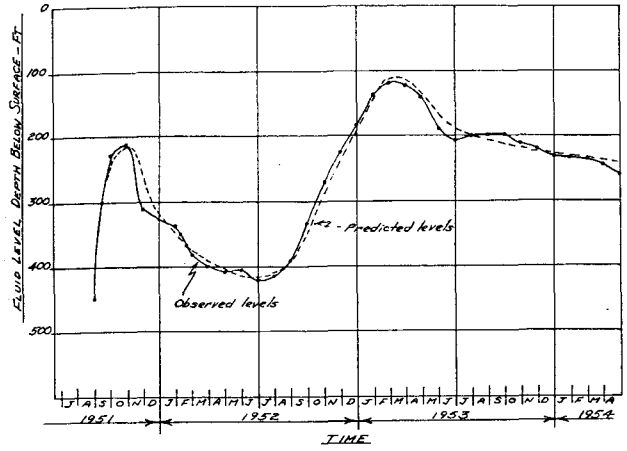


FIGURE 4.—Hydrograph of observation well two miles from injection well.

The density of the waste fluid will have an appreciable effect on the injection pressures. Figure 3 gives an indication of the importance of fluid densities in accordance with Equation 6. This is a plot of well head injection pressures versus rates of injection for various fluid specific gravities. The data were developed in a series of relatively short injection tests for a well which was completed in a porous and permeable limestone formation at 3,600 ft. To inject a 1.074 gravity fluid at a rate of 150 gpm would require approximately 194 psi well head pressure. For the same flow using a 1.160 gravity fluid the well head pressure would be 45 psi. This particular well has been used for disposal of waste salt fluids for over five years and continues to perform in accord with data in Figure 3.

Reservoir Behavior

The relation between reservoir behavior and individual well characteristics is quite broad. The long-term effect of injection into a formation will depend on pressure, temperature, average formation capacity (transmissibility), storage factor (storage coefficient), and type of original displacement mechanism; as well as the number of wells, and the manner in which they are completed and operated.

To evaluate this effect requires a series of carefully controlled pumping (injection) tests. One method is to use a single well for injection and one or more wells for observation, at varying distances (and if possible direction) from the injection well. The injection well should be operated at a steady rate with continuous fluid level measurements being taken at the observation wells. These data can be used in a non-equilibrium formula to determine the transmissibility and stor-

age coefficients. With these additional tools it is possible to predict the long-term effects of injection. Figure 4 is a plot of the fluid level rise and fall in an observation well 2 miles from the injection well. The solid line is the actual observed level while the dashed line is the level as predicted using the coefficients of transmissibility and storage determined by previous pumping tests.

Improving Well Performance

The improvement of individual well and reservoir performance has received much study and development. Formation permeability can, in many cases, be increased by acidifying, hydraulically fracturing, shooting with explosives, perforating with gun, or jetting. The type of treatment used to obtain maximum results depends on the physical and chemical characteristics of the formation.

Areal Subsurface Geology

Large areal extent was listed as one of the requirements for a good disposal system. Size becomes important because the connate waters within the formation must be compressed as waste fluids are injected. Because the formation waters are only slightly compressible there must be sufficient room to allow for this compression. To illustrate the magnitude of area, the following hypothetical situation is assumed: The problem is to dispose of a waste fluid at a rate of 50 gpm over a 10-yr period. As a control, it has been established that there must not be a rise in the original formation pressure of 500 psi over its original pressure. The compressibility of connate water is assumed to be approximately 3×10^{-6} unit volumes per psi. The formation is 100 ft thick and averages 20-percent effective porosity.

If

$$\text{Total volume (10 yr)} = 262{,}000{,}000 \text{ gal},$$

$$\text{Volume required in place} = \frac{262 \times 10^6}{500(3 \times 10^{-6})} = 174 \times 10^9 \text{ gal},$$

where

$$\text{Volume} = \text{area} \times \text{height} \times \text{percent porosity},$$

and

$$A = \frac{V}{hxp} = \frac{174 \times 10^9 \text{ gal}}{100 \text{ ft} \times 0.20 \times 7.48 \text{ gal/cu ft}}$$

Then

$$A = 1.16 \times 10^9 \text{ sq ft} \cong 26{,}600 \text{ acres},$$

or

$$A \cong 42 \text{ sq miles}.$$

The areal extent of the formation may be established by geological investigation. The logs of all wells drilled in the area should be studied. Not all will have penetrated the zone of interest. The study of area geology should be the first step taken in the preliminary evaluation of subsurface disposal. Geological data, on potential reservoir size, combined with pumping tests to determine hydraulic interconnection can establish the long-term potential of the reservoir.

Geological investigation also will furnish information on fresh water aquifers and the type and kind of cap rocks.

Well Construction and Completion

There does not appear to be a standard way for constructing or completing wells for subsurface disposal. Sometimes there is little uniformity within the same operating fields. Where there are rules by a regulatory body with respect to construction and completion methods, these must be observed or exceptions must be requested. In general, the rules prescribe that casings be cemented to protect all gas, oil, and fresh water strata.

In some projects waste fluids are injected through casing without tubing. In others the fluid is injected through tubing suspended within the larger casing. When tubing is used, the annulus area, between tubing and casing, can be packed off using packers of various design. This procedure adds further protection for upper zones and protection of casing from corrosion when this area is filled with an inhibiting fluid. Corrosiveness of waste fluid may also dictate whether or not plastic-lined casing or tubing is used. The intended life of the project helps determine whether or not casing and tubing are used.

Figure 5 shows a suggested construction program for a well completed in the big lime formation in Cuyahoga County, Ohio.

Completion practices are designed to remove any drilling muds which may have penetrated or plugged the face of the formation during drilling or cementing operations. The methods used may involve circulating with clean fresh water, mechanically scratching the well bore, swabbing, and acidifying with special acids. After the hole has been thoroughly cleaned the final com-

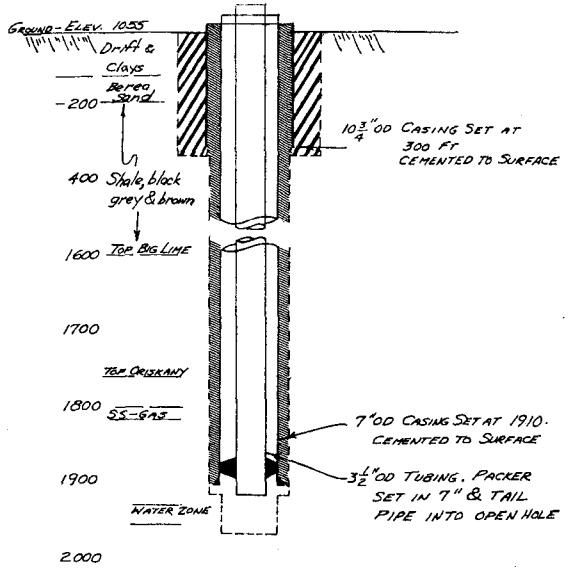


FIGURE 5.—Cross section of well constructed in Cuyahoga County, Ohio.

pletion will improve formation permeability using one of the methods mentioned earlier.

Summary

Subsurface disposal may provide the only method of disposal where toxic or odoriferous wastes are involved. Where wastes are concentrated and have high specific gravities it may be the most economical method. The method should be considered and evaluated early in wastes treatment planning along with other treatment methods.

It must be pointed out that the method has limitations and responsibilities. The limitations can be evaluated through detailed study and reservoir testing. Because it is of vital concern in protecting sources of water, surface and subsurface, these responsibilities must be accepted.

FIRST INDUSTRIAL AIR AND WATER PROTECTION AWARD IN PACIFIC NORTHWEST



Federation President Harry E. Schlenz is shown above (at left) presenting the Pacific Northwest Control Association's first Industrial Air and Water Protection Award to Don Allen, who accepted for Weyerhaeuser Company's Springfield, Oregon, plant.

The Award is given to an industry for outstanding pollution control measures. The above presentation took place at the Association's 28th annual meeting, held in Tacoma, Washington, Oct. 25–28, 1961.

Don Allen is Assistant Technical Director at the Springfield plant and Harry Schlenz is President of the Pacific Flush Tank Company, Chicago, Illinois.

LUBRICATION OF EQUIPMENT

Harold B. Hemphill

Management and plant personnel today are faced with ever increasing work loads in operating a sewage treatment plant. As the volume of wastewater increases it becomes necessary to use complex machinery and processes to keep pace with demand. It is increasingly important to have uninterrupted service, full-capacity operation, and maximum service life from each piece of equipment.

Industry, with the help of lubrication specialists, has made studies of the problem of maximum machine life and dependable operation. Regular preventive maintenance and correct lubrication to hold wear and machine downtime to a minimum have proved to be the best solution. Preventive maintenance programs must be carried out by competent repairmen to keep breakdowns at a minimum and reduce the inconvenience due to the loss of service from a machine.

Proper Application

Properly selected and applied petroleum products keep moving parts in service during their expected life time. It is reasonable to assume then, that the oiler (if properly trained) will be a valuable assistant in helping the program succeed. His most important duty, of course, is to properly apply the correct lubricant. In addition he should observe the equipment as he makes his rounds and report anything that is operating differently from past experience. For example, he may report excessive grease leaking from a bearing, a gear case that is operating at a temperature much higher than in the past, or unusual sounds coming from machine parts. These should be reported and proper inspection made. It is not necessary nor should an oiler or maintenance man try to be familiar with the complex formulations or methods of selection of a lubricant. However, he should be trained on lubrication application. For example, he should understand that certain type bearings can be packed and should have no grease added, sometimes for six months or longer. On the other hand another type bearing must be lubricated possibly as often as each shift or weekly. During the educational period for the oiler it must be made very clear that he is not to deviate from his instructions. Too much lubrication can cause certain types of bearings and seals to fail while too little lubrication or the wrong lubricant can also cause failures. When it is found that maintenance, repairs, and lubrication costs are out of line it often follows that little thought was given to selection and application of lubricants. The combination of the operator's knowledge of the machinery and operating conditions together with the lubrication engineer's knowledge of lubricants and application can mean a saving in man hours, repair parts, and total cost of lubricants.

Records

Very often it has been found that no records are established to indicate the frequency of application of grease or oil. Also lacking are recommendation charts showing the lubricant to use for each application. Plant rec-

Harold B. Hemphill is Industrial Representative for the Mobil Oil Company, Hastings, Nebr.

This paper was presented at the Nebraska Sewage and Industrial Wastes Assn. Annual Meeting in Omaha, Nov. 3–4, 1960.