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Project Summary

A Feasibility Study of the Effectiveness of Drilling Mud as a Plugging Agent in Abandoned Wells

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The Hazardous and Solid Waste Amendment of 1984 requires the Environmental Protection Agency to assess environmental suitability of liquid-waste injection into subsurface rock. Accordingly, the reaction among injected wastes, reservoirs, and original formation fluids is under evaluation.

The main objective of the feasibility study described here was to test the hypothesis that properly plugged wells are effectively sealed by drilling mud. While achieving such an objective, knowledge of the dynamics of building mud cake on the wellbore-face is obtained, as well as comprehension of changes that occur in drilling mud from the time it is placed in a well until it reaches equilibrium.

A system was developed to simulate (a) building mud cake in a borehole, (b) plugging the well, and (c) injecting salt water in a nearby well, with concomitant migration of salt water into the plugged well. The system "duplicates" reservoir pressures, mud pressures, and reservoir-formation characteristics that develop while mud cake is built, as in drilling a well. Salt-water injection is simulated, to monitor any fluid migration through the reservoir.

A 2100-ft. well and ancillary equipment permit controlled variation of simulated depth, porosity and permeability of reservoir rock, fluid composition, fluid pressure, injection pressure, and mud properties. Data can be recorded continuously by computer.

The synthetic-sandstone reservoir is cylindrical, 3 ft. in diameter and 2 ft. thick. It has porosity and permeability similar to those of several natural reservoirs.

Pressures commensurate with those in 5000-ft.-deep wells were to be measured; associated differential pressures were required. A system developed to measure differential mud pressures includes undiminished pressure-transmittal by diaphragm-interface.

Also, a high-pressure, low-flow-rate, high-accuracy flow meter system was developed to monitor the slightest amount of fluid movement. Flow meters were developed to measure (a) fluid from the reservoir, (b) mud-column flow from above the reservoir, and salt water being injected.

An in-place system provides for extensive testing of the many variables that influence effective plugging of boreholes.

This Project Summary was developed by EPA's Robert S. Kerr Environmental Research Laboratory, Ada, OK, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The Environmental Protection Agency is required by the Hazardous and Solid Waste Amendment of 1984 to assess the environmental suitability of injection of liquid wastes into subsurface formations. The Agency's approach to this matter is composed of three general activities: (1) to evaluate the construction of injection wells and the capability for monitoring them, in order to detect failures; (2) to assess the relationship among the rock-stratigraphic units, the fluids injected, and the integrity of the bounding confining beds; and (3) to evaluate the reaction among the injected waste, the formation, and the formation fluids.

The primary objective of the research described here is to test this hypothesis: Drilling mud in abandoned, properly plugged wells effectively seals the borehole. Therefore, if fluids injected into reservoirs at depth were to migrate up the boreholes of properly plugged wells, filter cake nevertheless would prevent passage of these fluids into other reservoirs. The alternate hypotheses need no elaboration

A 2100-ft. well and ancillary facilities compose a system that permits controlled variation of simulated down-hole conditions, including depth, porosity and permeability of reservoirs, compositions of fluids, pressures of fluids, injection pressures, and properties of plugging agents. Instrumentation was designed and assembled, or manufactured, in order to test the feasibility of monitoring variation in pressures and rates of flow of fluids, under several regimes of injection. Computer software was written for continuous reception and recording of data. Methods were developed for construction of an artificial sandstone reservoir; porosity and permeability of this reservoir and some actual reservoirs are similar.

Procedure

The facility is designed for testing under conditions that simulate a well plugged for abandonment. In actual wells, the wellbore above the protected zone (Figure 1) is to be filled with drilling mud and capped with a cement plug. The specific requirements are in regulations set out by the states. A zone in the upper region of the simulated well is an underground source of drinking water (protected zone, Figure 1), and the intention is to not contaminate it. Below the fresh-water-bearing formation is a formation used for injection (Figure 1), pressurized by disposal of salt water into a nearby well. Pressure is translated through the injection zone to the abandoned well. Therefore, a potential exists for salt water to migrate up the wellbore and invade the underground source of drinking water. The purpose of the testing design is to determine the array of conditions that could allow invasion of the zone of fresh water to occur.

The testing facility is divided into four basic areas, which are associated with zones in a plugged and abandoned well, shown diagrammatically in Figure 1. These areas are dedicated to study of the wellbore above the reservoir being protected (Figure 1, Region 1), the protected reservoir and wellbore (Region 2), the wellbore below the protected reservoir, and the salt-water disposal reservoir (Region 3), and the overall part of the facility that simulates drilling the well and building mud cake on the wall of the wellbore. Regions 1 and 2 shown in Figure 1 are simulated by facilities located above ground level, whereas Region 3 is an actual well, 2100 ft. deep. The part of the facility that simulates building of mud cake is also above ground.

Figure 2 is a plan view of the facility. Individual systems are required to obtain quantitative data on results of injecting salt water into a reservoir and the effects of invasion on a shallow, fresh-water-bearing formation in a nearby abandoned well. The Instrumentation Building houses the computer used for data acquisition. About 15 ft. east of the building, at the site labeled "Artificial Reservoir" (Figure 2) is the Instrumentation Console, the main source of test data. The Assembly Stand (Location A, Figure 2) is the mounting stand for the reservoir housing, used when the artificial reservoir is poured (Figure 3) and for determining porosity and permeability of the reservoir. The salt-water tank, lines and pump, effluent tank and connecting lines, mud tank, mud mixer, mud pump, controls and pipe network are clustered in the northeastern part of the facility (Figure 2). Casing and tubing are stored on the pipe rack and are moved to Location B through the v-door on the northern part of the pipe rack.

Figure 4 is a functional schematic drawing of the system. It shows the general configuration of the components, their interconnections, controls, and instrumentation.

To simulate a drilling stage and then a plugging stage, the reservoir first is filled with water under pressure commensurate with the depth being simulated. Then the drilling operation is simulated by circulating mud from bottom to top past the porous medium, which is maintained at reservoir pressure. Mud in the column is maintained at the pressure appropriate for depth of the well and density of the mud. This process is continued until mud cake is fully developed – when there is no more flow of filtrate into the reservoir.

Because communication from an injection well through a subsurface injection zone has the potential of mixing salt water with drilling mud and considerably raising the pressure in the mud column, it is not sufficient to simulate the only direct effect that depth and borehole volume have on the process. Thus it was determined to make possible a range of depths from about 200 ft. to 2000 ft. This was accomplished by drilling the 2100-ft. well, cementing it from bottom to top, and placing a full open head on the top casing joint with 5 1/2-in. slips. Casing can be run in the hole to the desired depth and hung on the casing-head slips. Rather than drilling an adjacent well and injecting salt water in it, hoping that some of the salt water would get to the test wellbore, the simulation is done by running a string of 1 1/4-in. tubing on the outside of the 5 1/2-in. casing and supplying salt water directly into the casing at the injection point. Injection pressure for the saltwater is supplied by an accumulator with nitrogen in the bladder and the column head of salt water going to the injection point.

In large reservoirs, at places distant from the borehole, reservoir pressure is maintained until a large amount of fluid is injected into the reservoir. Because a virgin fresh-water reservoir is simulated in the case at hand, and because this reservoir pressure would influence the full development of mud cake, a constant reservoir pressure must be maintained. Pressure is developed by a nitrogen-filled accumulator bladder.

The largest feasible artificial reservoir was desired. Expense and handling-operations were the limiting factors. The resulting dimensions of the reservoir housing are 2 ft. in height and 3 ft. in diameter. The synthetic-sandstone reservoir (Figure 3) is composed of quartzose sand and resin. Mixing and pouring were designed to simulate porosity and permeability of actual reservoirs. Fluid is injected through the core of the reservoir. Associated with this reservoir housing is a hose system (Figure 5), to provide a path for fluid forced out of the reservoir at its periphery to be directed to the effluent tank (Figure 3).

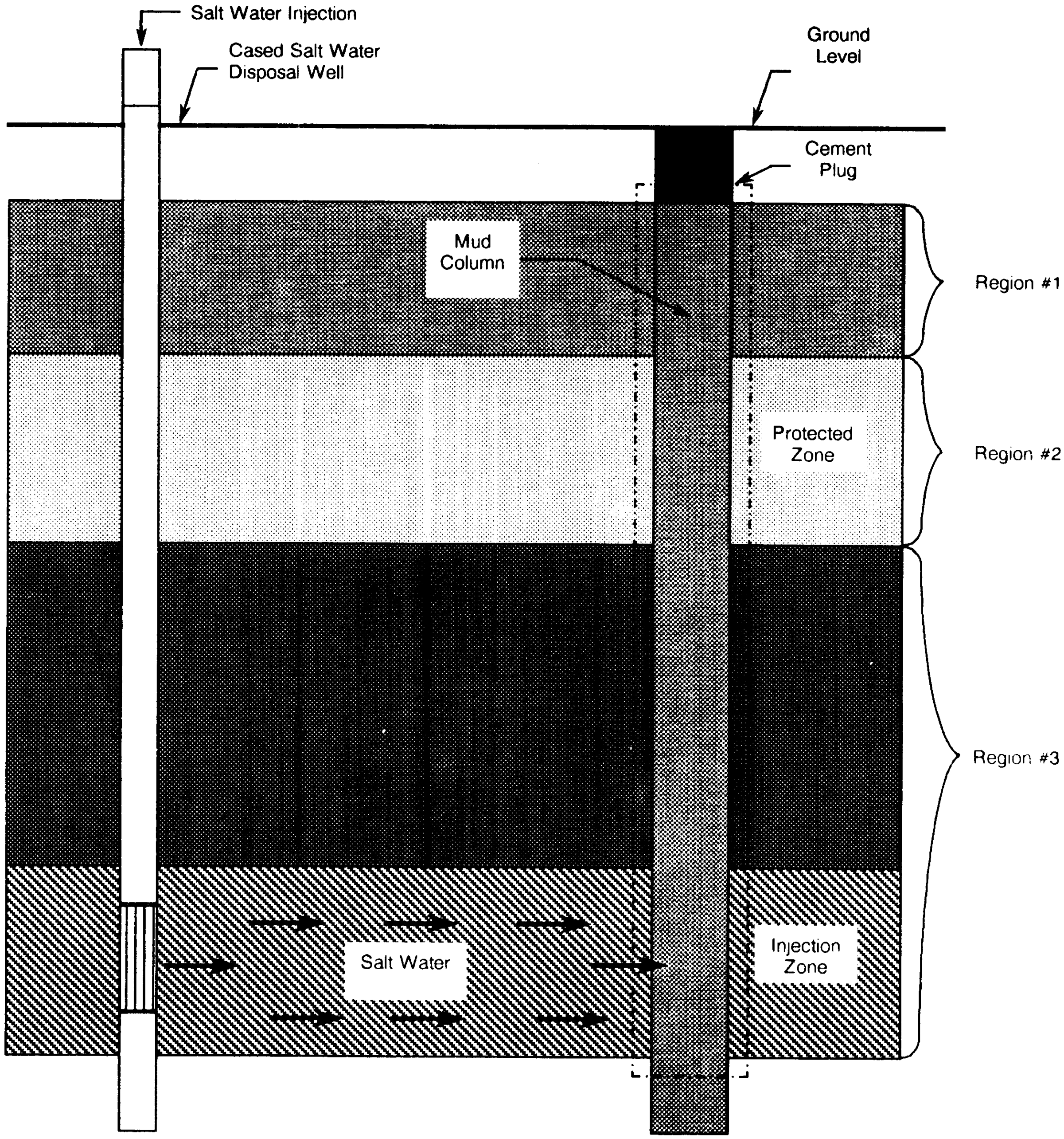

Figure 1. *Representative injection and abandoned well.*

Information from this reservoir is acquired with differential-pressure transducers, pressure transducers, temperature sensors and a flow meter. These data, in conjunction with the axial differential pressure, will provide the reservoir radial pressure gradient. This gradient will be used for permeability calculations and for correlating the potential invasion flow-rate across the mud cake.

In order to determine the mud characteristics and dynamic behavior of the mud column in the injection area, a sequence of differential-pressure transducers was placed on the 5 1/2-in. casing and run down-hole. Signals are transmitted to the computer by a multiplexer, which requires only one cable from the surface. Multiple sensors can be attached to the casing from a series of locations below the multiplexer. The multiplexer can serially select a given sensor and send that part of the signal up-hole, cycle to the next and repeat the operation until all sensors are sampled.

Conclusions and Recommendations

1. Feasibility of designing and equipping a shallow well for the purpose of the experiment has been demonstrated.

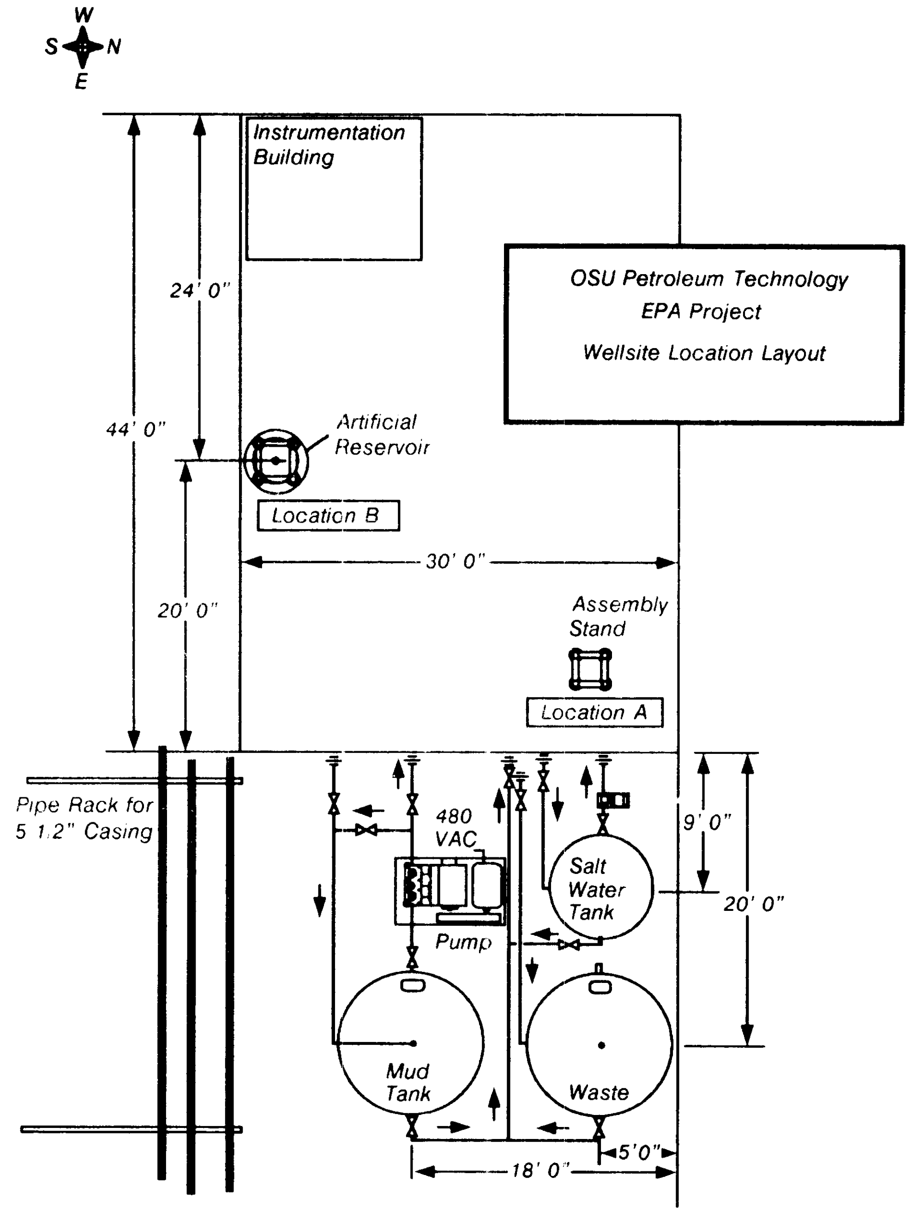

Figure 2. *Plan-view schematic drawing of test facility.*

2. A technique and hardware were developed to measure down-hole pressure gradients accurately.
3. A multiplexer to transfer data from down-hole to the surface was designed and built, as were a computer board and software, to accept, process and store data.
4. Other equipment designed, built, and developed included a diaphragm-seal housing assembly, a temperature-sensor circuit, a flow-meter and flow-control system (for uncommonly low rates of flow at high pressure), and a mud-maintenance, mud-flow network and control system.
5. An artificial reservoir with lithic properties, porosity, and permeability similar to actual injection-formations was constructed, complete with housing and attendant instrumentation. After initial guidance by Halliburton Company, techniques were developed for composing, mixing, emplacing and consolidating reservoir material, to obtain porosity and permeability within specified limits. Moreover, methods were developed to isolate and measure radial flow through the large artificial reservoir.
6. A cased-well system, designed and constructed, allows simulation of conditions below the artificial reservoir

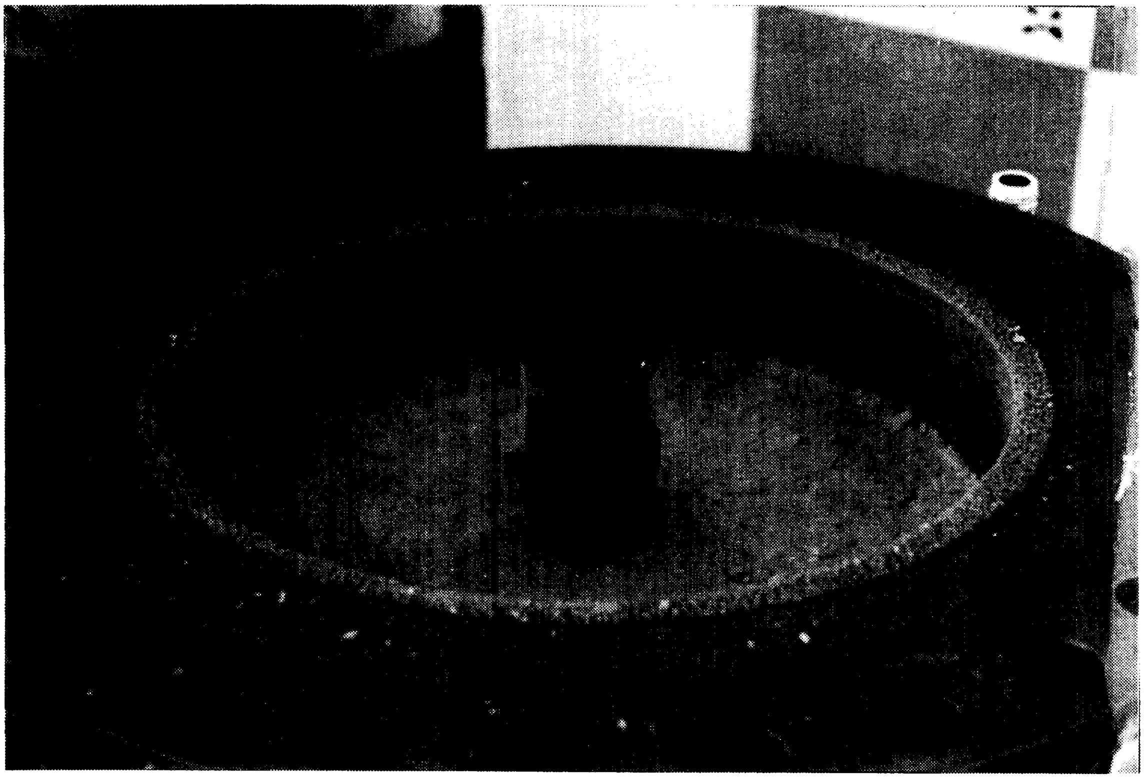

Figure 3. *Artificial reservoir, nearly completed. Several "lifts" of fine-grained material emplaced and compacted within the hardened, coarse-grained outer shell of reservoir.*

of depths as great as 2000 ft. and controlled injection of fluids at depths of 100 to 2000 ft. The facility could, and should, be used to define the entire array of critical conditions of mud-plugging. Also, it should be employed for experimentation and development of new products and techniques for protecting fresh-water aquifers.

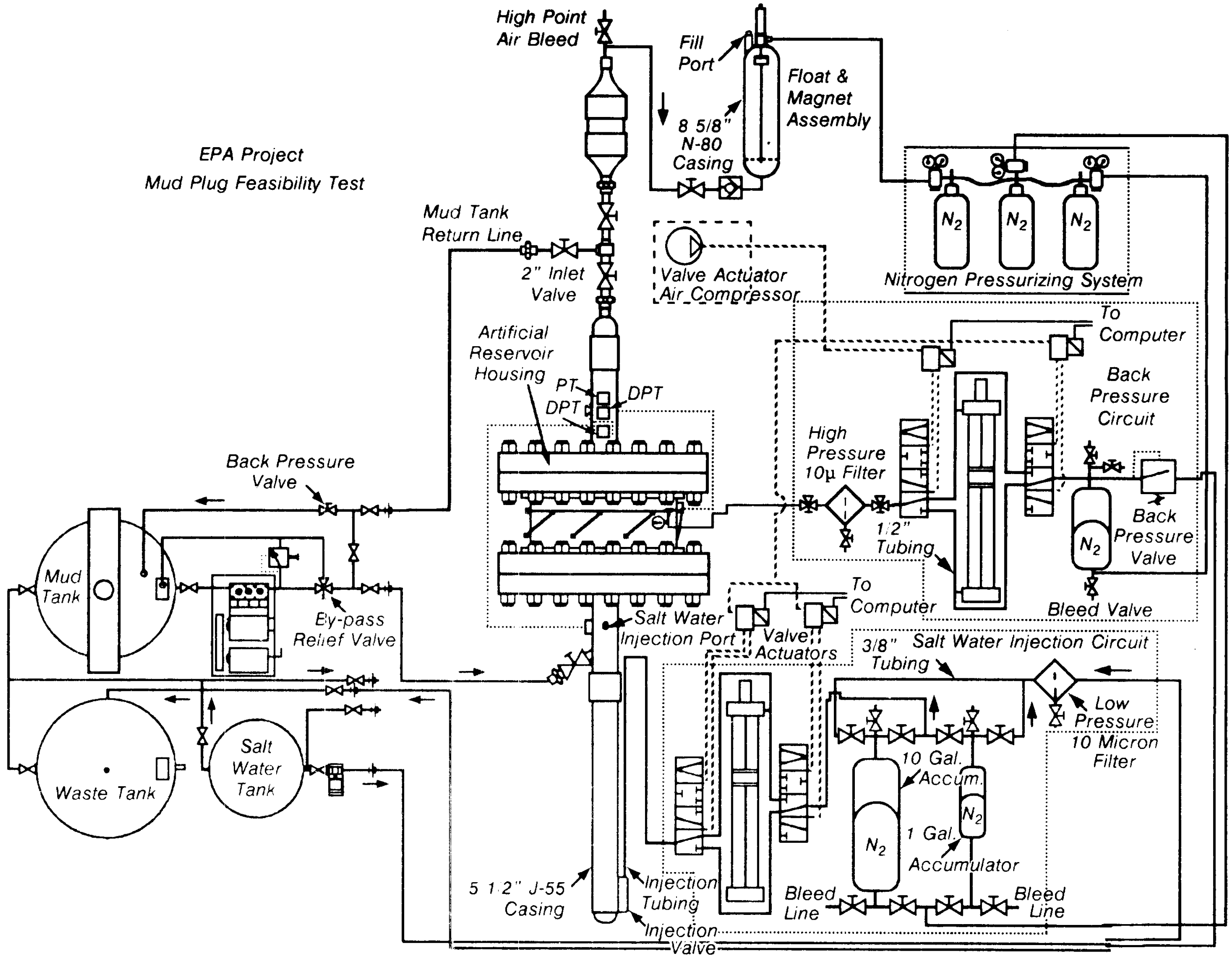

Figure 4. *Functional schematic drawing of test facility.*

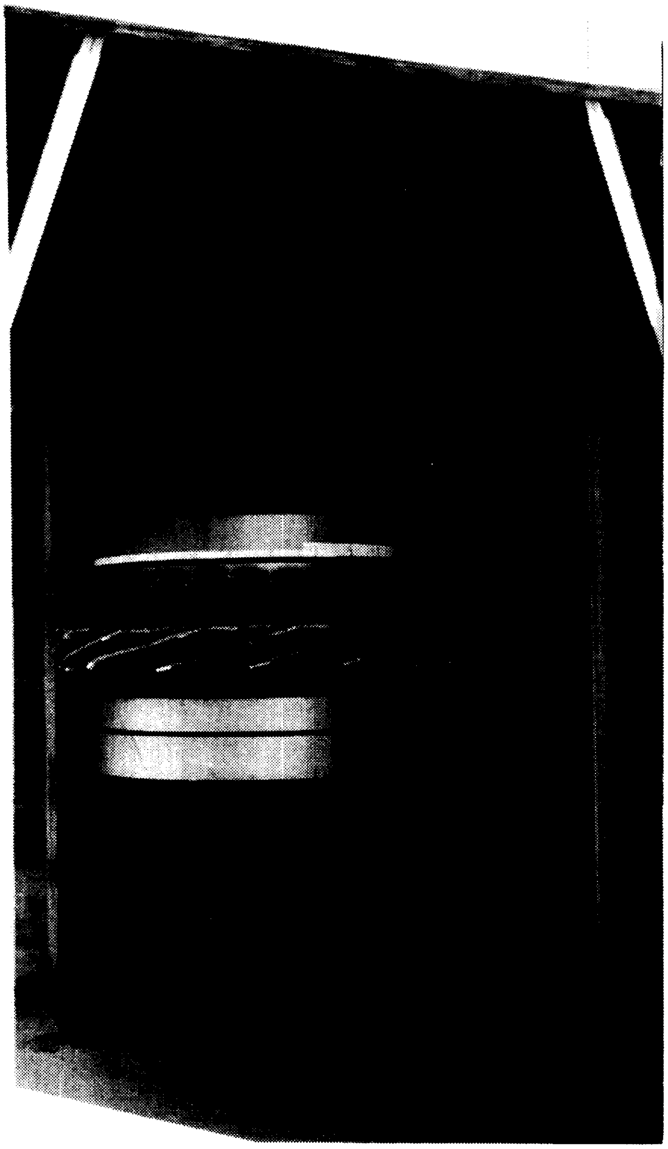

Figure 5. *Artificial-reservoir housing assembly.*

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The complete report, entitled "A Feasibility Study of the Effectiveness of Drilling Mud as a Plugging Agent in Abandoned Wells," (Order No. PB 90-227 232/AS; Cost: $31.00, subject to change) will be available only from:
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