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INFLATABLE STRADDLE PACKERS AND ASSOCIATED EQUIPMENT FOR HYDRAULIC FRACTURING AND HYDROLOGIC TESTING

By Eugene Shuter and R. R. Pemberton

ABSTRACT

Independent testing of aquifers is the only way to fully understand the hydrology encountered in boreholes intersecting multiple aquifers. The most feasible method of testing multiple-aquifer wells is through the use of inflatable packers. The straddle packers and associated equipment herein described are valuable tools for making tests of isolated aquifers as well as conducting hydraulic-fracturing experiments. The system permits multiple tests in a borehole without the necessity of tripping in and out of the hole to redress the packers prior to testing each zone. Electronic pressure transducers, the output of which was fed into strip-chart recorders, were used to monitor the zone being tested, as well as to monitor the zones above and below the packers. This was necessary to ensure that no leaking had occurred around the packers, causing hydraulic continuity between the isolated zones.

INTRODUCTION

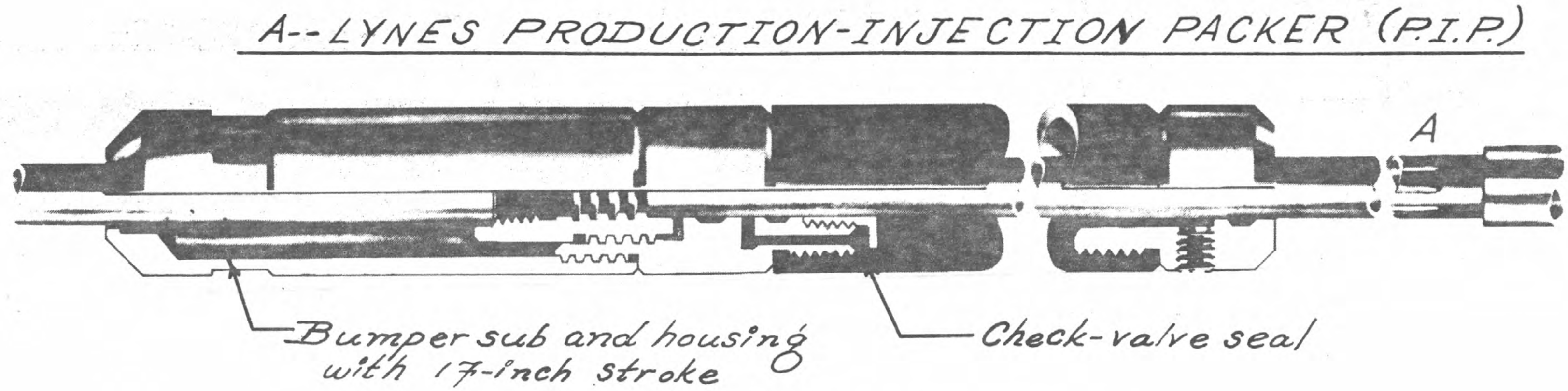
For approximately 15 years, the Water Resources Division, USGS, has been utilizing inflatable borehole packers for testing isolated aquifers. Although the use of isolation packers is of tremendous value in testing multiaquifer wells, their use has been restricted to only a few projects. This restricted use of so valuable a tool is primarily due to (1) relatively high cost, and (2) hydrologists' lack of experience in adapting oil-field tools and testing techniques. Current increased activity in utilizing aquifers for energy-related, industrial, and waste-disposal purposes, as well as massive water-supply sources, requires sophisticated techniques for testing isolated aquifers to obtain data necessary for critical decisions. The testing of independent aquifers is the only way to obtain data from boreholes intersecting multiple aquifers, and the use of inflatable packers is usually the most feasible method of testing multiple-aquifer wells.

EQUIPMENT CONSIDERATIONS

The packers and associated testing tools described in this paper were either designed by the authors, or were modified from commercially available equipment. The equipment can be utilized in a variety of ways for aquifer tests in almost any shallow ground water environment; that is, to depths of about 1,500 feet (ft) or 457 meters (m). Prior to the design and assembly of the tools described in this paper, the Water Resources Division had only two types of packers available for testing isolated aquifers. One type was the production injection packer manufactured by [1]Lynes, Inc. of Houston, Tex. (fig. 1A), and the other was an airflate packer (fig. 2) developed by the authors and manufactured for use by the Geological Survey in testing isolated aquifers. Before performing a testing program (in the Piceance Creek basin in northwest Colorado) designed to both hydraulically fracture and perform pump tests of selected zones, and requiring the flexibility of as many as 50 hydrofracs and (or) hydraulic tests in a short period of time, it became obvious that our existing tools were inadequate. Because of the desire to conduct testing of isolated aquifers as well as hydrofracing of as many as 8-10 zones during one trip into the test hole, neither of the types of packers available was satisfactory, for the following reasons:

1. The Lynes production-injection packer is inflated against the wall of the hole by filling the run-in pipe with fluid and pump-pressuring through a built-in check-valve assembly to about 1,000 pounds per square inch (lb/in^2) or 70.3 kilograms per square centimeter (kg/cm^2). After packers have been set and the required tests conducted in the straddled zone, the packers have to be released and returned to the surface for redressing. This necessitates a complete round trip in and out of the hole for each test. In addition to the time consumed in installing and removing the packer assembly for each zone tested, it is also necessary to install a submersible pump at some depth in the packer run-in pipe if water samples for chemical analyses or head tests are desired. The one additional objection to using the hydraulically inflated

[1]Any use of company names, trade names, and trademarks in this publication is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.



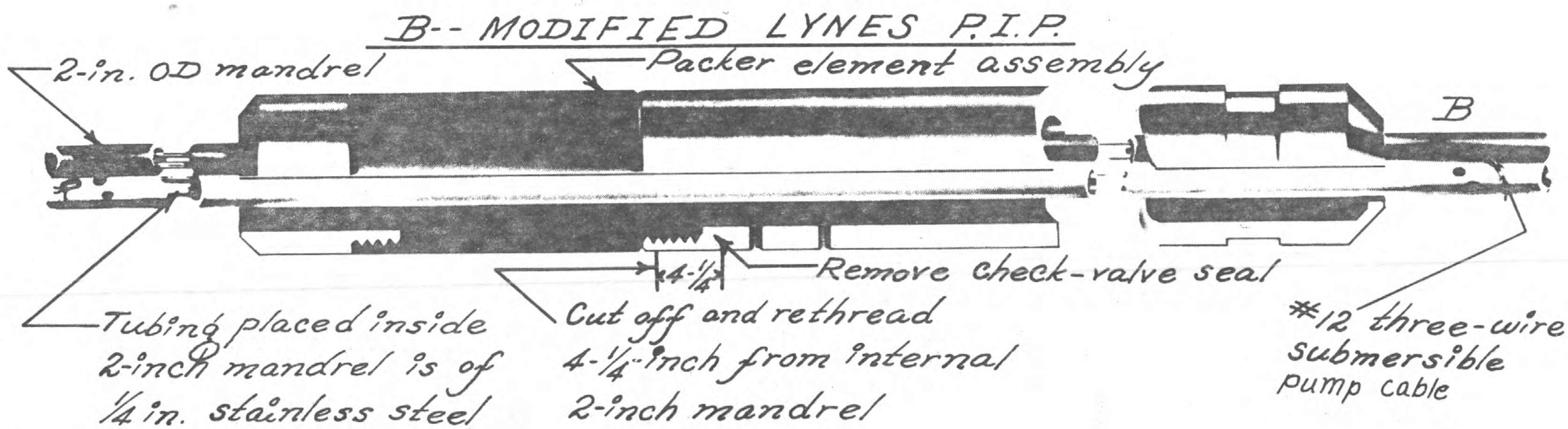


Figure 1.-- A. Lynes 4¼-inch production packer. B. Lynes packer modified to permit gas inflation and head measuring lines and pump cable to be passed through packer(s).

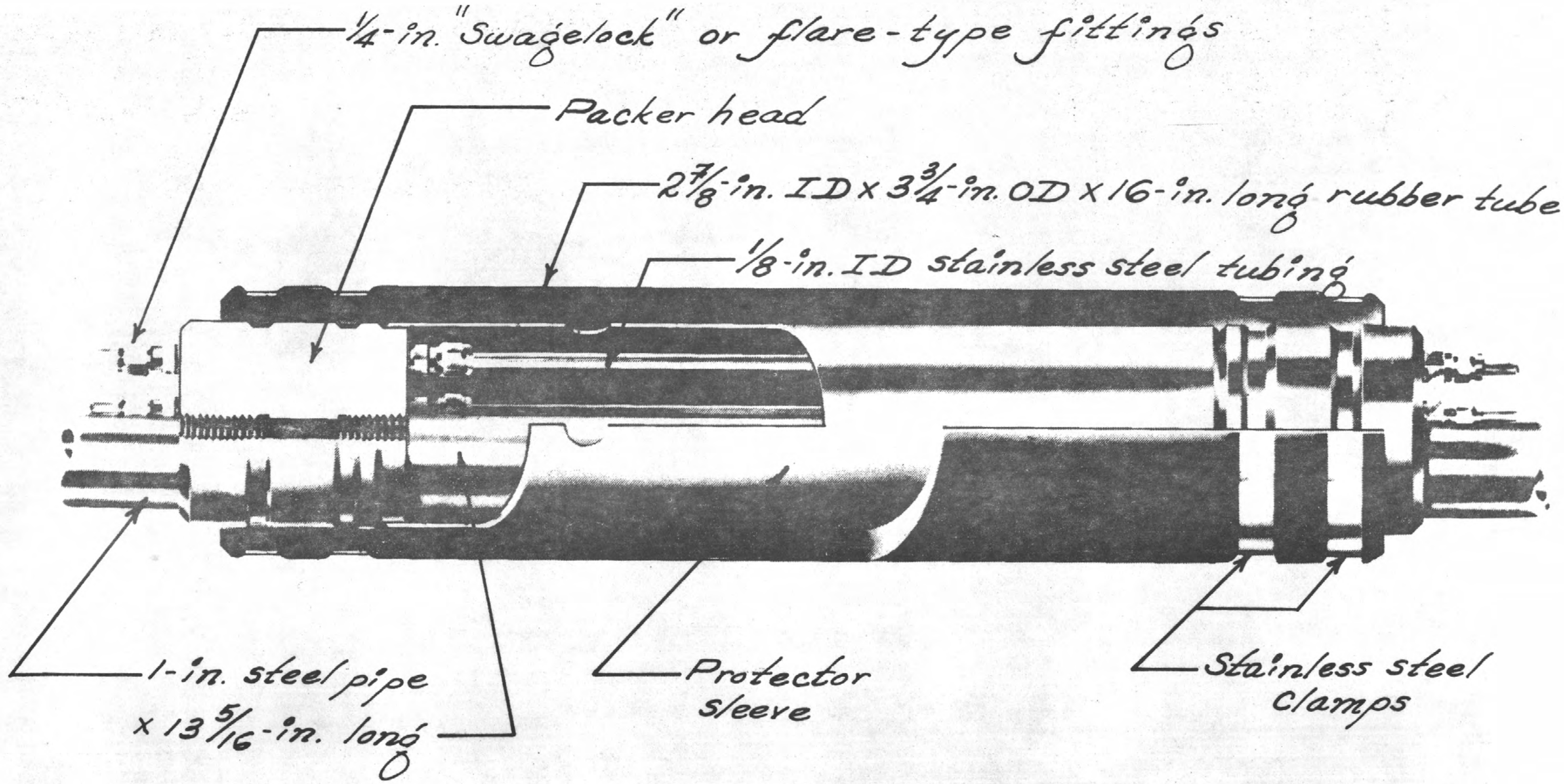


Figure 2.--"AIRFLATE" packer used for testing isolated aquifers with low-head differential.

production packer is not having access tubes through the packer elements, permitting monitoring of head changes in the packed-off zone as well as the zone below the bottom packer. Monitoring of these zones is necessary to obtain data to show whether or not packers have isolated the desired interval. A change in pressure, either above the upper packer or below the lower packer, during a test indicates communication with the tested interval.

2. The "airflate"-type packers (fig. 2) did not meet the criteria for this type of testing owing to their weakness in withstanding differential pressures. A differential pressure of as little as 300 lb/in^2 (22 kg/cm^2) would either slide the rubber element off the end subs or cause it to rupture.

The requirements for the tool string and hydrofracturing equipment were set as follows:

1. The straddle packers should be inflatable by gas so that they could be deflated and reinflated opposite as many zones as desired, thus permitting testing of all zones of interest during one trip into and out of the hole. It was also required that the packers be able to withstand 1,500 lb/in^2 (105 kg/cm^2) inflating pressure.

2. A submersible pump should be installed between the packers so that water samples and hydraulic data could be collected in addition to providing an opportunity to obtain hydrofracturing data of each zone of interest.

3. A multiple-purpose valve should be provided between the packers and above the pump that would (a) permit opening the tubing to the packed-off zone for hydrofracturing and slug testing, and (b) shut off ports to the packed-off zone when pumping from either the straddled zone or the zone below the upper packer.

4. A high-pressure injection pumping system (1,500 lb/in^2 or 105 kg/cm^2) capable of producing at least 30 gallons per minute (gal/min) or 1.9 liters per second (L/s), and associated equipment should be provided that would permit inducing fractures in the rock and propping them for later surveillance with a sonic borehole televiewer.

SOLUTION OF EQUIPMENT NEEDS

Straddle Packers

To meet the requirements above, it was decided to convert a set of Lynes production-type straddle packers to Survey needs. This was accomplished in the following manner: The check-valve rubber and retainer rings were removed and the 2-in (5.08-cm) enamelized mandrel was shortened by 4.25 in (10.8 cm) in order to remove the regular hydraulic inflating ports (see fig. 1B for all conversions of packer). Three stainless steel lines were run through the top packer and coupled to 0.25-in or 6.35-millimeter (mm) elbows welded into the 2-in (5.08-cm) mandrel above and below the inflating element. The purpose of these three tubes is: (1) to measure the head between the packers, (2) to inflate the lower packer by adding whatever amount of tubing the straddle requires, and (3) to measure the head below the lower packer. One additional tubing fitting is installed in the upper packer for inflating that element. The lower packer element has only two 0.25-in (6.35-m) tubes installed in it. The purpose of these two lengths of tubing is as described in (2) and (3). There was also a 0.5-in (12.7-mm) tubing run through the upper packer mandrel to accommodate the power cord of a submersible pump. This tubing was welded into the mandrel and was equipped with two 0.75-in (19.05-mm) elbow-type packing glands so that no leakage would occur through the pack.

Submersible Pump

A 5-horsepower (hp) Reda submersible pump capable of producing 20 gal/min (1.26 L/s) was installed between the packers for collecting quality-of-water samples from isolated zones and creating drawdown for hydrologic analysis. The pump was powered by a 15-kilowatt (kw) portable generator at the surface.

Multipurpose Valve

A multipurpose valve was designed and constructed (fig. 3) that would permit the following functions by manipulation of the tool string: (1) access to the packed-off zone when open, permitting injection (either for hydrologic testing or hydraulic fracturing), or (2) isolation when closed, permitting pumping from the straddled zone. Inflation of only one packer isolates either the lower or upper section of hole for injection or withdrawal of fluid as desired.

These choices of functions and manipulations of the tool string can best be explained by the following step-by-step procedure of a testing-fracing sequence:

1. Total tool string is run into the hole to the preselected test depth.

2. Bottom packer is set against the hole wall to the required pressure, and the tool string is then lowered 0.1 ft (3.05 cm) to rest on the bottom shoulder of the valve. This allows the valve ports to be open to the zone between the packers.

3. Top packer is set to required pressure, isolating the zone between the packers for testing. The usual procedure for testing at this stage is to run a slug test of the packed-off zone by quickly injecting a measured volume of water in the tubing and observing the rate of decay of the imposed head increase. If hydrofracing of the packed-off zone is desired, the tubing is filled with fluid and pressured up to break pressure with the hydro pump. The hydraulic heads of the packed-off zone, and the head of the zones above and below the packers are monitored during the fracturing experiment, using electronic pressure transducers.

If it is desired to pump the packed-off zone, the two packers are set without lowering the tool string by the aforementioned 0.1 ft (3.05 cm). In this mode, the multipurpose valve remains closed to the packed-off zone, allowing the pump to deliver water past the valve and up the tubing to the surface.

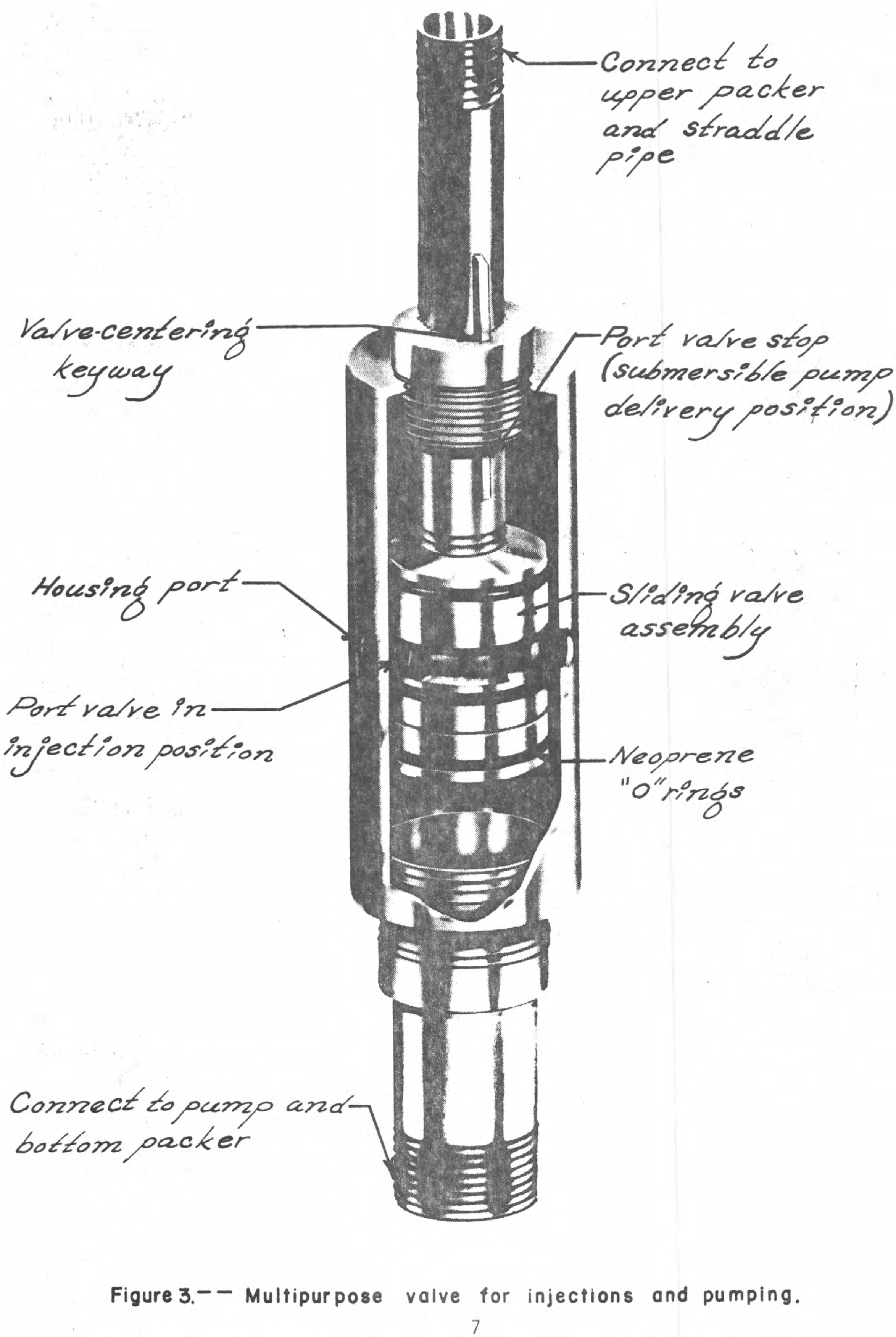


Figure 3.-- Multipurpose valve for injections and pumping.

Hydraulic Fracturing Pump and Associated Equipment

An FWI piston-type (Model 7024) pump, capable of producing up to 40 gal/min (2.52 L/s) and 1,800 lb/in^2 (126.6 kg/cm^2) of pressure was selected for hydraulic fracturing. The pump and associated equipment (schematic fig. 4) were assembled and mounted on a 24-ft (7.4 m) flatbed trailer. The pump is powered by a 70-hp gasoline engine and driven by sprocket and chain. Two calibrated 20-cubic-foot (ft^3) or a 0.6-cubic meter (m^3) mixing and holding tanks are included as part of the pump system. One tank is used to hold the propping material, which consists of a mixture of water, Lucite, or ground walnut hulls, and Johnson "Revert" to hold the Lucite or hulls in suspension. A measured volume of fracing fluid containing propping material is followed by a measured volume of clear water used to flush the propping material from the hoses, pump, and pipe into the fractures. The hydrofrac pump is equipped with pressure gages to monitor the pressure being applied at the surface to the injection string during fracturing. True formation-fracturing pressures were monitored by downhole transducers, the outputs of which were fed into strip-chart recorders. See figure 5 for schematic illustration of pressure transducer and the recorder system.

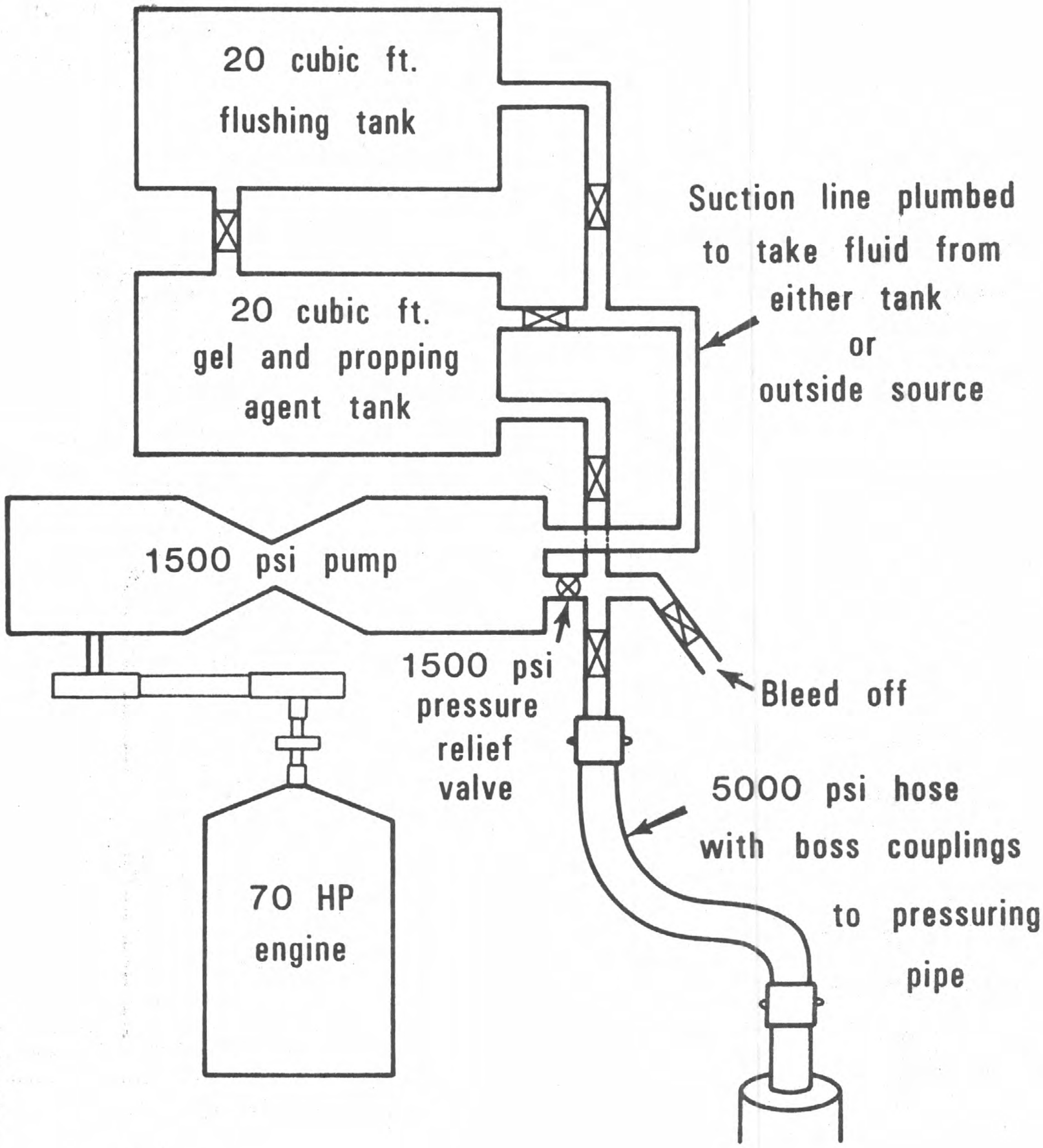
An important part of the plumbing system attached to the hydrofrac pump is an in-line bypass valve or choke that allows control of the rate of pressure buildup. This is particularly important in "tight" rock where this pressure buildup can be essentially instantaneous; this may or may not be desirable. Bypassing is accomplished by opening the valve in a line connected from the pump output to the propping-agent holding tank. When the pumping operation is started preparatory to fracing, the choke is completely opened, allowing most of the pump discharge to circulate back to the tank. The choke is then very gradually closed, permitting a controlled pressure build-up until fracturing occurs.

An important concern in working with this high-pressure system is the potential danger involved should fittings or hoses rupture, or a fitting be blown off. To minimize this danger, extra-heavy-duty pipe is used in all of the pressure lines from the pump, including the packer-tubing hoses. All plumbing from the pump to the packer tubing is engineered to withstand 5,000 lb/in^2 (351.6 kg/cm^2). In addition to these precautions, an in-line safety blowoff valve (1,500 lb/in^2 or 105 kg/cm^2) was installed.

RESULTS OF EQUIPMENT USE

For discussion of the results of the hydraulic-fracturing experiments in the Piceance Creek basin, see Bredehoeft and others (1976).

The following results were obtained using the equipment described and are intended to demonstrate its usefulness in borehole testing. An example of the data obtained from a slug test in a packed-off zone is shown in figure 6. This test was conducted with the packers set at 232 ft (70.7 m) and 240 ft (73.1 m) below land surface with the tubing open to the 8-ft (2.4-m) interval between the packers. The test consisted of injecting a nearly instantaneous slug of water into the packer tubing and observing the decay rate using the



NOTE: All plumbing and valve fittings are of high pressure schedule

Figure 4.-- Schematic of hydraulic-fracturing pump and associated equipment.

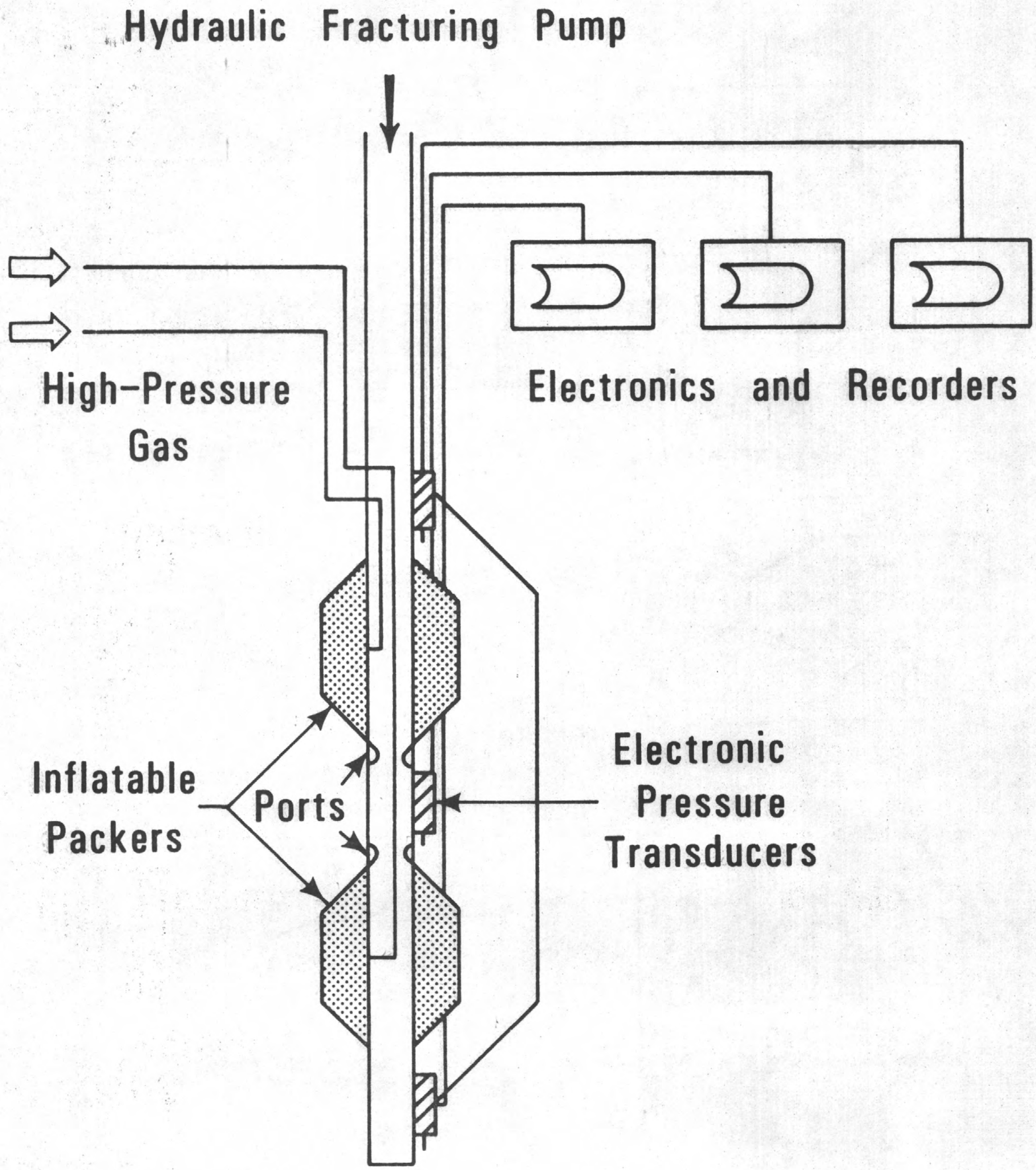


Figure 5.--Schematic of tool setup for stress measurements.

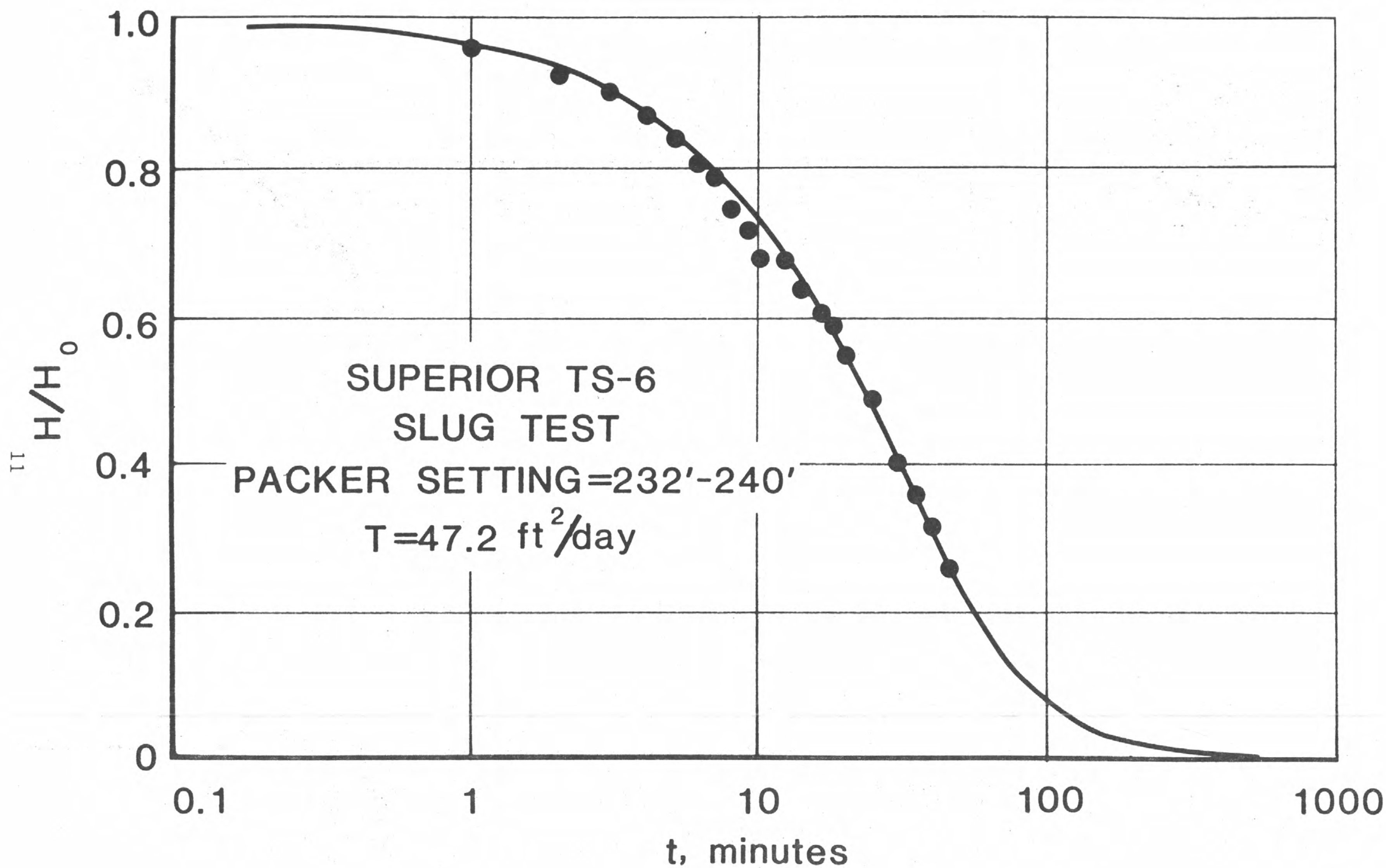


Figure 6.-- Results of a slug test in an 8-ft straddled zone.

downhole pressure transducers. The test was analyzed using the methods given in Papadopulos and others (1973). Slug tests were conducted in all packed-off zones to estimate the hydraulic conductivity prior to fracturing. Out equipment was not designed to hydraulically fracture highly permeable zones.

The data shown in figure 7 were obtained by pumping from a straddled zone. The packers were set from 1,229 ft (375 m) to 1,269 ft (387 m) below land surface and the 40-ft (12.2-m) interval pumped at a rate of 19 gal/min (1.2 L/s).

Figure 8 represents data collected from pumping the total zone above the bottom packer. This was accomplished by simply deflating the upper packer, permitting the total hole above the bottom packer to respond to the pump.

Figure 9 demonstrates the use of the equipment for hydraulic fracturing. The packers were set from 1,047 ft (319.1 m) to 1,055 ft (321.7 m), and pressure of 600 lb/in^2 (44 kg/cm^2) was required to fracture the rock. The fractures can be clearly seen from the "before" and "after" televiewer logs. The sequence for fracturing as explained in Wolff and others (1975) is as follows: "Once the packers were positioned in the hole at the proper depth, the procedure was to: (1) inflate the packers to a pressure approximately 100 psi (7 kg/cm^2) above the expected breakdown pressure; (2) run a slug test (Cooper and others, 1967; Papadopulos and others, 1973) to determine approximately the permeability of the interval to be fractured; (3) hydraulically fracture with water, cycling through at least three cycles of pumping and decay, and (4) prop the fracture by pumping in a metered quality of fluid containing suspended propping material, Lucite, followed by a metered amount of clear water just sufficient to displace the propping material into the fracture."

CONCLUSIONS

Borehole packers are useful in a variety of tests in boreholes containing multiple hydrologic zones of interest. Also, they greatly expedite the hydraulic fracturing of isolated zones. The primary advantage of the tool string described in this paper is the time saved in testing and fracturing. With a conventional set of hydraulically inflated packers, approximately 12 hours (h) would be required to run tubing and packers to a depth of 1,000 ft (304.8 m), test or fracture, deflate packers, and return to surface for redressing procedure. With the tool string herein described, we completed as many as four hydrofracs in 1 day's time at depths of 1000+ ft (304.8+ m). In addition to the savings in "running" time, this versatile tool string makes it possible to pump test any section of the hole desired without having to run the pump in as a separate trip. The system also allows the monitoring of pressures above, between, and below packers, which is a most desirable procedure for detecting bypassing of the packers.

The most restrictive component in extending the depth capability (1,500 ft or 457 m) of the described tool string is the Nylaflow tubing used for inflating the packers. The burst strength of this tubing is approximately 2,500 lb/in^2 (175.8 kg/cm^2), but its working pressure is only about 1,200 lb/in^2 (84.4 kg/cm^2). In working at depths of 1,500 ft (457 m), allowing for

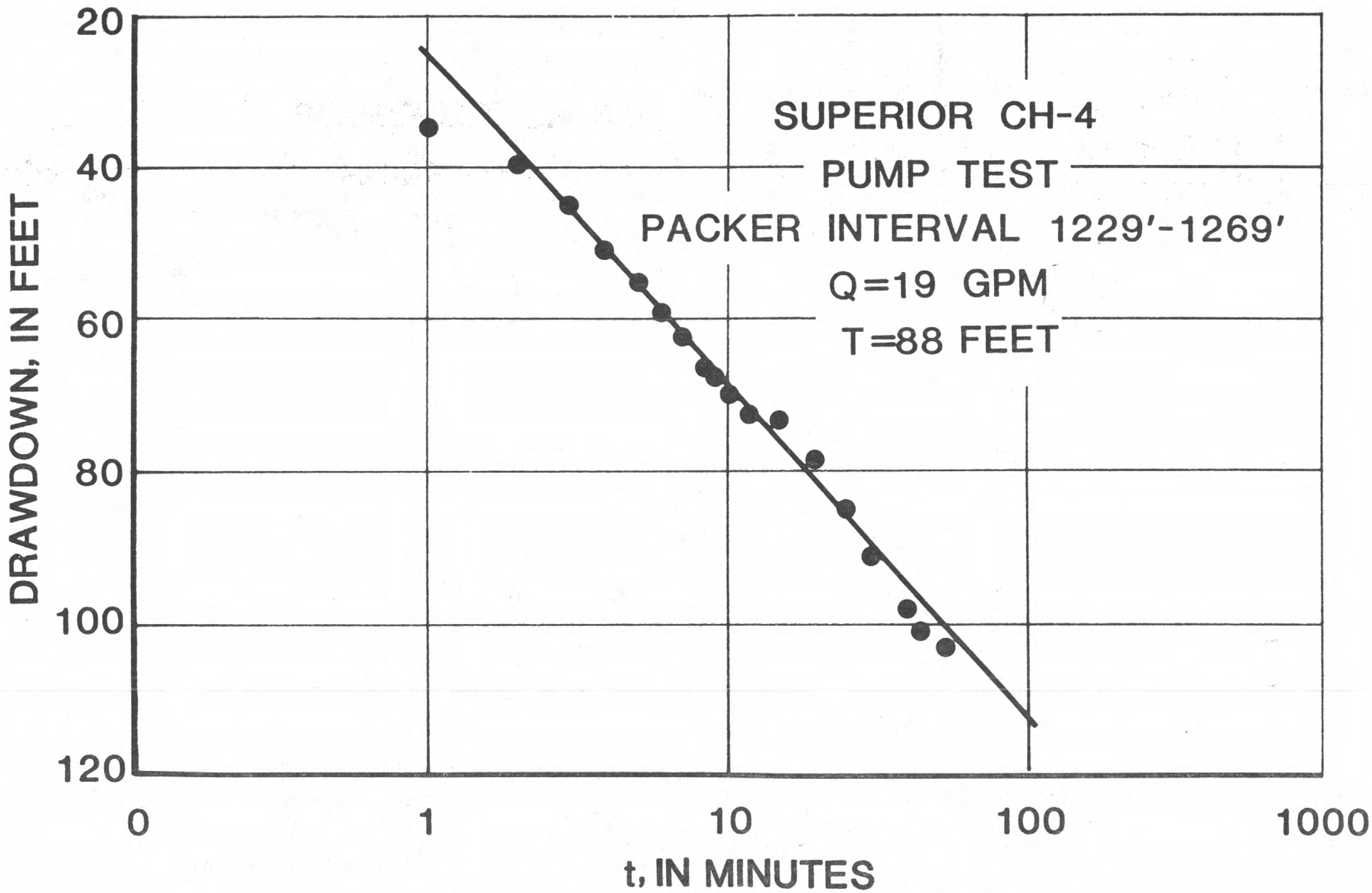


Figure 7. — — Results from pumping in a 40-ft straddled zone.

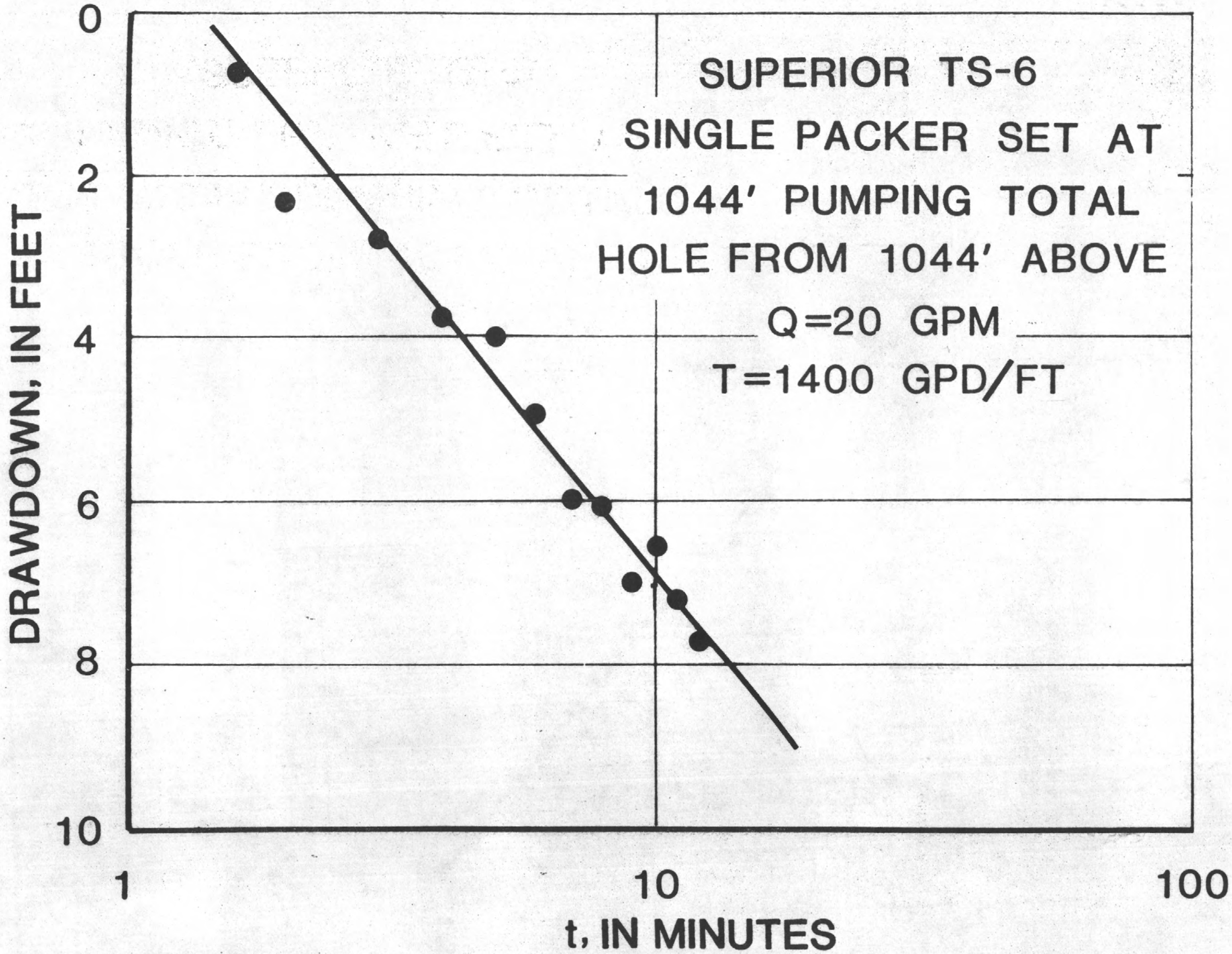


Figure 8.-- Results from pumping total hole above bottom packer.

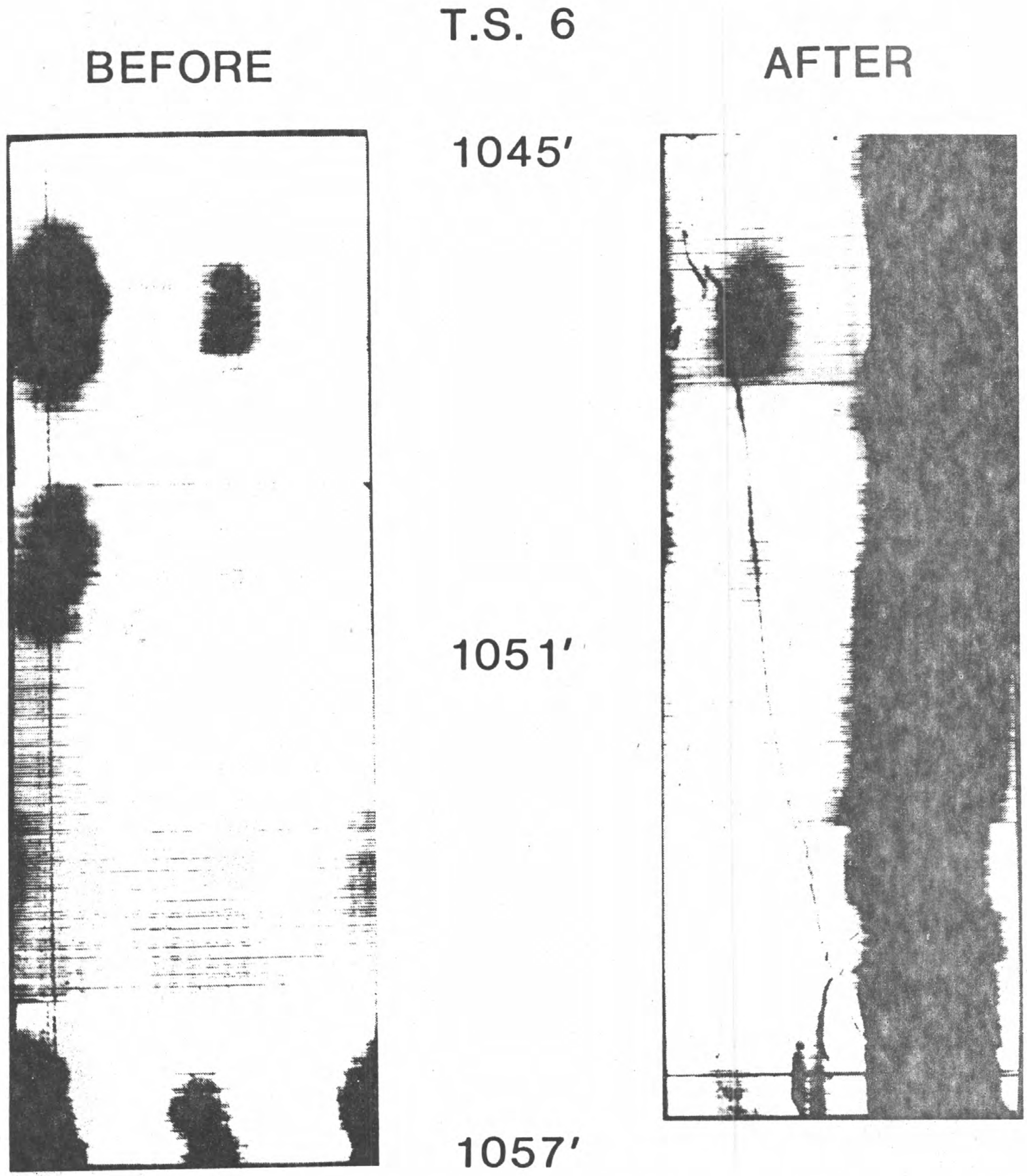


Figure 9.-- Example of televiewer logs before and after hydrofracturing.

600+ lb/in^2 (44+ kg/cm^2) inhole pressure head and as much as 500-600 lb/in^2 (3744 kg/cm^2) packer-setting pressure, we are approaching or sometimes exceeding the working pressure of the tubing. The authors are currently testing high-pressure tubings that are rated at 3,000 lb/in^2 (210 kg/cm^2) working pressure. If this tubing proves satisfactory, the capability of the tool string will be extended to greater depth, perhaps as much as 6,000 ft (1,828 m).

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