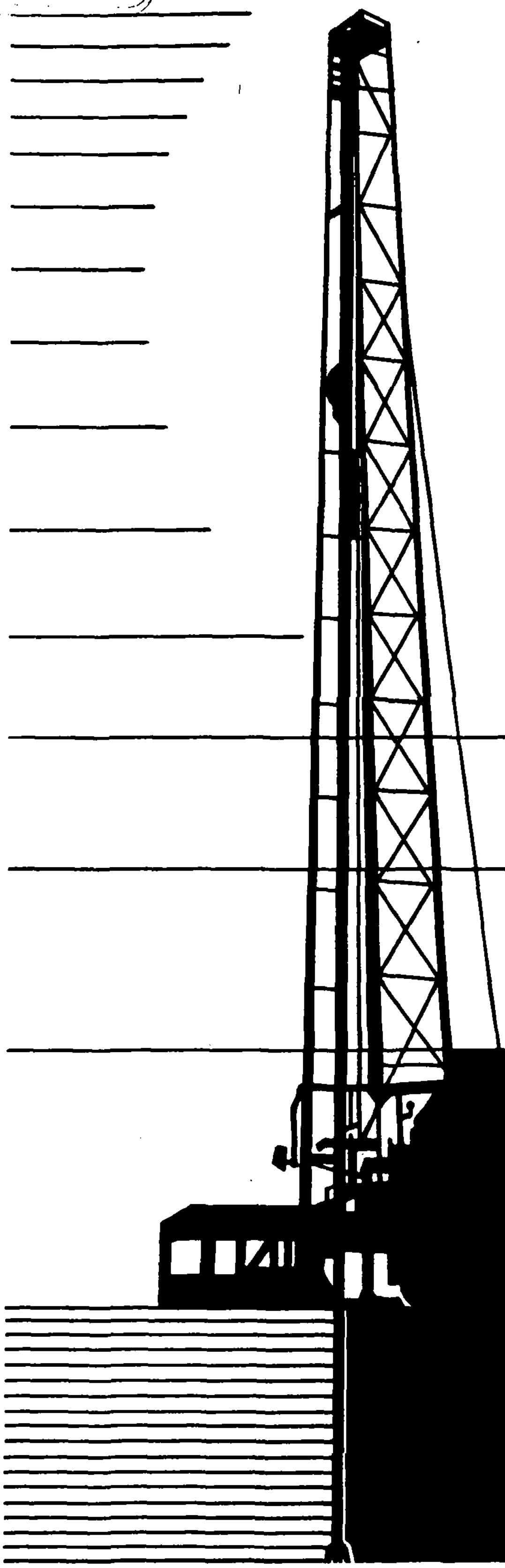

WATER WELL DRILLER'S BEGINNING TRAINING MANUAL

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A complete guidebook for the beginning well driller on design, construction and maintenance of water wells and pump installation.

published by
the National Water Well Association
Columbus, Ohio 1979

Dedication

The "Water Well Driller's Beginning Training Manual" is dedicated to the officers and directors, past, present and future, of the National Water Well Association who give so freely of their time and energy on behalf of their industry.

Special thanks go to the members of the 1969 Board of Directors of the National Water Well Association who originated and guided this project toward completion and to the members and member companies who contributed the individual articles.

All the articles which comprise the Water Well Driller's Training Manual, appeared originally in *Ground Water Age* magazine, whose editors cooperated with the National Water Well Association in the preparation and publication of this material.

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INTRODUCTION

To help you train new men . . .

The Water Well Driller's Beginning Training Manual is designed for use by water well contractors in the training of new men. It reduces to the barest essentials the knowledge a man must have in order to begin to learn how to be a water well driller.

The article which starts on the opposite page is the first of fifteen chapters. They range from the simplest outline of ground water hydrology through the use of various types of drilling equipment for the construction of wells to the reasons for records and reports.

The need for such a guidebook is well documented by a statistical analysis of the manpower shortage in the water well industry. Surveys show that the most widespread source of new workers are the contractors' own on-the-job training programs. This manual is designed for use with just such a program, no matter how informal it may be. The information presented represents a foundation on which each contractor can build the knowledge of new employees to suit his own operations. But it is a foundation only. Other, more comprehensive books and manuals are designed to cover a wider range of water technology. The ruling principle here has been to envision a man with no prior knowledge of water well work at all. Emphasis is on strictly introductory material which the employing contractor can supplement according to his own desires and local conditions.

A few chapters have been prepared by the editorial staff of GWA. Most of the material, however, comes from leading water well contractors who contributed their efforts for the National Water Well Association.

Chapter 1 - Drilling Wells for Water

By James Tolman

Editor-in-Chief

GROUND WATER AGE

COOL, CLEAR WATER is precious stuff. Not only man, but all life depends on it. No water anywhere is cooler, or clearer, than the water which exists underground. Nor is any other supply of fresh water as plentiful. More than 97% of this earth's fluid fresh water is ground water.

It is plain to see why, then, a career in the water well industry, where men make their living by developing the use of this great natural resource, is both important and rewarding.

Within the water well industry, the men who provide the access to these vast reservoirs of cool, clear water are the drillers. This article and the others which follow are an introduction to the knowledge a man must acquire to become a water well driller.

The modern driller

There still are places all over the world where people dig wells, as they have done for uncounted thousands of years. Water wells also are driven or bored. The practical importance of ground water in today's world, however, is due to the development of modern water well drilling.

Drilled wells can go deeper to tap water supplies far below the surface. Drilled wells can be larger or smaller as needs dictate. Drilled wells can protect the generally greater purity of underground water more easily and more securely. Today's water well driller is both the provider and the protector of the nation's ground water resources.

Different drilling methods are used to tap different ground water formations. The major ones and their proper uses will be explained later in this manual. Briefly, they include cable-tool percussion drilling and hydraulic rotary drilling.

Cable tool equipment drills holes for wells by steadily dropping and lifting and dropping again a heavy string of tools. A rotary rig drills with a rotating bit, removing its cuttings by means of a continually circulating drilling fluid. There are variations of both, and each is suited to particular drilling problems.

Drilling problems provide the challenges of water well work. They differ widely. This is because the earth's geologic formations, the ground under our feet, differs from one place to the next. To begin with, then, a driller must know something about the places where ground water occurs and how it got there in order to make it available for proper use.

The water cycle

If over 97% of our fresh water is underground, then less than 3% exists on the surface. Because surface water, in lakes, streams, and reservoirs, is where we can see it and where we apparently can get at it easily, we use far more

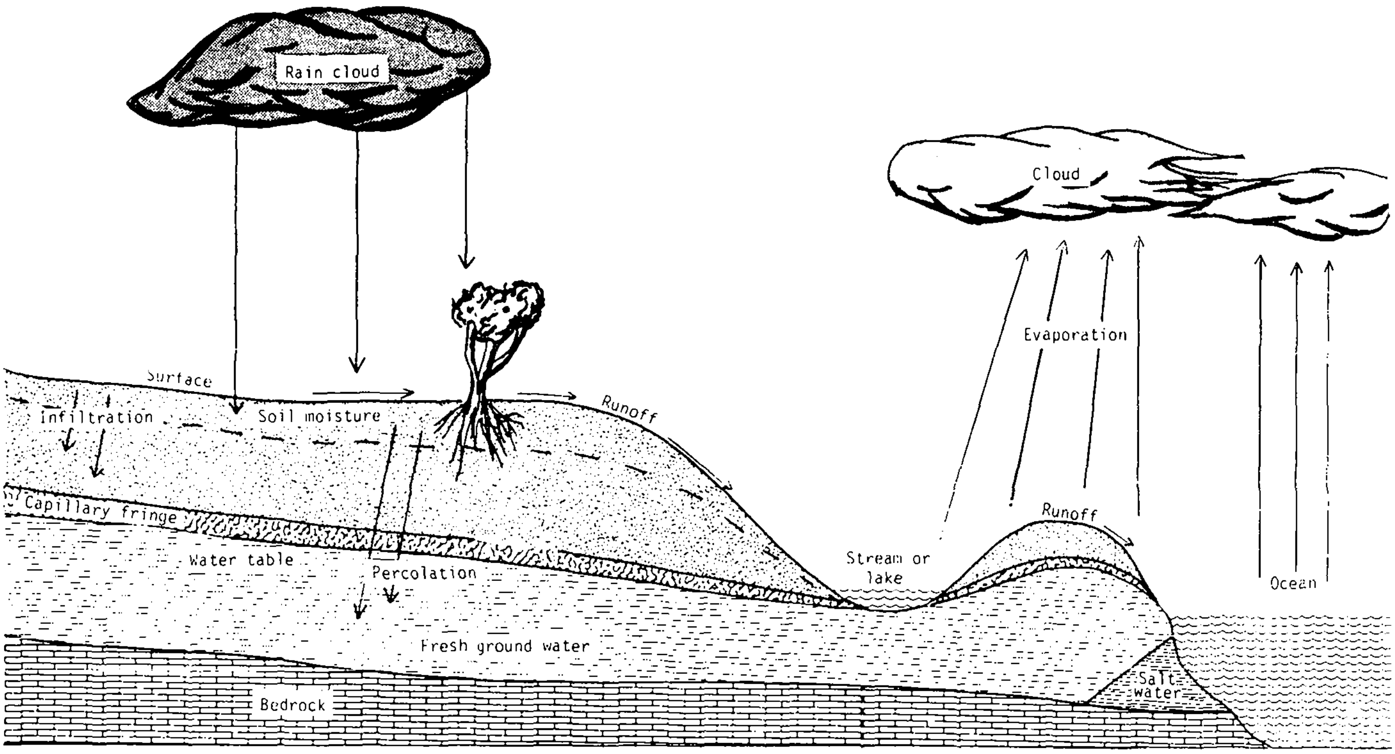

Figure 1-1. Nature's water cycle

of it than we do ground water. In fact, we overuse and mis-use our surface water supplies at staggering annual costs which are far greater than would be necessary to use fully, safely, and properly our ground water resources.

Ground water exists simply because the surface of the earth is not sealed tight; it is porous. Rain falls upon the land, and some of it runs off into ponds and streams; some of it evaporates; growing plants return some of it to the atmosphere; and some of it filters down through the soil into ground water reservoirs. The rain itself, of course, came from the evaporation of surface water supplies which include the oceans as well as lakes and streams. This continual process of evaporation and rainfall (or snow or sleet) is called the water cycle.

The oceans, which cover 3/4 of the earth's surface, are the most important sources of evaporation. Only the rain which falls upon the land enters our fresh water supplies. Eventually, a small portion of this rainfall joins a body of ground water. This water moves through the pores of different materials beneath the surface and may even appear on the surface again at a point lower than that at which it entered the ground water reservoir. This reentry may be in the form of a spring, or it may simply seep into a stream (thus maintaining stream flow during dry periods). Streams then carry both surface runoff and ground water discharge back eventually to the oceans. The basic points of the water cycle are illustrated in Figure 1-1.

What is ground water?

What geologists call "the zone of rock fracture" is the porous outer part of the earth's crust. The pores or openings in this portion exist at different depths below the surface in different places. Not all the water which exists in these openings is called ground water. Some is held near the surface as soil moisture. Just below this is a layer of openings partially filled with water which clings to the material in which or around which the openings occur. This lies over something called the capillary fringe, which in turn rests on top of the water table. The water table is the upper limit of the ground water reservoir, a layer of material whose pores are filled, or saturated, with water. By capillary action (the tendency of water to rise in a small tube, for example, when the lower end of the tube is placed below the water's surface), some additional water is drawn into the partially filled openings just above the water table to form the capillary fringe. See Figure 1–2.

The levels between the water table and the surface make up the zone of aeration. That below the water table, where the pores are full of water, is the zone of saturation. Only water occurring in the zone of saturation properly is called ground water. The rest, together with the ground water, is called subsurface water. The formation in which the zone of saturation exists is called an aquifer.

Types of aquifers

When the upper limit of an aquifer is the top of the zone of saturation itself, ground water is said to occur under water table conditions. The water in the openings at the water table is under atmospheric pressure just as though it were in an open tank. The aquifer itself is called a water-table aquifer. The water pressure at any level within a water table aquifer is equal to the depth from the water table and may be expressed as hydraulic head in feet of water.

The water table does not stay the same at all times. When water is added to the zone of saturation, the water table rises. During drought, when ground water is discharged through springs, streams, or wells, it falls.

Some zones of saturation include both layers with openings in which ground water can occur and impermeable layers through which it cannot penetrate. Only the permeable layers are aquifers. When an aquifer is sandwiched between impermeable layers, it and the water in it are confined. The upper layer prevents the ground water from being open to atmospheric pressure, and it occurs within the openings under artesian conditions. Such an aquifer is called an artesian aquifer.

When a well is drilled through the upper confining layer into an artesian aquifer, water rises in the well to a point somewhere above the top of the aquifer. This point is at the "piezometric level" of the aquifer, a term used to describe an imaginary surface similar to the real water surface (or water table) of a water table aquifer. Pressure at any point within an artesian aquifer is equal to the depth from the piezometric level and also is expressed as hydraulic head in feet of water.

Sometimes the pressure within an artesian aquifer is great enough for the piezometric level to be above the surface of the earth above it. When a well is drilled into such an artesian aquifer, a flowing artesian well results. The water rises above the surface under its own pressure.

Sources of ground water

Besides the replenishment of ground water reservoirs by direct rainfall on the land above, there are other sources. Where the surfaces of lakes and streams are higher than the water table, and their beds are permeable, surface water seeps into the aquifer. Of course, movement goes the other way when the water table is higher than the surface water.

The rate at which ground water is replenished depends, then, upon both a supply of water above the zone of saturation and the permeability of the soil and other formations through which the water must move in order to reach the ground water reservoir.

Other factors also are important. The condition and moisture content of the soil at the time of rainfall. The slope of the land. The rate at which rain falls on the land. Whether subsoil beneath melting snow is frozen.

Soil which already contains a great deal of moisture will allow greater runoff of rainfall to surface water reservoirs. Steep slopes increase runoff (and flat land tends to have more tightly packed soil which slows infiltration and favors greater evaporation back into the atmosphere. Heavy rainfalls compact the soil, decreasing its permeability, while also encouraging greater surface runoff.

Thus replenishment of ground water is affected by two groups of factors. One group includes the physical conditions of the area in which the aquifer exists, and the other includes climatic conditions.

Where does ground water occur?

Both consolidated materials, or hard rock, and unconsolidated materials, including sand, gravel, or soft rock, may hold ground water. So

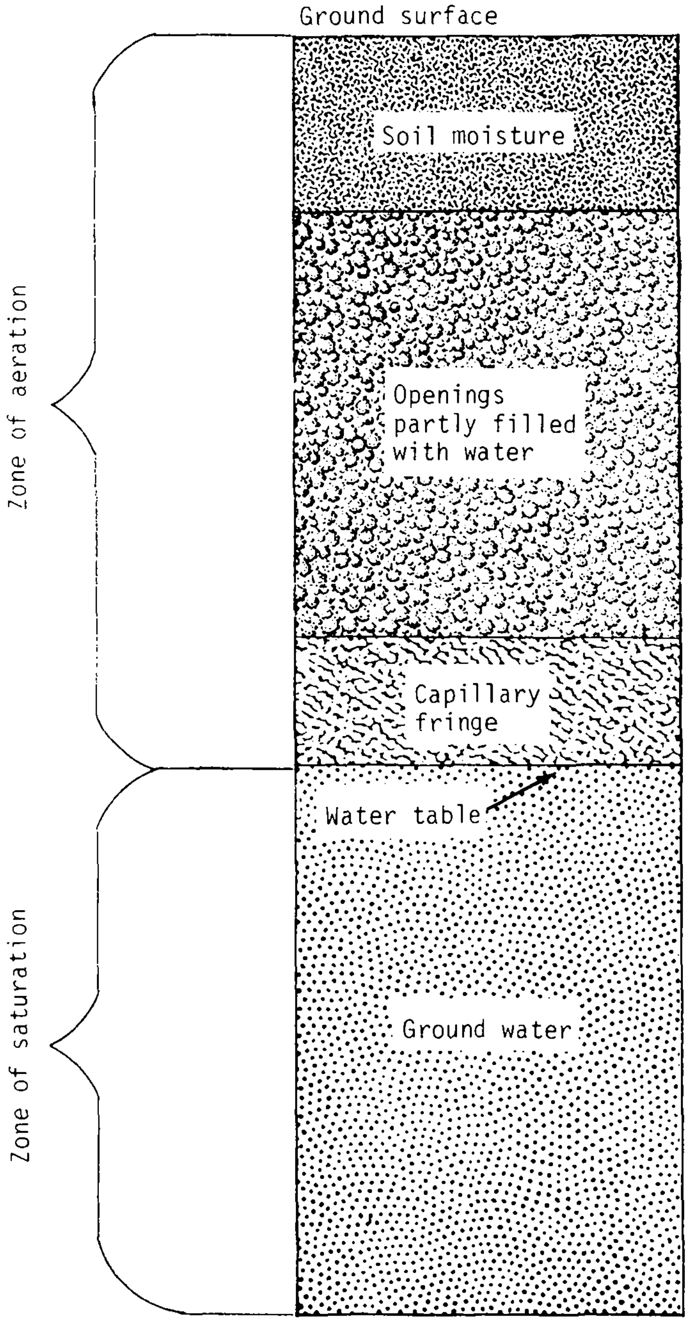

Figure 1-2. Subsurface water layers

long as it is porous enough and permeable enough, any kind of rock may be an aquifer.

Most aquifers are deposits of sedimentary rocks. These result from erosion of pre-existing rocks and include both hard and soft varieties. Limestone and dolomite are two hard sedimentary rocks in which earth movements have produced fractures. Water entering these openings enlarges some of them into solution channels which yield large amounts of water to wells.

Other hard sedimentary rocks result from deposits of sands and clays. Where the weight of upper formations has compacted the sands and hardened the clays into shales, aquifers seldom result, although they may provide small amounts of water from earth fractures. Sandstone, on the other hand, especially when fractured or only partially cemented, may offer really significant amounts of water; but sandstone yields vary widely.

Soft sedimentary formations include sand, gravel, and mixtures of both. These unconsolidated materials have a wide range of water content due to the many variations in particle size and therefore in the openings between particles. Overall, though, they are our most productive aquifers.

Igneous rocks formed when hot molten materials from deep in the earth cooled and solidified eons ago. Granite is such a rock, and the only openings it contains are crevices here and there in the upper part where it has weathered.

Metamorphic rocks are both sedimentary and igneous rocks which have been subjected to great heat and pressure. Generally, they are poor aquifers with only occasional cracks and crevices near the top of the formation to hold water. Marble, however, can be an exception. Since it is metamophosed limestone, it can be an excellent aquifer where solution channels exist.

For further reading

There is much, much more to the origin and occurrence of ground water than appears here. This brief introduction is designed only to sketch the bare outlines. Hopefully, they are enough to provide some idea of the great variety of water well drilling challenges and the skills needed to meet them. This information is based largely on material appearing in "Ground Water and Wells," published by Edward E. Johnson, Inc., and available from UOP-Johnson Div., St. Paul, Minn. The book is recommended for further reading on all subjects covered by this manual.

Chapter 2 — Safety on the job

by William Lovett
Editor
GROUND WATER AGE

NOW THAT THE SUBJECT of exactly what ground water is, and where it is likely to be found, has been covered we move on to another subject that must be considered before going into the actual operation of drilling equipment — Safety. Safe work practices, learned early, help reduce the possibility of accidents occurring. For this reason, we have included a chapter on safety as one of the initial parts of this manual.

Serious thought must be given to the subject of on-the-job safety for a number of reasons. Accidents cost money, be this in the form of time lost on the job, the payment of benefits to the injured employee during his period of recuperation, or in the form of increased insurance premiums. In the case of a fatality, no amount of compensation can make up for the loss of a life.

In all phases of the construction industry, the chances of being injured on the job are great. Teaching a new employee good safety practices at the start of his career will both bring an awareness of the areas of work that represent the greatest potential danger and lead to the cultivation of work habits that will lessen the chances for injury being sustained.

Hazards exist in nearly all well drilling or pump installation operations. Working with electricity, hand tools, drilling rigs, pump hoists and other equipment heightens the possibility of accidents occurring, not to mention the potential risks involved in merely moving to and from the work site. On the other hand, it has been determined that about 50% of the accidents that occur could have been prevented.

Safety on the rig

There are several common sources of accidents encountered in rotary and percussion drilling that must be taken into consideration when thinking of safe work practices. Some sources of the hazards in drilling operations include: Starting drill rig motors when brakes are not set and when gears are not in neutral; starting the air compressor motors when the receiver tank valves are closed; moving the drilling rig over rough terrain, steep inclines, narrow roadways, and slippery road surfaces; and contacting power transmission lines while moving the rig.

There are also some errors that can be made by operators during the operation of the drilling equipment that can lead to injury. Among these are touching the revolving drill steel; not wearing gloves while disconnecting hot drill rod from the drill head, or while removing hot drill from the hole; employees positioning themselves where they can be struck or can lose their balance if the drill steel breaks or sticks; hanging on the mast while the drill is in operation; failing to cover or guard drill holes which have been completed; letting rods or reamers slip into the drill hole; operating the drill from positions where it is difficult to reach lever controls; working on machinery that is moving; wearing loose clothing or neglecting to wear personal protective equipment; shutting down the drill improperly; or leaving it in a hazardous area at the end of the work day.

Some other complications that might arise and should be considered are the accidental parting at hose connections, rupturing, or severing of the air hose; rods falling from racks, particularly from racks at the top of the mast; neglecting precautions against slips and falls; leaving machinery unguarded and failing to properly ground machinery; poor maintenance of equipment that could cause a hazardous situation; and the possibility of fire and dust hazards.

Equipment with moving parts always presents a possible source of injury and care should be taken that open gears, fans, drive belts, and chains have adequate guards. Even with these guards present, the new employee should be cautioned to exercise care while working around these areas. There are also some points to keep in mind when positioning the rig prior to drilling the hole. One of the first is to avoid obviously hazardous faults or positioning the rig on slips that are filled with loose clay or other unstable material. Others include: Positioning rigs on old rock fills; on surface soils or vegetation overlying sloping rock surfaces; within 15 feet of energized electrical transmission lines; where weather conditions are conducive to bank failures or slides; close to traffic hazards; and under dangerous banks. New employees should also be taught to find and correct conditions where machine power controls can be accidentally activated; to inspect the drill and equipment before beginning work, particularly checking the air and water gauges and pressure valves; to use the system for wetting down or controlling dust incorporated in the drilling process — if using rotary drilling; to keep flammables in properly marked, approved containers and stored away from sources of heat; to practice good housekeeping around the drilling rig to minimize the possibility of slips and falls; to use ladders, stairs and handrails provided for safe access to equipment; to keep safety guards in place and in good condition; and to inspect air hoses before the start of each shift for cuts, abrasions, and loose hose connections.

Finally, the new employee should be informed about some of the personal protective equipment that will help reduce the possibility of injury. First and foremost is the safety hat. The National Safety Council reported an average of 116,000 head injuries per year, excluding eye injuries, for the period from 1960 to 1965. This was about 6% of the total disabling injuries of all types of injuries in industry in the United States. Other pieces of personal protective equipment include safety glasses, safety shoes (preferably with steel toe guards), and snug-fitting clothing.

Handling electrical equipment

Failure to ground portable electrical equipment, especially if it is defective and used where resistance to ground is low, can cause burns and shock which can be fatal. Moreover, the National Safety Council reports that numerous industrial injuries can be traced to a non-injuring electric shock. To minimize the hazard of electric shock, it is important that a separate low resistance ground wire be provided. This is then attached to the framework of the equipment and connected to a good ground to remove the flow of current in case a defect develops.

There are two types of grounding systems that can be used to effectively ground electrical equipment. One system uses such things as water pipes, metal framework of buildings, or other metal structures such as well casings that are in direct contact with the earth and provide a low resistance path. The other system uses a group of driven electrodes, buried plates and strips, or similar arrangements in direct contact with the earth. When possible to use them, water pipes offer a very good means of grounding electric equipment. The only exceptions to this occur when the pipe joints are connected with insulating materials, or are connected to mains constructed of nonconductive materials. Some safety practices that should be followed when working with electrical equipment are: protect portable equipment cables by stringing them overhead or enclosing with tapered ramps; don't lay tools and other heavy equipment upon cables; keep cords free of oil and solvents as they may have a tendency to eat through the insulation; don't pull cords taut or around or over sharp objects; and finally, don't use defective equipment.

As little electrical current as 1/10 of an ampere through the heart can cause death. A current 1/50 of an ampere is very painful and can result in loss of muscle control. These low currents can be forced through wet skin by an electrical pressure of 100 volts, and this is a lot less current than is carried in many overhead powerlines. This makes the ground of mobile equipment a must if there is any chance of either a rig or pump hoist coming in contact with such a powerline. IDEALLY, THE RIG OR PUMP HOIST WON'T BE SET UP ANY NEARER THAN 15 FEET OF SUCH AN ELECTRIC LINE.

Cleaning machinery and motors

Machinery and electrical equipment is at its best when it is free of dirt and grime. This cleaning also reduces the possibility of accidents. However, care must be taken in cleaning this machinery and electrical equipment. First, before any cleaning is started, the machine or electric motor should be stopped and the power disconnected.

There are four methods for cleaning machinery and electric motors, and each requires that some precautions be taken. These methods include steam cleaning, using high-pressure air, dipping or brushing machinery with alkaline or detergent solutions, or using flammable or nonflammable solvents to remove oil and grease.

With steam cleaning, the operator of the equipment stands the chance of becoming burned. Using high-pressure air he stands the chance of getting foreign objects blown into his eyes or being injured if the air hose whips around and strikes him. Strong alkaline solutions can cause chemical burns, especially to the eyes. Both flammable and nonflammable solvents present a health hazard from inhalation of toxic vapors, and flammable solvents present the additional hazard of explosion.

Reduction of the possibility of sustaining injuries while working with steam cleaning equipment is possible by keeping the pressure as low as possible. The National Safety Council recommends that this pressure never exceed 25 psi. This hazard can be further reduced by having the employee wear protective clothing. With compressed air cleaning, the pressure should be regulated to not more than 40 psi and preferably to 25 psi. Moist air at pressures above 40 psi can damage the insulation on an electric motor. Alkaline solutions should never be used on electrical equipment as they are likely to cause short circuits, insulation breakdown, corrosion, and other damage. Again, protective clothing is deemed best to protect against injury from alkaline solutions. A water hose, emergency shower, or water pails should also be available in case it becomes necessary for the person doing the cleaning to flush himself off in case he is splashed with the compound. As for solvents, the chief hazards they present are either due to explosion or inhalation. Both of these hazards are substantially reduced by properly ventilating the area in which the work is being done. In the case of cleaning with a flammable solvent, care should be exercised to insure that no sparks can set off the mixture. Electrical equipment should be turned off when working with flammable solvents and no welding or brazing should be done in the vicinity.

Handling heavy items

Backaches and strains are but two of the complications that can arise through the faulty lifting of heavy items. On a larger scale more serious complications can arise through the improper use of lifting devices used to move large lengths of pipe, pumps, etc.

Back injuries resulting from the improper lifting of heavy weights, or not so heavy weights, can be substantially reduced by following several simple rules. 1. If the weight appears to be too heavy or bulky to lift, get some assistance. 2. When preparing to lift something, stand with your feet about shoulder-width apart and bend at the knees to grasp the item to be lifted. 3. With the weight centered between the knees, lift slowly, keeping your back as straight as possible. 4. This procedure can be reversed when lowering a heavy weight.

Care must also be exercised when handling weights which must be moved with artificial means, such as pipe used for casing, etc. Employees assigned to loading or unloading such pipe should be required to wear hard hats and safety shoes. Leather gloves which afford some protection to the hands should also be mandatory. Care should also be taken in transporting pipe from the point of purchase to the point of use. Pipe that extends from the rear of the truck or trailer should be marked by a flag during daylight hours. At night, the proper warning signals required by state regulations should be used. Also, when transporting pipe by truck the driver should stop after a short distance and inspect all chains being used to secure the load to insure that the chains haven't become loosened as the load shifts. Furthermore, the driver of the truck should try to avoid any sudden stops, as this might cause the load to shift forward and might possibly result in serious injury to the driver. Careful driving is the best insurance that accidents of this nature will not occur. Most of the injuries on the job site are hand and foot injuries. Pipe can be rolled safely by hand if the rolling is done from the ends and the hands are kept out of the ends of the pipe. Another method of handling pipe on the job site is through the use of pipe hooks. These hooks should be of such a design that they will not damage the threaded or beveled ends of the pipe or break under the load. To facilitate handling of such pipe, a two-legged brindle sling is ordinarily used. Normally, two control lines, one on each of the two hooks, are used to maintain control of the pipe as it is being moved. These control lines should be of at least 3/4 in. hemp rope with knots at the end for easy gripping.

In general, care should be exercised whenever lifting something, be it heavy or light. In the case of lifting and moving heavy weights, chains, ropes and pipe hooks should be checked to insure that they are in good condition, and employees should be cautioned to wear safety hats and safety shoes.

Flammable liquids

Flammable liquids, especially gasoline and liquefied petroleum, are found at all drilling sites. Some simple safety precautions must be followed when using these substances. When refilling gas tanks, the engine should be stopped and it should be allowed to cool. The tank should not be overfilled, and some room should be left in the tank for the expansion of the gasoline. Also, if any of the gasoline leaks or spills from the tank it should be cleaned up immediately. In conjunction with this, oily rags and the like should never be left around the drilling equipment as it may be the cause of a fire. Liquefied petroleum, sometimes used as fuel for the drilling rig, should similarly be treated with care as it too can burn with explosive force.

Safety on the road

While the possibility of becoming injured on the job site exists, the possibility also exists of becoming injured while traveling to and from the job site. Accidents involving vehicles can result from either inattention while driving, or from operating unsafe equipment. Employers should be sure that employees have been checked out on trucks that they have never driven before to insure that they will be able to operate them safely. Some sort of checklist should also be available with which to make a physical check of the truck. This checklist should include such things as condition of the tires, brakes, lights, turn signals, etc. Any deficiencies in the equipment should be corrected immediately as they might contribute to injuries which could have been avoided.

Lessening the risk of accidents

The vast majority of accidents which happen on the job can be avoided if attention is given to minor details before they happen. Many of the accidents which happen share common ingredients. A check of accidents which have occurred in the past may well show a common failing which may contribute to present accidents, be it inadequate safety procedures, faulty equipment, or carelessness. Whatever the causes, the chances are quite good that the accident could have been avoided. Recognition of the causes of previous accidents may result in the prevention of future accidents. ■ ■

Chapter 3 - Cable Tool Drilling

By T. T. Renner
E. H. Renner & Sons
Minneapolis, Minn.

CABLE TOOL DRILLING also is known as the percussion method, as churn-drill drilling, as spudding, and by several other names. It is a much older method of drilling than the use of rotary equipment.

Cable tool rigs (as the machines are called) drill by regularly lifting and dropping a string of heavy tools into the hole. Skill and experience on the part of the driller make a greater difference in the efficient operation of cable tool equipment than anywhere else today. There are great satisfactions in learning to do this work properly.

Although it is not always the most rapid method of drilling, the cable tool is still very economical and will remain so for many years to come. It is a fine method for drilling water wells, especially when drilling in unconsolidated materials as well as in many rock formations. Not surprisingly, the cost of setting up a drilling business is less with cable tool equipment than with the machinery needed for the new super-fast drilling methods. Maintenance and repair of cable tool equipment also is economical, and with proper care will net years of service at minimum cost.

Cable tool equipment

Although it takes some time at the controls for a man to become proficient at making good wells efficiently, cable tool rigs are simple to operate. They are made in many sizes and are rated according to tool weight and depth of hole. It always is necessary to know local conditions in order to select properly a size or make of machine. Portability, for example, is important in small equipment so that it can move from job to job quickly. Large equipment is more apt to stay at work in one place longer. Local road laws will dictate the type of mounting needed for compliance.

Most drillers find gasoline power best, although diesel power may be considered for work in high altitudes. Propane or butane (depending on your local climate) conversions of gasoline engines have merit in many cases.

Tool string & joints

While the machine imparts the lifting and dropping action to the tool string, the string is the equipment which does the work in the hole. It has four basic components whose combined weight provides the force needed to drill the well. These are the rope socket, the drilling jars, the drill stem, and the drill bit itself. They are connected (from top to bottom in that order) to each other by means of tool joints.

Cable tool joints consist of a tapered threaded pin and its conforming box, the dimensions of which are critical for many phases of drilling. The chief measurements of interest to the driller are the dimensions of the threaded areas, the diameters of the pin collar and of the box collar, and the size of the wrench squares. See Figure 3–1 for identification of these parts of the tool joint as well as of tool string components.

As its name implies, the rope socket is the tool which holds the string on the cable, or wire rope. Its body diameter will be the same as the box collar diameter of the cable tool joint selected.

To the rope socket is connected the drilling jar — when used. Drilling jars go in the tool string as a precaution against the bit sticking and always are positioned between the rope socket and the drill stem. When starting the hole, however, the drilling tool string should not include jars.

The drill stem furnishes most of the weight

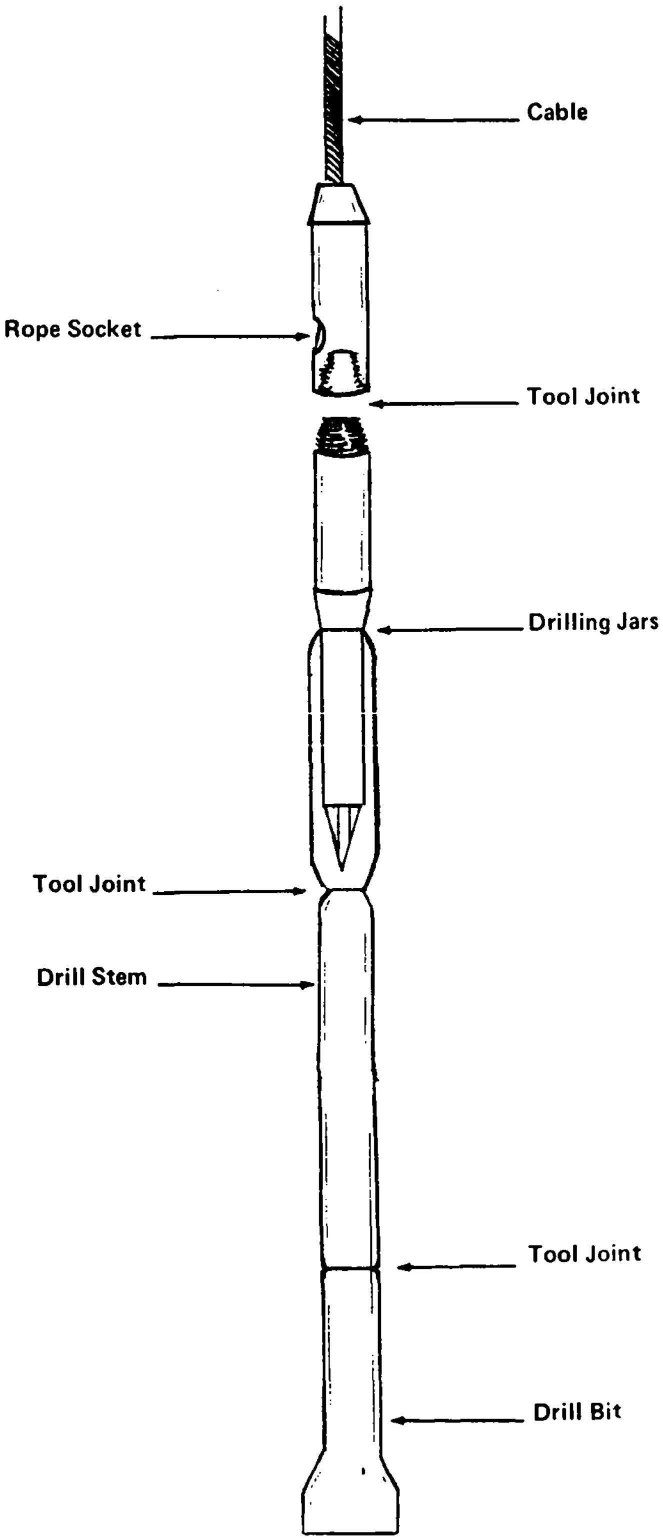

Fig. 3-1 Cable tool string

needed to perform the drilling operation and also guides the rest of the tools as they rise and fall in the hole. It is basically a round bar of steel with a pin joint at its upper end and a box joint below. The body of the stem will not exceed the pin collar diameter, although the box collar may be a size or two larger.

At the business end of the tool string is the drill bit. This is the tool which does the actual cutting. The bottom is flared out beyond the body to the diameter of the hole to be drilled. Length determines bit weight, and water well bits usually are four to five feet long.

Cable

Since this chapter deals with cable tool equipment, it is logical to deal with cable itself. Drilling line is a left lay cable of 6 x 19 or 6 x 21 construction. The proper size is obtainable from the cable manufacturer. A 5/8″ line normally is used on 3″, 4″, 5″, & 6″ well sizes; 3/4″ line is used on 6″, 8″, & 10″ holes; big-hole machines use 7/8″ or 1″ cable.

Bailer lines (explained below) are 3/8″, 7/16″, or 1/2″ and usually are regular lay cable of 6 x 25 construction.

Cable life depends on the care it is given. A cable flexes and bends as it goes over the sheaves and drums of the machines. Excessive internal wear is certain if the line is not properly lubricated. Lubricant is now available in spray cans, and all cable manufacturers can supply the proper materials for lubrication. They also have many fine publications on the selection and care of cable.

Importance of set-up

It often seems that contractors do not impress on new drillers the importance of properly setting up their equipment. It actually is critical.

The author believes that it is best to dig and curb a 6′ to 8′ pit about 4′ to 5′ square as a place to start a drilling job. The pit accommodates the handling of pipe and later facilitates installation of a pitless adapter (a point in well construction which will be discussed in a later chapter.) This pit can be dispensed with if a limited amount of pipe driving will be required, but is helpful otherwise. A properly built platform, at least 8′ square, will give an adequate and safe working area. Planking should be 3″ x 8″ sound lumber about 8′ long; the height should be such that the drill rig levers are most handy for the operator. Use of this platform can prevent serious accidents and will speed up drilling time. In northern winters, a gas or oil salamander and a wind break will keep the platform comfortable, and it should be kept free of ice at all times.

Now is a good time to return to the cable, or wire rope for a moment. Keep it lubricated, and keep it clean. Prevent dog legs or close bends. Spool it on from the bottom of the spool, and do not drill with the drum full of cable.

Attaching the rope socket to the line is an art in itself, so we'll just mention a few points here. The frequency with which it must be done depends upon the weight of the drilling tools. In larger diameter drilling (12″ and over) a socket change is required every 40 to 50 hours. For 4″ to 10″ holes you might go 80 to 120 hours.

Operational notes

All cable tool drilling should be done with a tight line. The machine should be reaching for the bottom at all times. In so doing, the bit and tools will rotate properly.

The speed you run depends upon the formation. A hard rock formation calls for faster speeds; a clay or soft formation is drilled more slowly. Keep that line taut when lowering into the hole, and do not allow the bit to run into the bottom so that a slack line can occur. The cable can be damaged and the pins broken if you do.

In hard formations, make sure you keep the drill bit cut to size, as it means the hole tapers. This will cause a full diameter bit to stick. In such formations do not allow the bit to get more than 1/4″ below gauge. If an undersized bit is used, the fresh sharpened bit will drag or stick.

In soft formations, such as shale or clay, use bits which are quite flat and not pointed.

Keep the hole open

Many dry materials will stand open and allow you to drill ahead of your casing. This is good practice and should be done whenever possible. When you do drive the pipe, quit before it hits the bottom of the drill hole. Leave room for shavings and a chance to make a longer hole with the drill.

In many areas, the ground will have water pressure on it before you get too deep. If this be your case, keep the water level in the hole higher than the natural water table. This will prevent the pressure from caving or sloughing your borehole. When you encounter fine sands, or unconsolidated sandstone, it may be necessary to allow the formation to heave up into the casing in order to make it drive. There will be times when it is an advantage to have 40′ or 50′ of heave in the casing. Just bail a couple of times and drive your pipe. Drilling at this time is useless.

Bailing

Bailing, or removal of drill cuttings, is very important in cable tool drilling. There is no magic number for bailing; frequency depends strictly on the formation and how you're cutting through it.

The bailer is a section of pipe with a check valve on the bottom. The valve is either a flat pattern or a ball-and-tongue pattern called a dart valve. This tool is suspended by a handle from a cable called the bailer line or sand line. It also may include a suction rod and plunger called a sand pump, and this is the author's preference.

Clean gravel or heavier materials require bailing more often than clays or shales. The longer the stones you can pull into the bailer, the less drilling is needed. But a bailer is not made to drill with, so treat it with care. Don't hit the bottom too hard or fast, and don't pick it off the bottom too fast. Keep the plunger in repair so that it will suck without speed action. Build a good trough to lead the bailer dumpings away from the rig and work area.

Equipment maintenance

There is a great deal more than this to cable tool drilling, but the purpose of this chapter is just to start talking about it. It's appropriate to mention once again, however, the importance of the care of your equipment. Daily greasing and periodic lubrication of bronze bearings and anti-friction bearings are very important, for example. A good grade of gear grease is needed for spudder gear and gear drives.

Cleaning and lubrication of cable tool joints is critical. This is precision machinery. The pins must be kept clean, and all threaded surfaces oiled at all times. Do not make the mistake of leaving drill tools assembled; they will last many years longer if taken apart after each job. Clean them with solvent or gasoline and wipe with a clean, absorbent cloth. Use a light grade of motor oil to lubricate before joint is tightened. Cable tool joints must be protected from dirt and rust when not in use.

For the new man, cable tool drilling and maintenance offers much satisfaction and the chance to develop real skills. ■■

Chapter 4—Introduction to rotary drilling

by Robert R. Peters
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Layne Atlantic Company

THE PRINCIPLE OF ROTARY DRILLING is based upon a revolving shaft or drill stem which is hollow and has a fluid of mud or other substance flowing through it for the purpose of floating or circulating cuttings to the surface.There is a several fold purpose for the fluid. First — for the removal of the cuttings; second — for cooling of the drill stem rotating in the bore hole; third — sealing of formation walls to prevent caving and water loss.

Drilling equipment

This method of drilling requires the use of a drilling machine as illustrated (Fig. 1) which consists of a mast with sheave wheels mounted at the top for the purpose of operating a hoisting mechanism. Hanging in the mast or derrick by a block assembly is a square or keyed drive called a kelly. At the top of the kelly is a swivel to which is connected a rubber hose or steel with flexible joints as pressure dictates. This kelly is driven by a rotary drive assembly which has inserts or blocks to fit the kelly. The kelly is larger than the drill rods in order to drill down a few feet below to enable a section of drill pipe to be added as the hole progresses deeper. To the bottom of this kelly are attached hollow drill rods and by the use of attachments, subs, the rotary bit. As we drill deeper additional rods are added to the string just below the kelly. The bit has holes in the bottom through which the fluid can flow. Moving back on the machine we find the draw works which operates the hoisting mechanism. Also mounted either on the machine or sitting beside it is found the pump which forces the drilling fluid through the lines to the swivel down the kelly and out the bottom of the bit.

Drilling bits

The different types of bits can best be described by illustration. We start with the simple star or fishtail drag type of bit (Fig. 2). This bit is used in soft unconsolidated formations such as clay and sands. They have fluid courses which tend to jet the formations and the blades are very effective on sticky clays.

The cone type of roller bits have two to four cone type of cutters mounted on roller bearings which have teeth in varying lengths that intermesh (Fig. 2a). This bit has fluid courses which depending upon the design either jet directly on the formations or wash the cutters clean when the stream is directed on the cones themselves. The bits vary from long tooth cutters for use in soft formations to short intermeshing cutters which tend to chip in very hard material. The harder the formations the shorter the cone teeth. As a general rule we rotate soft formation bits

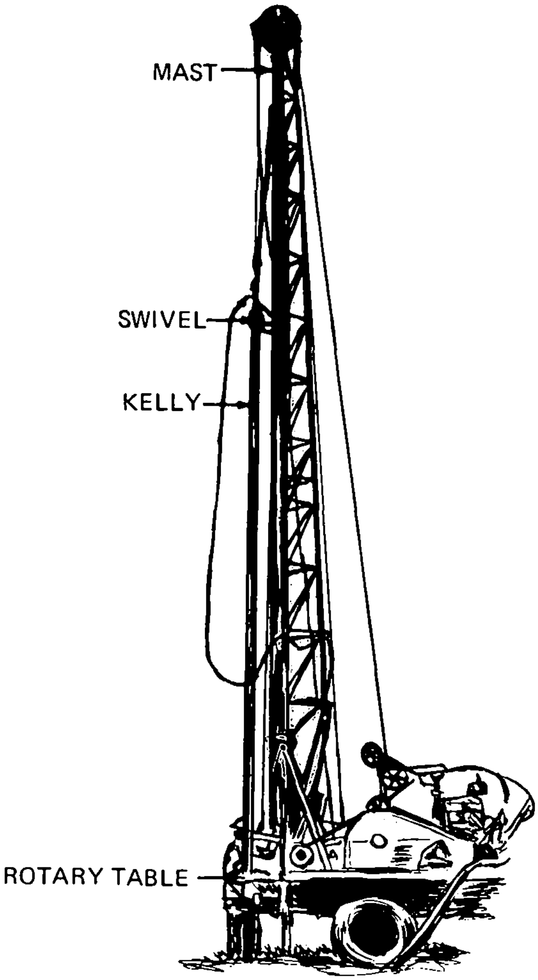
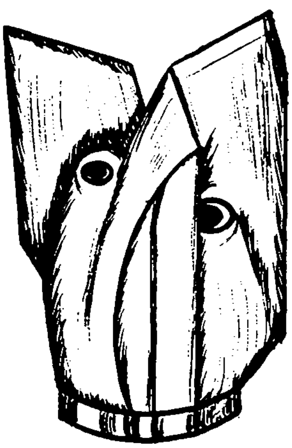
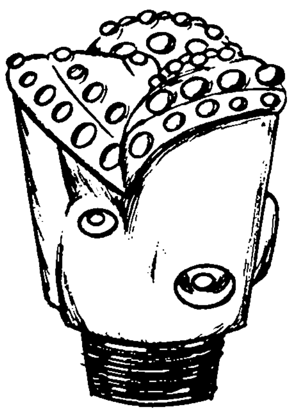


Fig. 1



FISHTAIL BITS

Fig. 2a



CONE BITS

Fig. 2b

at higher speeds and have much lower bit weight. As a general guide soft formation bits will be used at speeds from 50 to 150 RPM with bit weights from 1,000 to 4,000 pounds per inch of bit diameter. The very hard formation bits will be used at speeds of 30 to 50 RPM with 2,000 to 5,000 pounds per inch of bit diameter.

Varying manufacturers have different designs of the fishtail such as finger bits to many types of roller bits. This is a wide field and experience in an area will solve the problem of the most efficient type of bits to use in a particular area and formation.

Hole openers

As we increase the diameter of the hole, which is done in stages, we find the need for larger bits. The hole is constructed by the same method as used for drilling a hole in steel. The first step is to drill a pilot hole and increase the size in stages. Large diameter fishtail bits can be used successfully in the soft formations, but when we have to enlarge the diameter in consolidated formations we use a different type of roller bit. This bit has cutters mounted on the outer radius to enlarge the hole. It has either a pilot fishtail or a box for the use of a small roller cone bit for the pilot. For the enlarging of the hole below a casing to a diameter larger than the casing through which we are drilling, we use an underreamer. There are several types of these tools, but basically we have only two, one being hydraulic where a jetting type of tool is used in soft formations to wash out a pocket. This is done by directing high pressure fluid through nozzles directed toward the face of the formation. This is not effective in hard or consolidated formations. The mechanical type has blades which extend out from the body of the bit when fluid pressure is applied. This type of bit is satisfactory in formations which are consolidated, but relatively soft. When necessary to underream hard formations a bit which has expandable rotary cones is employed. This particular type varies from one manufacturer to another . . . as to the type of rollers used.

Surface pipe

Surface pipe is sometimes necessary and its purpose is to prevent caving in the immediate vicinity of the surface around the rig. This caving can be very hazardous if allowed to continue. It can develop to a point where the machine can actually sink into the ground. It is not normally required below the first hard or clay formation and is usually less than one hundred feet.

Rotary drilling

The idea of rotary drilling was to create a hole in the earth by circulating fluid out the end of a hollow string of pipe washing the cuttings back to the surface. This principle worked very well until the formations encountered began to take or absorb more water than was being pumped down the drill stem. This presented a problem of loss of circulation. Many methods of overcoming this problem were tried and as a general solution a mixture of clay and water was used to seal the formations and prevent water loss. In early construction, drillers would locate a clay bank from which they would secure enough clay to make a slurry which would prevent the loss of the drilling fluid (Fig. 3). This principle was employed until the present method of rotary drilling was established. It consists of a drilling machine which has a hoisting rig which usually has two drums. The principle of this type of drilling involves the use of hollow drill tools through which a drilling fluid, consisting of refined clays in a mixture of water, is circulated. As previously stated the main purpose is to remove or float the cuttings to the surface. Once the fluid is at the surface its velocity is reduced to allow the settling of the cuttings in the mud ditch thereby allowing the reverse of the fluid for the further removal of cuttings. We have, therefore, arrived at the general principle of rotary drilling. We must now begin to explore the principles which enable us to construct a successful well by this means.

The first order of business is to have a machine capable of drilling to the depth and diameter contemplated. Then it is important we level the machine to allow the drilling of a vertical hole in which we may set our casing and work. The machine will allow the operator to perform this function. We must realize that if the machine is not level then we tend to have a drill hole which will not follow a plumb and vertical line. Immediately upon the beginning of the set up we must begin to prepare the drilling fluid. This is very important as with the modern fluids they require a time for swelling. If they are used before the time necessary we tend to pump or place undeveloped fluids opposite formations — thereby creating a situation which will allow them to swell in place. The modern clays for drilling require curing time and therefore if ignored they tend to cure in place. If this happens we can see what happens when we attempt to develop the formation. I only mention this and attempt to emphasize at the beginning how important it is to prepare this drilling fluid before using same.

The next principle is the drilling of the actual hole. We begin by allowing the drill string to penetrate the formation which consists of a rotating or revolving of the drill tools and concentrically pumping the drilling fluid through the hollow string. This allows the fluid to discharge out of the bit and circulate to the surface. The viscosity or thickness of the drilling fluid will carry the cuttings to the surface due to the velocity. The construction of the mud ditches on the surface reduces the velocity and thereby allows the cuttings to settle. This enables us to reuse the fluid over and over again. It is very important that the sand or cuttings settle in the slush pit to prevent the pump from circulating high volumes of cuttings which will cause excessive wear in the pumps.

Rotary drilling as previously stated consists of the removal of formations by pumping a drilling fluid through a string of hollow tools removing the formations encountered by the bit. The principle of water well drilling is to construct a plumb or straight hole. In rotary drilling this is accomplished by not running a slack line. In other words we must not allow the full weight of the string to apply upon the bit. If this should happen we will cause a bow in the line of tools and thereby cause the bit to wander or move in a direction other than plumb. The proper way to maintain a straight or plumb hole is by the use of drill collars in deep holes. A drill collar is a section of very heavy wall pipe that consists of considerable steel which allows weight to be exerted directly upon the bit and also causes the string to be pulled taut or plumb. In order to get the designed penetration from the bits used we must apply a certain force or pounds per square foot of area drilled. In other words a certain force is necessary to penetrate the formations. From the driller's manuals we see that pressures vary depending upon formations encountered.

It is very important to mentally visualize the formations encountered. This must be done by the drilling or reaction of the machine itself. This is a matter of experience from the watching of the machine operate in various formations. Sand, for instance, will tend to cause a chatter and drill

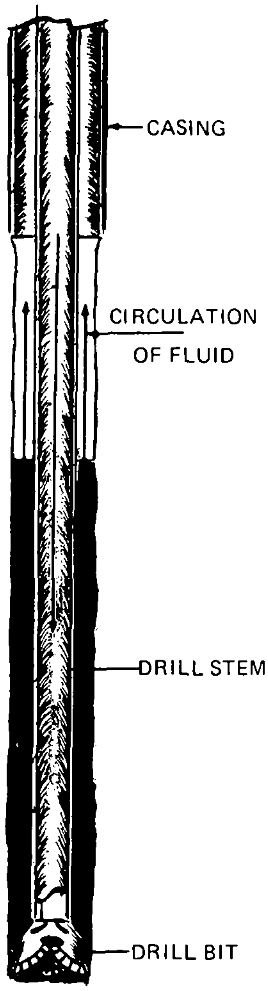


Fig. 3

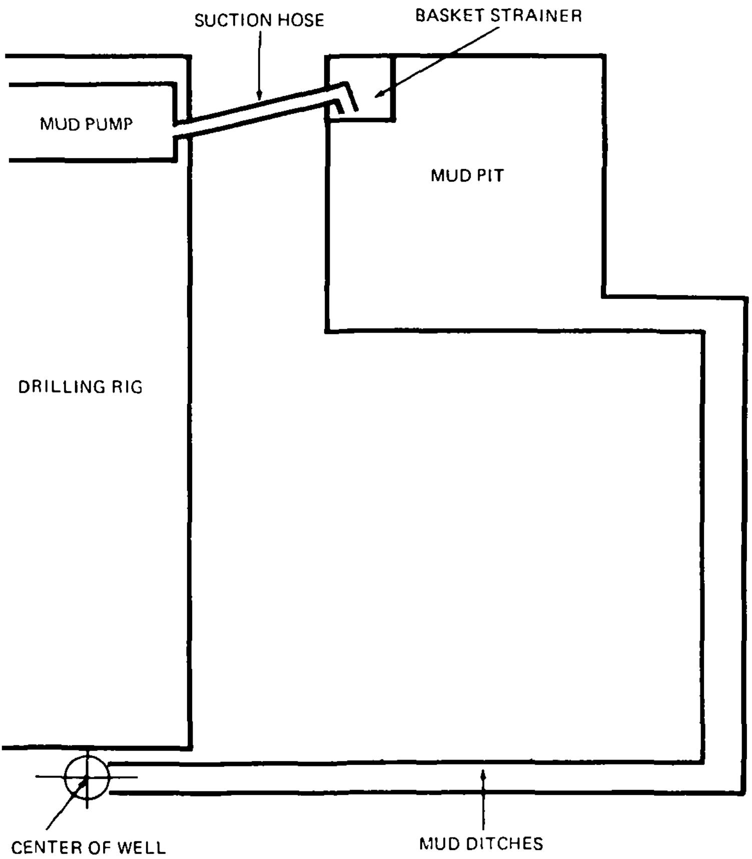


Fig. 4

rather fast; while clay will cause the machine to run rather smooth and drill slow. Other than this we find the drilling procedure to be a combination of varying drilling conditions. This varying speed of the drilling vs operation of the machine through experience will enable the driller to determine the formations penetrated.

In recent years the use of the electric log enables us to confirm various formations penetrated to a much greater degree than before. The types of pumps used in the drilling depends upon the formations and depths to which the drilling will be done. A centrifugal type of pump will allow us to have rather high volumes of fluid to relative shallow depths but is limited when the friction loss in the drill pipe becomes high due to long lengths or small size. When drilling to deep depths it is necessary that high pressure piston pumps be used. They do require careful design of the mud pits together with good mud control to prevent high sand contents in the fluid. High volumes of sand in this type of pump will cause rapid wear of the pistons and liners.

Mud pits and ditches

Mud pits and ditches are designed to reduce the velocity of the drilling fluid to a point where the cuttings will settle to the bottom and not be carried to the pump (Fig. 4). We do not want to recirculate any sand in our fluid if possible as this causes excessive wear on all equipment in and through which it passes. Another point is the high weight created by the sand content causes sealing of the formations with pressures not necessary.

Drilling fluid

Drilling fluid is one of the most important phases of hydraulic rotary drilling and needs to be understood by all drillers. It is relatively simple to handle and control if a few simple rules are followed. We can have very complex and sophisticated mud controls but normally they are not necessary to the degree of oil well construction. I cannot overemphasize, however, the importance of good mud control. With it lies the success or failure of each well you drill. We should mention at this point that bentonite clays are difficult to mix and the use of a jet hopper is desirable.

The idea of the drilling fluid being correct means its viscosity should be such that the proper sealing effect is maintained with as little invasion into the water bearing formations as possible. This is developed by having proper weights and viscosities. Once we have prepared our fluid to the recommended condition it is circulated in the bore hole and in so doing (the weight of the fluid being higher than the pressure of the formation) there is a tendency for the fluid to penetrate outward into the formations themselves. The fluid begins to form a wall of clay on the sides of the bore hole. In other words the formation itself filters out the clay particles and develops what we call a filter cake. The thickness of this cake is governed by the ability of the cake to retard water losses into the formations. If we maintain a relatively thin cake the water loss and formation contamination will be slight, however, a thick or deep penetrating cake is very hard to remove and thereby restricts or prevents flow from the formation into our finished well. We can begin the drilling of our well with a known fluid but one thing to always remember is that as we drill through native clays we have the mixing of same with our fluid and sometimes this contamination is very high. In order to maintain the type fluid with which we can construct the most efficient job we must perform tests on our fluid to know the qualities.

Marsh Funnel

First we have a Marsh Funnel and measuring cup, with a built-in screen to remove foreign material, which will give us the viscosity of our fluid. It is measured by placing 1500 cubic cm. of our fluid as it is being displaced from the well bore and placing it into the funnel. Our finger is over the end of the funnel and when removed one quart is allowed to flow into the measuring cup. Time required to flow one quart of fluid would be 25 to 30 seconds.

Mud Balance

The Mud Balance is used to determine the weight per gallon of the drilling fluid. It consists of base and graduated arm with cup, lid, knife edge, rider, level and counterweight. The cup is on one end of the arm and the counterweight on the other. Its use is by filling the cup level with a sample of mud taken as it comes from the bore of the well. It is then wiped clean, after placing lid, to remove excess mud from the outside. There is a small vent hole in the lid. To be sure the cup is filled always make sure some fluid comes out of the hole as the lid is pressed into place. The balance is then placed upon knife edge rest. The rider is then moved until the instrument is in balance. The weight per gallon can then be read directly from the graduated arm. To convert the weight per gallon to specific gravity we divide by 8.34. The weight of our fluid determines the pressure we place upon the formations. We only want the minimum pressures necessary to prevent formation caving. This should be in the range of 9 lb./gallon for most normal conditions. We must raise this weight when encountering high pressure formations to prevent their flowing during construction. This can be controlled by the addition of weighting agents to the degree necessary. It is important to note that this same instrument is used to determine the weight of our cement.

Sand content test

Another simple but important test is for sand content. It consists of a 200 mesh sieve, funnel, and glass measuring tube graduated 0-20% which can be read directly as to the percentage of sand in our drilling fluid. This sample is taken from our pits after settling or just before the pump. Its use is to add mud in the glass tube to a point marked, then add water to the point marked and shake This is then attached to the top of the screen which is then inserted into the glass tube. The sand is washed from the screen into the tube with clean water. The volume of sand can then be read directly on the tube. It is important to clean and dry the fine screen. A sand content of not more than 2-3% can be tolerated but the lower the better. High volumes of sand will cause excessive wear and also cause stuck pipe Pumping this heavier fluid requires additional horsepower and adds mud pressure to the formation.

pH of fluid

The pH of the fluid is important in that it tells what contaminants are being drilled. Normally our fluid will carry a pH of 8.0-9.0. Within these ranges we find removal and development is more readily controlled. A simplified method of pH determination is by the use of a paper indicator called Phydrion Dispenser. A strip of this paper is torn from the dispenser and allowed to absorb filtrate from the surface of the mud by placing it gently on the surface. It will change color and this is matched with color strips on the dispenser.

Good maintenance of equipment, proper techniques, suitable equipment and good mud control will enable you to successfully complete the construction. Hydraulic Rotary drilling success is extremely dependent upon a successful program. It, as all methods of construction, has its particular application. ■ ■

Chapter 5 —
Air rotary and air hammer drilling

By R. B. Heater
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THERE ARE TWO BASIC TYPES of machines which are used for air rotary drilling and air hammer drilling. Essentially the machines do the same job:

1. Provide air for the drilling operation
2. Provide rotation power to turn the drill.

All other equipment and accessories on the machine are there to help perform the two abovenamed operations. The air well drilling machine is most often found mounted on a truck for ease of mobility, but can also be found mounted on a tracked vehicle where distance between holes is very short, such as in the drilling of blast holes.

Illustration No. 1 shows an example of a tophead drive type air drilling machine. These machines come in both high-pressure and lowpressure models. The differences being in the capacity of the compressor that is mounted on the machine.

The top-head drive machine derives its name from the fact that the rotation power is applied from the top of the drill pipe to give it the necessary rotation power for drilling. Most of these machines will have a single large engine driving the compressor and will either use air to provide the rotation power, or will have a hydraulic pump driving off the same engine to provide hydraulic power to cause the rotation motor to function.

Top-head drive rigs

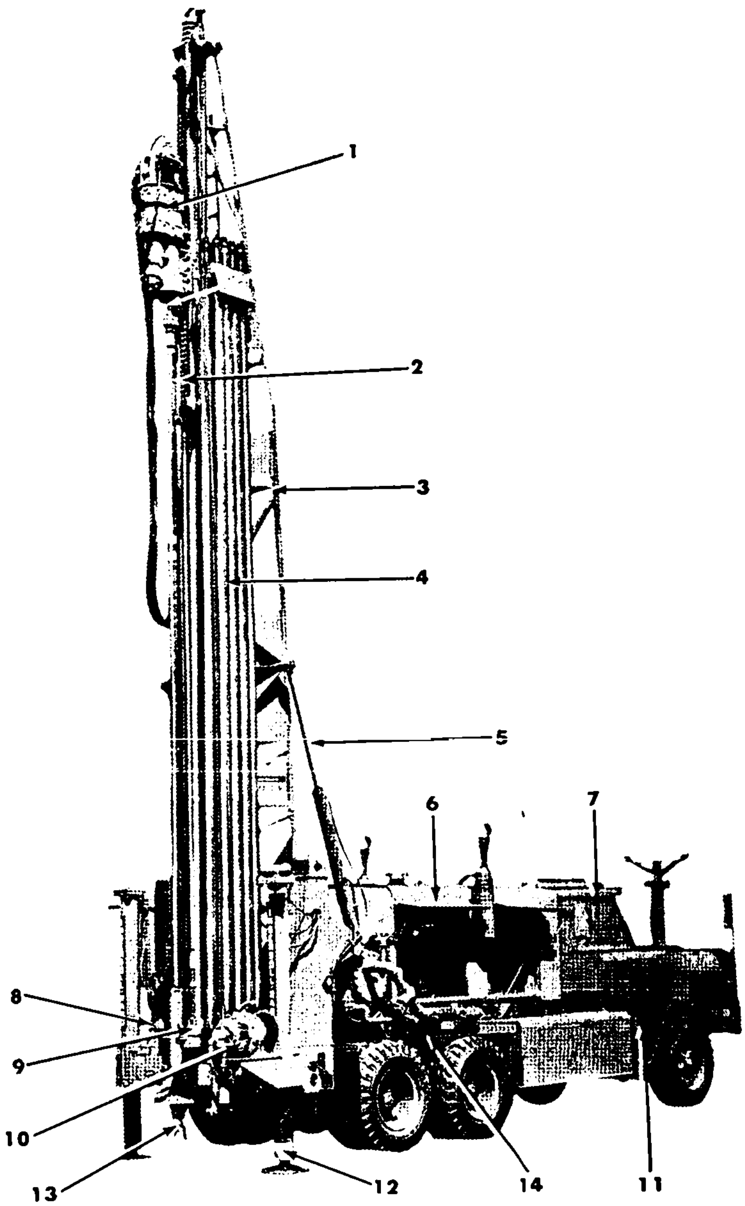
In illustration No. 1, Item #1 is the tophead drive which in this instance is driven by air. Item #2 is the drill rod which is connected to the rotation head. Item #3 is the derrick of the drilling machine and can be one of many different types. Item #4 shows the stacked additional drill pipe which is carried on the machine. Item #5 is the hydraulic cylinder which is used to raise the derrick from a horizontal to a vertical position to make the rig ready to drill. Item #6 shows the compressor and the engine portion of the machine. Item #7 is the cab of the machine.

In item #8, if you look closely, you can see the hydraulic cylinder that is used for operating the drill pipe tongs. Item #9 is a rod carrier assembly which is used to place new rods in position as the hole is drilled deeper. Item #10 shows an auxiliary winch which is used to pick up the drill rods and casing to move them around the machine.

Item #11 shows the fuel tank and item #12 shows the hydraulic leveling jacks which are used to level off the machine for drilling. Item #13 is the drilling bit which is located on the bottom end of the hammer. Item #14 is the airline lubricator which is used to place rock drill oil into the flow of air in order to lubricate the hammer or bit.

Rotary table drive rigs

Illustration No. 2 shows a picture of a rotary table drive type machine. The basic difference between the rotary table drive and the top-head drive machine is that on the rotary table drive machine the rotation power is applied to a rotary table and through this to a kelly; which is either a square, hexagonal, or fluted-type drill rod that



Illus. — I

passes through the table and picks up the rotation power from the table as it slides through a mated fitting on the table. The kelly is attached to the drill rod in the same manner as the rotary head is on a top-head'drive rig.

Item #1 of Illustration No. 2 is the rotary table. Item #2 is the kelly. Item #3 is the air hose that connects to the top of the kelly to transmit air to the inside of the kelly, and from there to the bit. Item #4 shows a section of the derrick. One of the hydraulic cylinders used to raise the derrick from the horizontal to the vertical, or drilling position, is shown by item #6. Item #5 shows the swivel. This keeps the air hose from turning with the kelly, but still passes air through the kelly without allowing for any leakage. Item #7 is the air compressor and item #8 is the truck cab. Item #9 is a dust collector and is very important when drilling just with air as a means of moving the cuttings out of the hole.

Even though these two types of machines are different in construction, they still come back to the same basic principle of providing air for drilling, and providing rotation to rotate the drill in the hole. Everything else is accessory to these two main facts.

Drilling accessories

Illustration No. 3 shows some of the accessories that are used with these machines. These accessories will vary from one machine to another, but the basic tools are similar. With regard to the bit detaching chuck shown, the shape may vary from one make to another, but each of the machines will have some type of chuck or holding device to use in detaching the bit from the hammer or drill rod. The centralizer split bushings are merely a device to keep the hammer in the center of a particular part of the machine, either the rotary table when a rotary table machine is used, or in a holding device when a top-head drive type machine is used.

The hydraulic wrench tong will be found in some fashion on each of the machines. Although on some rotary table drive machines the wrench tong does not connect to a hydraulic cylinder. Instead, it will attach to an arm on the machine. The rotation power of a rotary table is used to do the turning.

The centralizer is similar to the centralizer split bushing but is a solid piece, rather than being a split piece. The centralizer fork chuck is used in some manner with most makes of machines that are top-head drive, and the rotary table drive generally would have what is known as a set of slips which consist of two pieces made to fit in the rotary table and catch and hold the drill pipe. In either event they are used to hold the weight of the drill pipe while changes are being made and, in some instances, are being used to prevent the rotation of the drill pipe, or to cause it to rotate with the table.

The rod handling chuck is merely used to lift drill rods and varies in design from manufacturer to manufacturer. Some manufacturers use a swivel type box or pin to accomplish the same purpose. The drill rod latching bar is merely a locking device to hold the drill rods on the machine while traveling to the job site. In some machines use of this will be unnecessary and in some others pins or similar locking devices will be used. The rod handling sling is used to lift drill rods to prevent them from tilting when they are picked up. Some machines do not use these, but instead use a swivel lifting device on the top of the drill rod. These slings are generally used where the weight of the drill rod is picked up at the bottom and the sling is attached part-way up the drill rod to keep it from tilting over. A bit grinder is an air-driven grinder that is used to sharpen carbide-type bits.

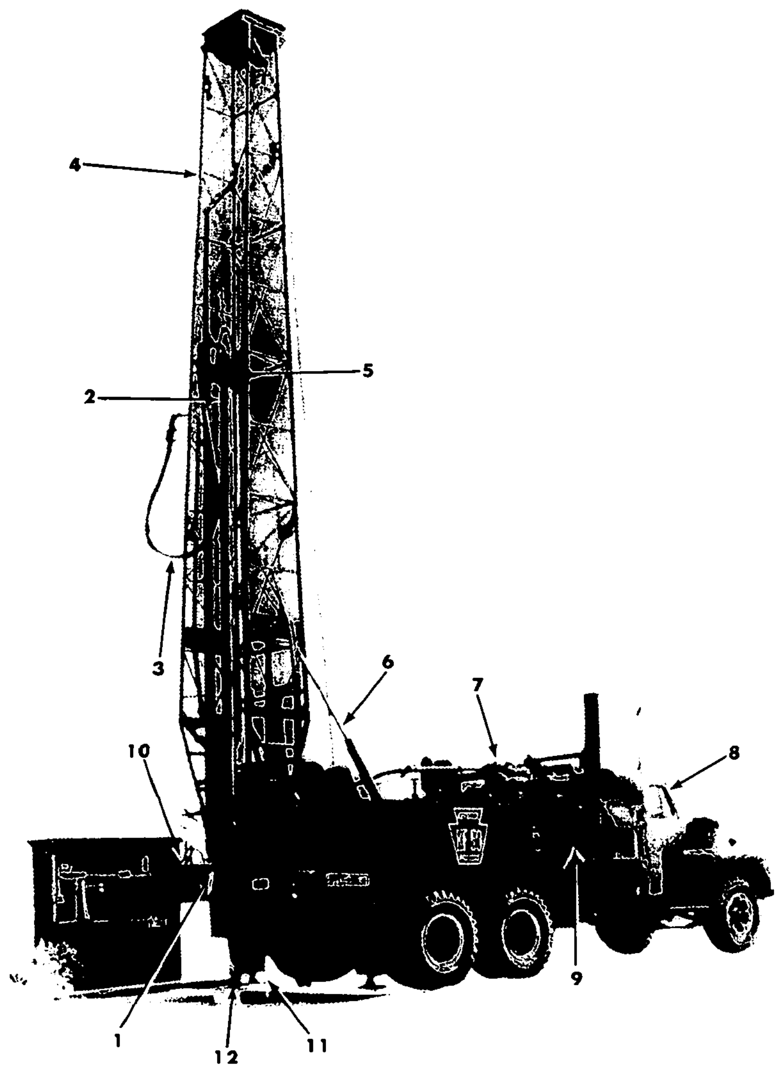
Principle of air rotary drilling

Air rotary drilling was the first method to be developed for use in drilling water wells. Roller type rock bits are used to do the drilling with this method and they consist of either two, three or four roller cones with teeth mounted on a bit body by means of roller or ball bearings. The bit is then rotated by means of the drill rods being rotated. As the bit rotates, the rollers in turn rotate, thus causing the cone to rotate under the bit. As the teeth on the bit strike the formation they force the formation to break up into smaller pieces.

Air is directed into the drill pipe and goes down through the kelly and through the bit as the bit rotates. As the air comes out at the bottom of the bit it strikes the formation being cut loose and blows it away from the bottom of the bit. This exposes new rock surface for the bit to drill upon. The velocity of the air coming out of the bit is great enough to carry these cuttings away from the bottom of the bit and return them to the surface of the ground. These cuttings are blown to the surface between the hole that has been drilled and the drill pipe which is turning the bit. Thus, the bit is continuously exposed to new formation and the material that has been cut is continuously being blown to the surface.

This method of drilling is really an extension of hydraulic rotary drilling with just the change from a mud-type medium to remove the cuttings from the hole to the use of an air-type medium to remove cuttings from the hole and, therefore, was not a major step forward.

In drilling with air rotary type equipment, it is generally recommended that rotation speeds in the range of 10 to 20 rpm be maintained on very hard rock, with a very high down-pressure



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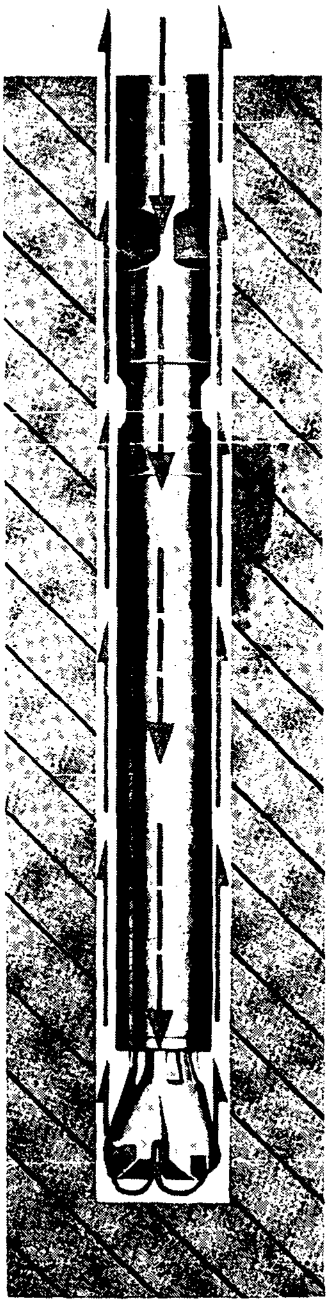
being applied to the bit by means of a down-pressure device on the drilling machine. The proper weight to be applied to a bit varies from bit to bit and depends largely on the design of the bit. The manufacturer's recommendations should be followed when applying down-pressure.

Roller type rock bits are designed with longer teeth for soft formations and shorter teeth for hard formations. Generally, with softer formations, less down-pressure and higher rotation speeds are called for.

Illus. — III



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Air hammer drilling

Air hammer drilling is a modernized version of cable tool of churn drilling, however with significant improvements to speed up the drilling operation. In air hammer drilling you still use the same drill rods coming away from the machine down into the well to attach to the top of the hammer. These drill rods take the rotation from the rotary head or rotary table and impart this rotation to the air hammer. The rotation keeps the hole round and allows you to use a bit that does not completely fill up the hole.

If you used a solid round bit you would not be able to get the cuttings up from the bottom of the hole. Therefore, any bit you use must be shaped in such a manner as to leave an opening for the cuttings to come up from under it. As a result of this the bit must be rotated to keep the hole round.

Again, as in air rotary drilling, air passes through the drill pipe down to the hammer. The path the air takes is similar to that in illustration No. 4, where the dashed arrows show the air passing through the center of the drill pipe, through the hammer, and coming up outside of the hammer and drill pipe to be pushed up to the surface of the ground.

The actual drilling operation of the hammer is caused by a piston that is forced down inside the hammer, causing it to strike the top of the bit. The bit then strikes the formation. Then, through use of a valve mechanism, the path that the air takes is changed to a point underneath the piston which causes the piston to be lifted by the air. When the piston reaches the top of the cylinder that it is operating in the valve switches again causing the air to enter above the piston and forces it down for the next blow on the bit.

You might describe it as being similar to putting the bit out on top of the ground and, taking a sledge hammer, hitting the top of the bit. But here you are using air and a piston to give you this hammer action. Even though the design of hammers vary, they are all basically working on the same principle, with the air forcing the piston down, lifting it, then forcing it down again.

The bits used with hammers are interchangeable so that you can take them off the hammer and sharpen them. Illustration No. 5 shows an X-type bit and illustration No. 6 shows an X-type drop center bit, the regular X-type bit and a drop center button bit. Bits work differently in different formations; therefore, each driller learns which bit does the best job in his formation through trial and error and then continues to use that type bit.

As the hammer is drilling, the piston strikes the bit, the bit in turn strikes the surface of the formation being cut. However, various speeds are used for the bit turning. These speeds will vary from 400 to 1,200 blows per minute depending on the particular hammer and the pressure at which it is operating. A great deal of controversy has arisen over which of the various makes of hammers and pressures on hammers drills the fastest. I believe you will find that this will vary from formation to formation and that some bits will do better than others. But the principle of operation is still the same.

As the chips are knocked out of the formation by the bit striking it, the air coming out of the bottom of the bit lifts these chips and carries them back to the surface on the outside of the hammer and drill pipe. When chips and/or dust come out of the top of the well the velocity of the air immediately drops because it is no longer confined. Therefore, the chips fall to the ground in the immediate area around the well. The finer the chips or dust, the farther it will go before it drops to the ground.

After the hammer has cut the new hole to the depth of the drill rod to which it is attached the drilling is stopped and the drill rod is disconnected from either the rotary head or kelly — depending on the type of machinery being used. Then a new drill rod is inserted between the one already in the well and the rotary head or kelly. This, then, allows you to continue drilling the additional depth of the new drill rod.

Thus, as you go deeper, you merely add new drill rods. The depth the machine can drill to is only limited by the amount of weight the machine can handle, for as the hole gets deeper the amount of drill pipe increases and the weight gets much heavier on the machine. In a wet hole there are limitations as to the depth which can be drilled to due to the pressure the water exerts on the piston in the bottom of the hole. This eventually reaches the point that it equals the pressure of the air being injected at the top of the hole.

It is sufficient to say at this time in your introduction to air rotary and air hammer drilling that with large quantities of water in a well, a practical point is reached where it is not profitable to try to continue drilling deeper with an air drill due to the worsening efficiency of the hammer caused by the weight of the water.

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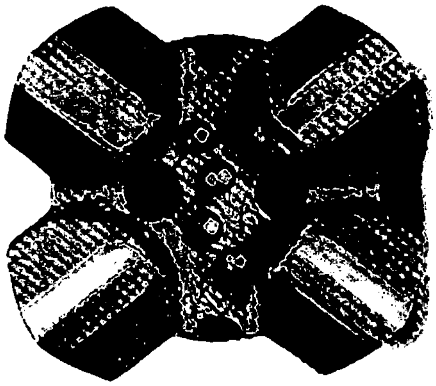
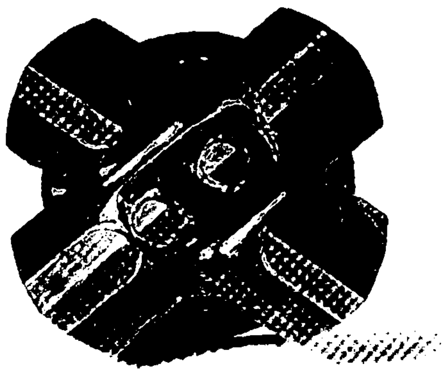


Illus. — V



Illus. — VI

Part II
Air rotary and air hammer drilling

By R. B. Heater
Vice president
Heater Well Company
Cary, North Carolina

SINCE YOU, AS A HELPER, will work in all phases of drilling, let us take an imaginary job and start at the beginning and go through to the completion of it.

The first thing you should do before leaving your yard is to check your machine and service truck thoroughly. This would include the normal maintenance on a truck such as lubrication and inspection, changing oil filters if they need to be changed, changing air filters if they are scheduled for cleaning, greasing the truck, checking the transmission, differential, and in particular observing for loose connections, bolts, fittings, and so forth.

Due to the nature of the work the well drilling machine is doing, it subjects the rig to very heavy vibration a large portion of the time and this quite frequently causes various connections to come loose. As a helper, one of your main functions will be to spot loose bolts, studs, nuts, and so forth, and keep them tight at all times.

Thinking ahead is one of the most important things a driller's helper must do. Before leaving the yard, you should think ahead as to what materials and equipment you are going to need on the job you are going to. Be sure you have adequate pipe of the right size and type with you, that you have a drive shoe and cap for the well so that if you finish it that day you can cap it off. Be sure you have adequate bits of the right size, a sufficient number of grinding rocks to sharpen the bit, etc.

The most time-consuming, unproductive occurrence on a well drilling job is returning to the yard for material which should have been included when the truck left the yard. Make your preparation for drilling thorough and complete before starting to the job.

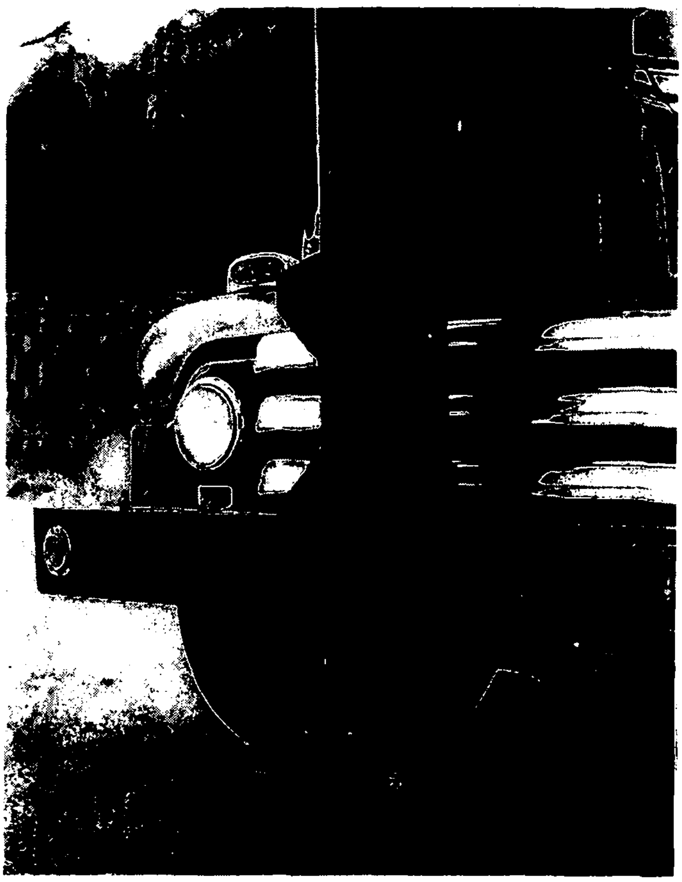
Moving to the Job

Since the regular air drilling machine is a very heavy piece of equipment you, as a helper, will not be driving it for quite a while. Therefore, you will be following the driller with the service truck while he leads with the well machine. This is not a time for a helper to be loafing. Not only should his attention be directed to safely driving the piece of equipment he is in, but he should also be on the lookout for any evidences of bent wheels, rock between tires, faulty brake lights on the rig, loose objects on the machine, and things of this nature while following the well machine, in order to correct them when they stop. Be sure to follow at a safe distance behind the rig for it is usually traveling slowly.

Setting Up

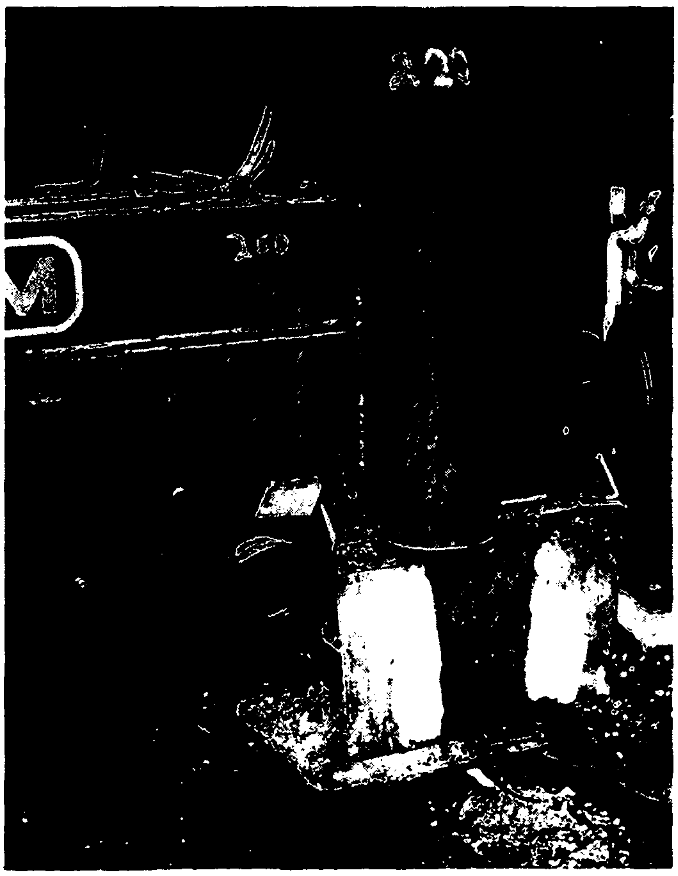
Once you arrive at the job, the first operation will be setting up the equipment for drilling. Once the well site is located you should select the direction in which the machine will be most level when it is in its natural position as it is driven in. Also, consideration should be given to the problem of getting the machine out. You should never set up the machine in such a manner as to block your exit once the new well is drilled.

Once you have selected the proper direction in which to place the machine, you should then check carefully for high tension power lines that come in contact with the derrick or the equipment you are working with. Many drillers' lives are lost through electrocution.



Front jack

Rear jack



Once you are sure you are clear of power lines, you should visually check the machine to be sure that nothing that should be tied down is loose and might fall when the derrick is raised.

With these things behind you, you are ready to start the actual set-up of the machine. The machine has two jacks on the back end and one jack on the front end. To avoid twisting the machine it is always best to level the back end of the machine before leveling the machine from front to rear.

If the back of the machine is going to have to be picked up very high, the front jack on the low side of the machine is extended to bring the machine to a level position. When the machine is level sideways, then it can be leveled front to rear using the front and/or rear jacks together.

Most machines will have either a spirit level or a plumb bob located on it at some point to tell you when the machine is level. Bring it to this point. Then, if your jacks have safety valves on them, the valves should be closed to be sure that the jacks will stay in the position you placed them. The next step will be to raise the derrick. As the derrick is raised you should be paying *particular* attention for any loose objects or loose lines that will allow any part of the equipment to slide or fall unexpectedly and injure someone. Once the derrick has been placed in the vertical position, the safety locks for the derrick should be put in place and the level of the machine checked. Frequently, when the derrick is raised, it will affect the level and the machine will have to be releveled. Once all of these steps are taken the machine should be in position to start drilling.

Drilling in Unconsolidated Formations

You are now about to begin to drill the well and in most cases you will be drilling with a tricone bit or a larger hammer bit. In either case, the bit will be large enough to give you a hole to allow the pipe to go easily into the hole.

Assuming that you are drilling with a tricone bit in the overburden, you will attach the tricone bit to the bottom of the drill pipe or kelly depending on the type of machine you are using by means of a sub. In well drilling terminology, a sub is an adapter from one type or one size of thread to another type or size of thread. Once the tricone bit has been placed on the machine you are ready to start drilling.

You lower the bit to the ground and start the rotation at a fairly rapid 35 to 50 rpm. Then, gradually turn on the air. The air then blows through the rod, out of the bit with the bit rotation, and you are ready to start drilling. You would apply a light down-pressure to the kelly or drill pipe forcing it into the ground. At this point you must be very careful to watch that pieces of rock or dirt are not thrown into your eyes for the air will be throwing the material at the base of the bit out in all directions since there is no hole to cause it to come straight up.

As the bit rotates, the down pressure is continuously applied to cause the bit to drill its way into the ground. At this point you would not want to put heavy down-pressure on the bit for it would cause the hole to become crooked.

You would continue on with this until you had drilled the length of the kelly or drill rod, depending on the type of machine. At this point the machine rotation would be stopped, the air left to blow a short period of time to clean the hole thoroughly, and then the air would be cut off.

With a top-head drive machine you would then attach a drill rod wrench such as the centralizer fork chuck under the flat portion of the drill rod and by reversing the rotation of the head you would unscrew the joint. The drill rod wrench would hold the rod in place when the head is not attached. The head would then be raised up to the top of the derrick and a new drill rod would be connected to it, and then lowered down and threaded onto the top of the drill rod that was in the hole.

Once this is tightened up, the drill rod wrench would be removed and you would then be ready to start your rotation and air and go back to drilling. In the case of a kelly type machine you would (1) pull the kelly from the hole, (2) place your drill rod wrench on the bit sub, (3) disconnect the kelly, (4) add a drill rod to the top of the bit sub, (5) take off the drill wrench, (6) lower the new drill rod into the hole, (7) attach the drill rod wrench to the top of the new drill rod and (8) attach the kelly to the top of the new drill rod thus connecting your drive line. The wrench would then be removed, the kelly lowered into the table and drilling would resume.

While this drilling is taking place you will note that a pile of cuttings builds up around the hole.

New button bit

Worn button bit

You as a helper are expected to keep this cleared away from the hole and out from under the driller's feet. You should, as standard practice, save a sample of cuttings that are coming from the hole every ten feet, or at any change of formation, to determine what formations you are passing through.

This process would be continued until you reach the top of the rock. You would then drill two to five feet into the rock to allow room to insert pipe to obtain a sanitary seal.

Once the hole has been drilled into the top of the rock, the driller would blow the hole quite vigorously to get it as clean as possible in order that he might not have any problem in placing the pipe in the hole. While the drilling is taking place, you, the helper, should be lining up casing to go into the well, measuring it, and attaching the drive shoe to the bottom of the pipe and then to the hoisting mechanism the driller uses, making it ready to go into the hole. Once the hole is good and clean the driller will remove the drill from the hole and you will be helping to disconnect each length of drill rod as it comes out and to stack it in its proper position on the machine. Care should be used in handling the drill rod so as not to batter or damage the threads. Once all the drill rods are out of the hole and the bit taken off, you are ready to install the casing.

In the event the hammer is used to drill the overburden, the principle is the same for drilling, the only difference being that the hammer would have the action of the hammer type bit instead of the cone type bit to cut the formation. In some areas of the United States, the overburden is so loose that it is impractical to try to drill an open hole with air through the overburden. In these cases the driller quite frequently drills the overburden using the hydraulic rotary process.

Installing Pipe

Since you are now ready to install pipe and have the drive shoe on, it is merely a matter of picking up the pipe, lowering it into the hole, and attaching the next joint, being sure that it is tightly joined together, if threaded, or that it is welded leakproof if you are using welded type pipe. The total number of joints needed to reach the bottom of the hole are placed in with a record being made of the type, size and length of each joint of pipe so that in the event some trouble should occur in the future, you will have this information available. In some areas it is necessary to cement the pipe in place, which is described in another chapter. In the areas where cement is not used, the pipe is merely driven into the top of the rock to effect a seal. Some drillers merely push the pipe as hard as possible while others use an old bit on the hammer, and hammer and push together to seat the pipe firmly into the bedrock.

Drilling Consolidated Material

Once the casing is in place, you then attach your tricone bit or hammer, whichever you are going to use, with the proper size bit onto your drill rods and put them back in the hole to the bottom. However, as you approach the bottom you should apply air to the hammer or drill bit as it is quite common for the pipe to have a plug of overburden in it when you go back into the hole after setting the pipe. By rotating and blowing as you re-enter the hole, you blow it out the top and do not plug up your bit. This would readily clear the hole, allowing your bit to sit down on the new rock formation at the bottom of the hole.

If at this point you are drilling with a roller type rock bit, you need to apply a very heavy down-pressure. Start a slow rotation of approximately 10 to 20 rpm to cut the rock, assuming that it is very hard rock. The softer the rock the faster the machine would be rotating and the lighter the pressure that would be needed to cut the formation.

You continue on in this manner drilling as you did in the overburden, with one exception. It is important that a stabilizer rod be used, whenever a tricone is used with heavy down-pressure, to prevent the hole from becoming crooked. A stabilizer rod is a short drill rod which is much larger in diameter and, in most instances, has several ridges on it that would almost take up the full diameter of the hole. The purpose of these ridges is to hit against the side of the hole to prevent the hole going crooked by holding the bit perfectly straight, yet still allowing room for the cuttings to come up beside the stabilizer.

In most cases where the rock is very hard you will be drilling with the air hammer instead of a tricone and the hammer tends to take the place of the stabilizer. Also, you could not run the hammer with heavy down-pressure. You would merely keep enough down-pressure on the hammer to keep it from bouncing up rather than having the bit bounce down when the piston strikes the bit.

You will continue drilling in this manner, adding drill rods, until you reach the desired depth or obtain the desired amount of water. As you get deeper into the hole the weight of the sure decreases. At a depth of approximately 200 feet you reach the point where the weight on the bit is becoming too great for hammer use from the weight of the drill rods alone and it then becomes desirable to hold up slightly on the drill rods to prevent their full weight from resting on the bit. Of course as you get deeper it is necessary to hold more and more weight off the hammer.

With either type of drilling, as you go into the hole you find that a heavy cloud of rock dust will be blowing out the top. You should keep this dust away from the pipe to give you a safe footing. Then, depending on which type of equipment being used, you will either start injecting water into the air so that it will travel down the drill pipe and out the bit to cause dampening of the dust to keep it from blowing, or you will have a dust collector from which a suction hose is placed around the drill pipe where it exits from the well. The dust is then sucked into the dust collector and separated from the air. On the dust collector type machine, it is the helper's job to periodically empty the dustbin.

While the drilling is proceeding the bits are usually sharpened, if they are sharpened at all in the field. While the driller is sharpening the bit which was used on the previous job you should observe him carefully to learn how he goes about sharpening bits. A good helper, after a period of approximately two weeks, should be in a position to start sharpening bits under the close supervision of the driller so that he can learn this important part of the drilling operation. When not busy with sharpening bits and emptying the dustbin, you should be cleaning up the tools you have been using. In particular, as soon after the casing is set, you should clean up the bit that was used to drill through the overburden. Both the cutter portion of it, the bearings, and the threaded portion of it should be cleaned. Then apply a thread protector on it and place the bit back on the machine where it is normally kept ready for use at the next job. One of the most important things that a good helper can do is to keep all the hand tools and drilling tools clean and ready for immediate use at all times.

You should make a habit whenever you pass the gauges on the machinery to look and see if they are at the proper operating range. If you notice any variation, quickly call the attention of the driller to the situation. As we mentioned earlier, the tightening of bolts and nuts in connections on the machine is something that should be continuously carried on and should always be watched for. You can spot a loose bolt much easier when the machine is running, for the vibrations will tend to cause the bolt to vibrate and you can more readily see that it is loose. A good helper will see to it that no bolt stays loose very long anywhere on the machine.

As the cuttings begin to come out of the hole and pile up around the casing, you should start to build a dam in a circle approximately 18″ out from the casing, completely around it and 6″ to 8″ high so that when water is struck it will be contained in this dammed up area. Each of these machines has a deflector type arrangement that the drill rod passes through which deflects the water and cuttings that are blown out of the ground to the immediate area of the casing. Once the dam has been sufficiently built up around the casing you should then take a piece of pipe and stick it into the dam so that the bottom of it will be approximately 3″ below the top of the dam. Thus, when water is struck in the well, it will be deflected down by the machine into the dammed up area and will run out through this discharge pipe. The pipe should be located so that it won't be in the way of the driller or you when you are changing rods.

Once water has been encountered, the driller will be periodically checking the flow coming through the discharge pipe by placing a bucket under the discharge pipe, and checking the time it takes to fill it. Using this method he can calculate the flow in gallons per minute by noting the time that it takes to fill the bucket. This is something that should be done at least twice with every section of drill rod and at any time there is an apparent change in the flow of water in order that you record at exactly what depth the water was picked up.

If the water you first hit is a very low flow — of one-half or less gallon per minute — and you are using a dust collector for drilling you will have to be on the lookout for what is known as collaring the hole. This occurs when there is just enough water in the well to mix with the cuttings to make a heavy mud-like compound that clings to the side of the well and gradually closes in against the sides of the drill pipe to the point drill rods increases the need for applying pres-where they eventually block the space between the hole and the drill pipe and prevent the flow of air and cuttings back to the surface. When this occurs it is necessary to either inject water into the well through the drill pipe or cut off the air and pour water down the outside of the drill pipe, or inside the drill pipe, to wash out the hole. Once this water is poured into the inside or outside of the drill pipe, it is given time to fall to the bottom, and then the air is turned on to flush the water back to the top. If water is poured through the drill pipe, care must be taken to be sure it is clear water to prevent any foreign material's going into the hammer and stopping it up. When the hole is properly cleaned again, drilling will continue until the desired capacity is obtained.

Checking samples

In consolidated drilling, as in unconsolidated drilling, the helper should catch a sample of the formation being blown out of the well at least every ten feet and at any time when there is a change in the formation. Keeping these samples available for study will be beneficial in picking another location if there is not enough water obtained in this well. Or, if unexpected trouble develops, they will indicate what the formation was.

Once you think the desired quantity of water has been obtained, the test (by collecting the water and checking the time it takes to fill the bucket) should be made very accurately to determine as nearly as possible exactly what the capacity of the well is. Of course it is desirable to run a pump test on a well, but this will be covered in a different chapter.

Assuming the machine did not complete the well the first day, when it is shut down that afternoon at quitting time, the fuel tank should be filled to the top to prevent condensation from forming. This is something the helper should do without being told, and he should also note any supplies that are needed such as rock drill oil, motor oil, compressor oil, fuel oil, pipe, grinding rocks, and so forth. At the same time he fills the fuel tank he should also fill the rock oil tank. If severe dusty conditions have been encountered during that day and the machine or compressor has an oil bath type air cleaner, this should be cleaned and fresh oil added in order that it will be ready to start up operations the next day.

Completion of the Well

Once the desired water has been obtained and the volume of it checked very carefully, you are ready to finish the job by completing the well. This includes getting an accurate measurement of the well, capping it with a proper cap and generally cleaning up the area around the machine to make sure no trash. tin cans, or other such material has been left there. The cuttings around the casing should either be spread out in a neat manner or hauled away, depending on the contract the driller has with the owner. As the equipment is loaded for transportation, you should be careful to see that each piece is put on in such a manner that it will not fall off during transportation and when the derrick is lowered you, as a helper, should be very observant for anything loose which might fall on someone's head.

Thus, you have been carried through the full operation of drilling a well in a very rapid, superficial manner as a new man. You can best help the driller by being on time in the morning, neatly and cleanly dressed, wide awake, and ready to do a good day's work. He is not going to expect you to know everything, but he will be expecting you to readily learn the names of various pieces of equipment used so that when he asks for it, you will know what he is referring to. To do the best job you are going to have to be wide awake.

You also should, within less than two days on repeat operations, recognize what tool is used, where, and when, and have it ready and waiting when it is needed and not require the driller to have to tell you each time what to get and where to put it. The most common mistake you should tend to avoid is that of becoming an immediate expert. Remember you are the helper on the machine and the new man. If anyone questions you about the work, refer them to the driller. Do not try to answer either bystanders' or customers' questions, for a wrong answer by you can cause great difficulties for the driller in trying to correct them. Follow the old adage of "learn by listening."

You will find that if you stick with this well drilling business that it is an interesting and most rewarding profession, for the happiest person you ever run into is the man who hears water flow after having been without it for several days. ■ ■

Chapter 6—Introduction to reverse circulation drilling

by Richard Lauman
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Bethpage, L.I., N.Y.

REVERSE CIRCULATION DRILLING is really a form of excavating. The equipment cleans out a hole in the ground as it rotates. The drill cuttings are sucked up into the machine similar to dust being sucked into a vacuum cleaner. It is through this method that large diameter, high capacity wells have become more feasible for municipalities, industry, irrigation and other large water users.

The reverse circulation procedure has been best proven in areas containing deep sand and gravel formations. It is capable of developing a well which will produce more water per cubic foot of usable formation than any other method of well construction now available to the industry. Reverse rotary is not, however, a rock well drill rig; at least not in hard rock areas. It can and has been used in soft prolific rock structures with some success. Its greatest performance is in "sand country" where large capacity wells are more prevalent.

Usually, you will find reverse rotary equipment being employed for drilling wells for high capacity projects. In some instances, reverse rotary has been instrumental in drilling large diameter entrance and feed holes for underground storage caverns for gas and water reserves.

Reverse circulation equipment

The equipment consists of a rotary table, an engine to run the rotary table, plus an engine to handle the pump. In some instances a single engine can be installed to handle both the pump and rotary table. Gasoline or diesel power is determined by preference of the drilling contractor. A pump with enough capability and stamina is necessary to handle 500 gpm and drill cuttings including stones up to six inches in diameter. It is normally a centrifugal suction pump. The mast is raised hydraulically and is constructed to handle maximum weights of drill rod and well casing based on diameter and depth rating of the rig.

Generally the rig is trailer mounted due to mechanical equipment space requirements. (Reverse rotary rigs for shallow, small diameter wells can be made up on truck mountings.) Usually a reverse rotary rig is operated around the clock until the well has reached a point of construction where no chance of collapse can occur. In order to operate on a 24-hour basis a generator is necessary and can be mounted on the rig for lights and hand tools.

Drill rod used may be in any diameter from three to eight inch and in any length from 10 to 30 feet. Again, requirements of the type of work to be done determine this factor along with general rig size. Most drill rods are flanged while some are threaded, (similar to mud rotary rod), with full hole diameter maintained at the joint.

Air compressors are a help when drilling deep holes. This equipment, coupled to an air line set inside of, or to enter, the drill rod at about 250 feet below drilling grade, will permit the operator to obtain greater depths with more ease by reducing the pressure inside the drill rod. This eases the strain on the pump in lifting the drill cuttings to the surface and discharging them into a pit.

The bits will vary with the type of material drilled. All have open bottoms to permit entry of the drill cuttings. Some bits are mounted on an eccentric and roll on a ball bearing race while penetrating. Others are true vertical and are equipped with horizontal blades used to cut the material as they scrape through the formation. Combination pilot and drill bits are also used to guide the hole progress. These are made up of graduated diameters until the desired hole diameter is reached. They are mounted one immediately on top of the other and look like an upside down Christmas tree. Some bits are equipped with rock rollers similar to conventional rotary rock bits. These are used in place of the blades on the drag bits in hard packed materials. In many cases the hard pack material will snap the blades of the drag bit causing an undersized hole, loss of time in repairs, and once in a while a prolonged fishing job.

Some necessary equipment to accompany the rig, assuming it is trailer mounted, is a tractor to pull the rig, a truck or tractor and trailer to carry drill rod, proper diameter surface casing to prevent the grade surface from sloughing in, flow casing to feed water through the surface casing, setting timbers, leveling jacks, additional gasoline/diesel fuel tanks (or delivery arrangements), crew and tool shanty, bits, and flood lights.

In addition, a bulldozer is required to dig the pit to hold the drill cuttings and drilling water. There is need for space for a trailer to hold the gravel pack material and a place close to the rig to store the well casing and screen.

Since this method of drilling is fast, and well construction completion can occur at any hour during a 24-hour period, it is necessary to have as much of the final material and accessory equipment as possible present on the site at the start of operations.

Wells of this type can be drilled from a minimum of 10 inch hole diameter to a maximum of 60 inches or more under normal drilling requirements. Depths can vary from 40 feet to over 1500 feet.

Drilling with reverse rotary

In order to drill a reverse rotary well — a well in which you will be excavating the hole and depositing the drill cuttings at the surface — a site suitable in size is necessary to accommodate the rig, pit and related equipment and materials.

The rig itself, assuming the rig tractor does not stay with it, measures generally nine feet by 30 feet, not including the mast length when in highway transport position. Approximately three feet of walk area should be allowed on either side of the rig. The working area in front of the rig at the Rotary table should be about five feet minimum by nine feet wide. The drill rod is laid in line with the drill rig. If, for example, it comes in 20 foot lengths, allow a storage space approximately 12 feet wide.

The pit is usually constructed next to the rig with space for the tool or crew shanty between the two. The pit should be excavated to sufficiently hold the anticipated volume of drillings removed from the hole and at least an equivalent amount of water. The rig pump will discharge into one end of the pit and the drilling water will flow by gravity from the other end of the pit through the flow casing into the surface casing and on down into the hole. The suction action of the rig pump lifts the water and drill cuttings up through the bit and drill rod, through the pump and out into the pit.

Water source required

Generally, a 250 GPM water source is required to drill a well with reverse rotary method. This will vary with the ability of the formation. Very porous formations will readily take excessive amounts of water. In such formations, it may be necessary to add drilling mud to the hole while drilling in order to seal the well bore and prevent loss of circulation of the drilling water. In many cases, natural clay formations will assist in sealing off such troublesome areas. The water source is one of the most important factors in drilling with reverse rotary equipment. It must be of sufficient capacity to handle both normal requirements and emergencies. It is beneficial to have municipal water available or a nearby well of sufficient capacity. In some cases, it is necessary to install a water supply prior to starting construction of the permanent well. When a test well is required, it can be equipped with a proper sized pump to supply the rig. A test hole or test boring may be completed as a well and equipped if necessary.

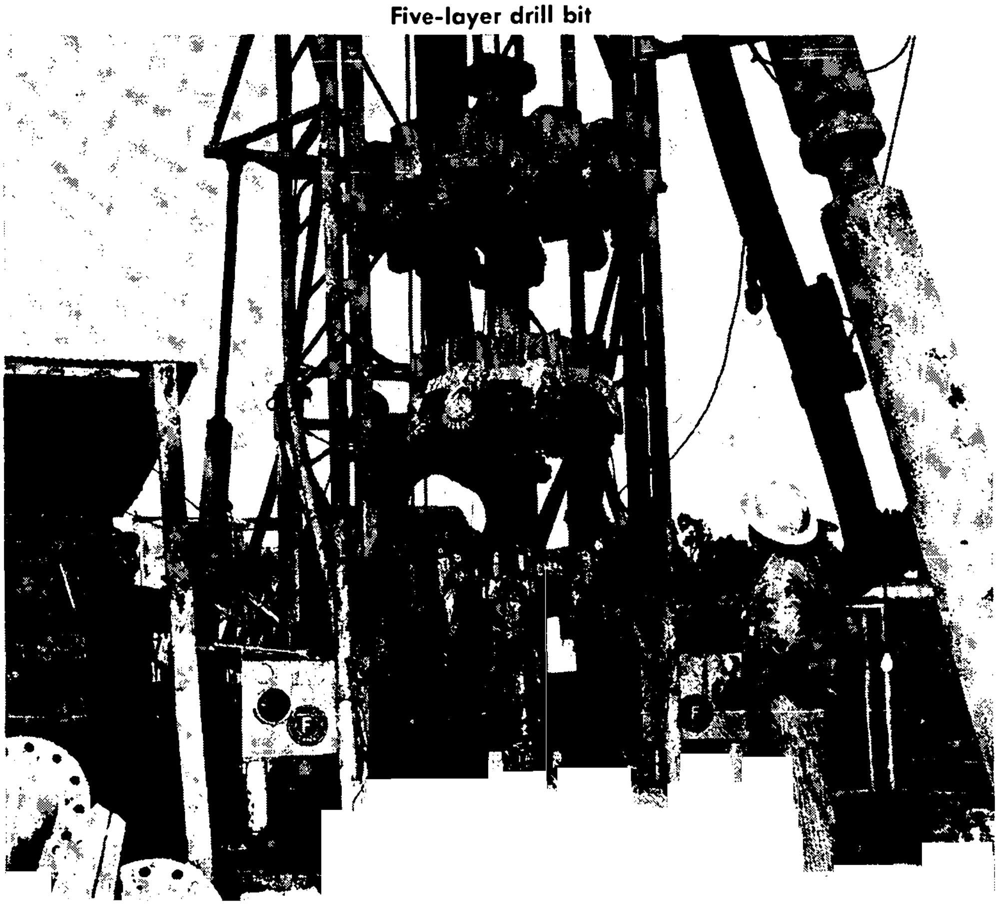
Occasionally, the pit's subsurface material is not capable of holding water. When this happens, the pit can be sealed with clay or plastic. Sometimes a pit dug into the ground is not permitted. In such cases a shallow pit is constructed by putting up low walls of wood planking or soil, or both, and laying plastic sheeting over the structure. Upon completion of well construction this pit must be totally removed including drill cuttings and the area left clean.

In some cases it is necessary to elevate the pit and the rig. The reverse rotary method drills open hole to the bottom. The only thing that prevents the hole from collapsing is an additional head of water above the natural static water level. Usually an additional six feet to 10 feet of water added above static in the hole will accomplish this. The weight of this additional water, regardless of the hole diameter, is the key to holding open the drilled, uncased hole. In order to maintain this head, and in order to be able to operate the equipment, the surface casing must extend to at least this much above static water level. If static is two feet below grade, the drilling surface will be plus six to plus eight feet above grade. Should a natural plus head condition be known to exist either at surface or when a lower formation is penetrated, the rig and pit build-up must be high enough to overcome this before drilling can start. It is thus necessary to elevate both by hauling in material to mound up for a pit and as a berm for the rig. The pit, in this case, must be water tight and the berm compacted to support the rig in a constant level condition. The surface casing must be inserted below natural grade to a depth that will insure positively against leakage and undermining of the superstructure.

With the rig and pit elevated, ramps and elevated areas are required for access, work room and materials storage. Needless to say, this type of set up can be expensive in time and material costs.

As mentioned earlier, sufficient water must be available to maintain the level of the pit and to keep a head on the well. There are many ways of assuring that the water level remains constant. Some are complicated and practically fool-proof, while others are quite simple. When working around the clock, a simple gate valve is all that is necessary to control the flow of water into the pit from the outside source. Once drilling is underway and normal conditions prevail, 50 gpm should be enough. With crews working around the clock, someone is available to adjust the valve as necessary. Should the job be stopped while the hole is still uncased, it is necessary to keep a 24-hour watch on the water level or install an automatic float system that will adjust the water flow itself. The watch is generally the surest method. The automatic system can be affected by icing conditions which negate its operation or can be upset by vandals. It is expensive to man equipment around the clock, but it is much more costly to lose a hole and damage equipment by not maintaining the proper water level.

Five-layer drill bit



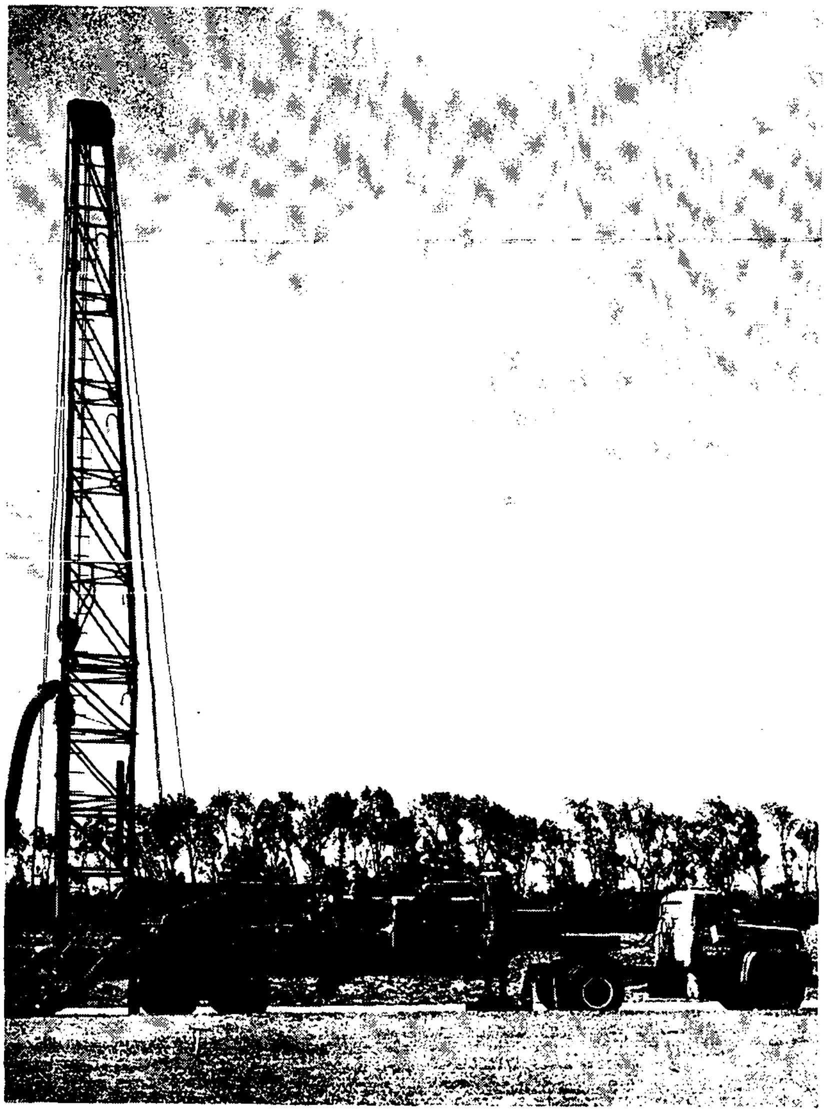
Losing water in the well

In general, drilling procedures are normal through the various sand and gravel formations. Occasionally a formation is encountered which "drinks" the drilling water faster than it can be supplied to the pit. This type of formation, and runny formations such as quicksand, must be shut off if drilling is to progress and the hole is to be preserved. One method of cutting off, or at least slowing down, the water loss is by muddying up the formation with drilling mud or clay as is used in conventional mud rotary drilling. The mud is added while the drilling fluid is circulating in the well. As the rate of loss decreases, drilling penetration is resumed slowly until the zone is passed and sealing has taken effect.

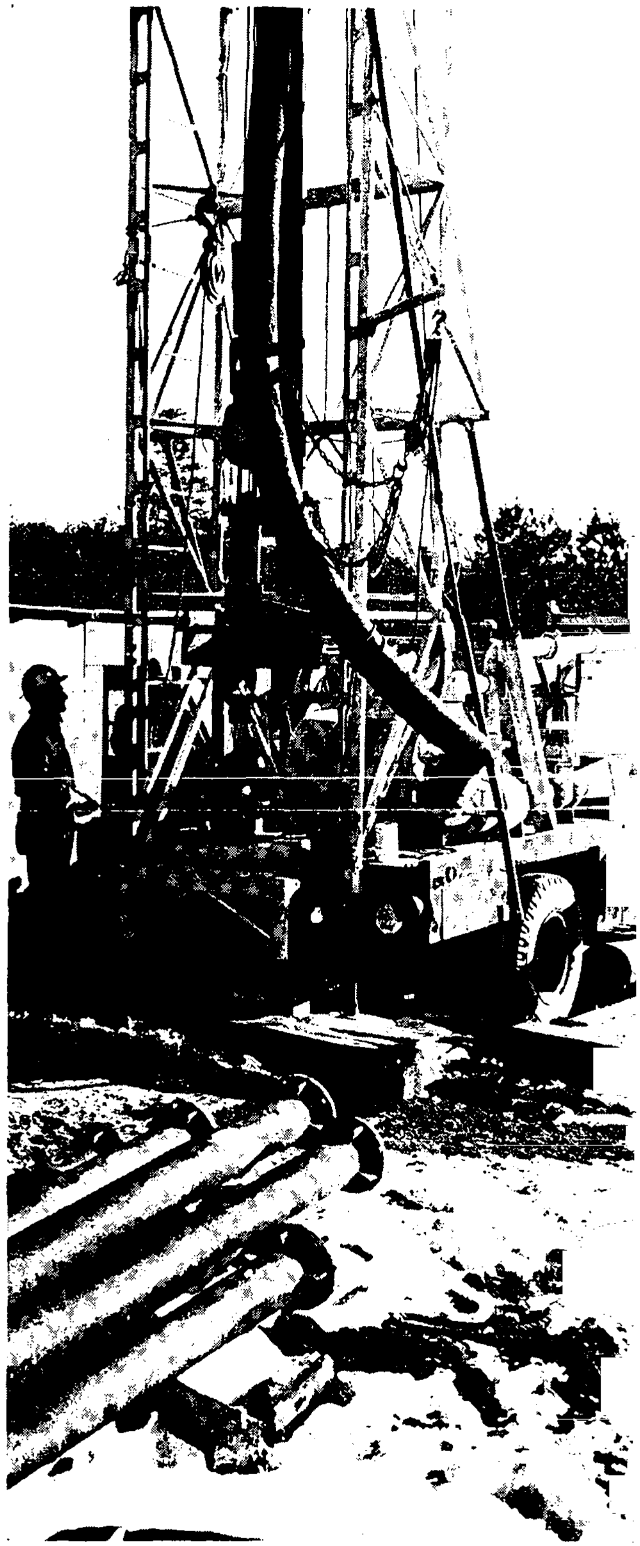
When it is impossible to stop the water loss, it becomes necessary to case the hole to the bottom of the troublesome area. The casing diameter, however, must be such that it does not interfere with the designed completion of the well. Should the screen setting zone be the area requiring casing while drilling, the casing must be set in order to set the string of screens and the gravel pack material. After this, the casing is pulled back to properly expose the screens.

In some cases, the natural clays through which the hole passes will help to mud-up a runny formation. There are cases, too, where the natural clays are too affective and cut down the yield of the potential water bearing sand aquifers. Care must be taken to keep the drilling water as thin as possible while penetrating clays. Thinning means delay in penetration as clear water is added and the clays circulated out of the hole. Such delays can be expensive both in labor costs and in penalties if the job is running behind. There are areas where the clay formations are naturally "dry". Once they are broken through

Breaking the bit at the rotary table



Trailer-hauled reverse circulation rig



Rear view showing rotary table

by the bit and wetted by the drilling water, they tend to swell and close in on the hole. As they close in, reaming action is necessary. This may delay downward progress and cause binding and breaking of the reamer blades.

Problems with boulders

Probably the greatest headache to any drilling contractor is boulders. In reverse circulation well drilling, boulders are still the worst form of deposit to penetrate. Depending on size and placement, they can cause problems ranging from blockage of the drill rod and pump to complete abandonment of the reverse rotary method. In extreme cases it is necessary to bring in a large cable tool rig to drive the casing through the boulder zone, then continue with reverse rotary. It may be necessary to have the two types of equipment on hand alternating drilling methods to complete a well.

No matter what depth the rig reaches and at what diameter, all wells are designed to be drilled as either straight, full diameter hole to the bottom, or as an under-reamed hole. The straight diameter hole is usually the fastest to drill and is good for wells that are single cased. Under-reamed holes, are generally called for when a well is double cased and the outside casing is cemented into place above the screen zone.

Under-reaming and screening

Briefly, in under-reaming, it is necessary to drill the straight hole large enough to accept the outer casing and allow enough diameter to permit sufficient grouting. Once the outer casing is set and cemented, the under-reamer is lowered to the bottom of the casing. At this point drilling resumes. As the under-reamer penetrates the virgin formation, the cutting blades gradually open. It takes about five feet or more of penetration to fully open the blades. Drilling then continues as straight hole drilling to the bottom. It is still necessary to maintain the false head on the well even though the upper portion has been cased. If the head is removed, the bottom section, still uncased, will collapse.

After drilling has been accomplished, the required screens and casings are set to the bottom. Gravel pack material is added to fill the area between the screen and the hole wall.

Well washed and graded rounded gravel is often used in this type of construction. It is selected based on the analysis of the formation sands. The slot opening size of the screen is then based on the gravel size. The grains must be large enough not to enter the screen itself, but small enough to hold back the sand of the formation. Angular or flat gravels are not recommended for pack material. They tend to pack together and form a solid mass. This restricts the water passing through and in severe cases can ruin the well. The rounded gravel maintains open spaces between grains permitting slow, smooth flowing water to enter the screen without turbulence. After the gravel is placed, the area above is backfilled with impervious fill to grade. Once this phase is completed the well is developed for capacity and clarity.

In double cased wells the impervious fill above the gravel pack, when called for, is usually not added until development is completed. During development the gravel pack material tends to compress. By having it accessible, the crew can add more gravel as it is required.

Developing the well

Development of reverse rotary constructed wells is usually handled with a turbine pump and engine drive. Pump capacity is usually that of the well plus 50%. In this way the well is pumped and back washed at a much higher capacity than required in order to assure the owner of obtaining contract capacity as a minimum. Development continues until no sands are pumped and the water is free of turbidity. With reverse rotary constructed wells, developing time is generally less than wells drilled by other methods. After development is completed the usual test pumping is performed. Length of pumping varies with the demands of the specifications and with the capability of the formations in the area involved.

In some instances surge blocks are used in the initial development stages. In some other cases air is used to develop the screen zones. In any case, the idea is to remove the finer sands from the formation in order to have a clean supply of fresh, clear water.

The surge blocks, air and turbine backwashing loosen the finer sand grains and pull them into the well through the gravel pack material. The violent action sometimes cleans up the formation faster than straight pumping. This insures the well owner that he will have a well free of the bothersome sand condition which occurs when a well is not fully and completely developed prior to completion.

The reverse rotary method of drilling water wells is the finest to date for major size sand drilling. This method, introduced twenty years ago, has become highly competitive in the past ten years. The rigs are constantly being improved upon and therefore become more complicated. Service and maintenance is practically non-stop as the rigs are run on a twenty-four hour basis as often as possible. ■■

Chapter 7— Jetting

By J. Frank Taylor
Palmetto Water Equipment
Charleston, So. Carolina

JETTING IMPLIES a flow of water gushing or shooting out from an orifice, pipe or nozzle, or even a drill, with some velocity behind it. The simplest form of jetting would be to connect a water hose to a section of pipe, position this vertically to the ground and simply turn on the water. The force of the water coming out of the pipe end would wash away the earth or sands, making a hole in the ground, at the same time forcing the loosened earth down in the hole, up and over the top of the hole. As the soil was washed out, the pipe would be lowered into the ground until the desired depth was reached — where ground water could then be pumped out of the sub-surface. This, in simple principle, is how jetting is accomplished.

Jetting in sandy soil

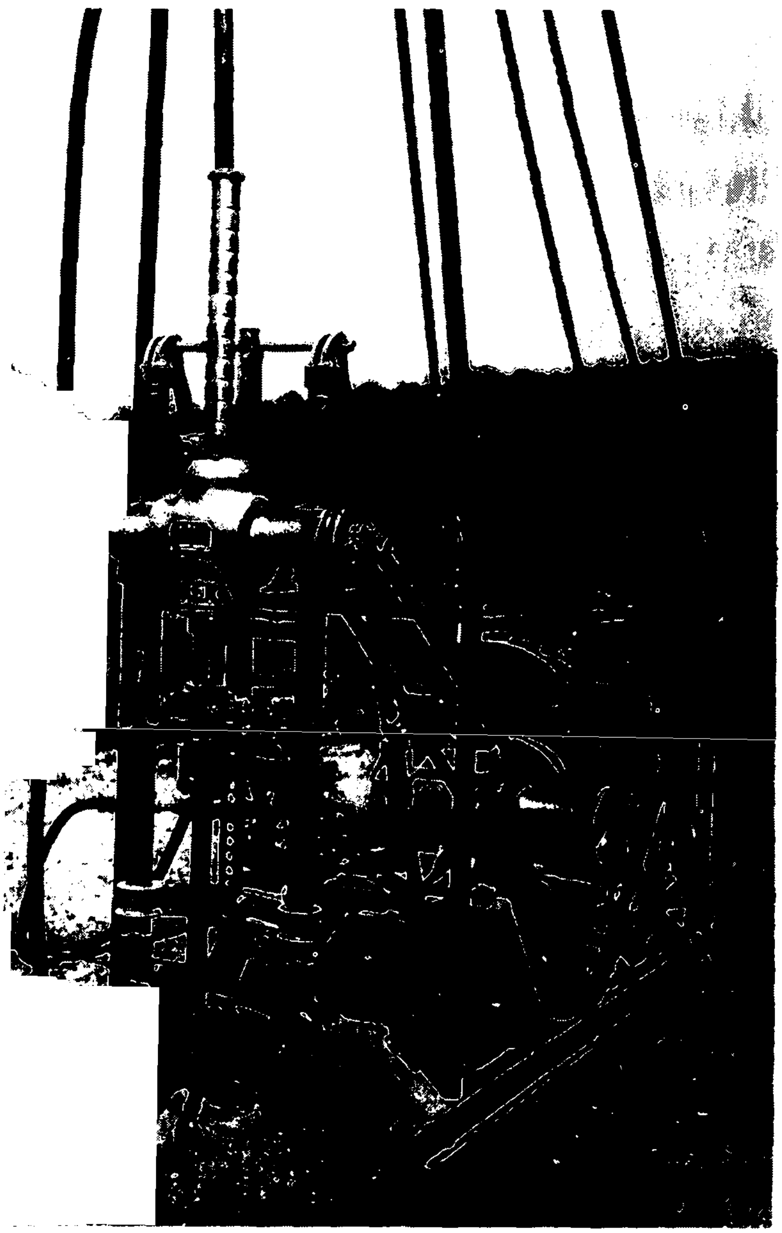
One of the simplest forms of applying jetting principles to ground water work, is the jetting of shallow water wells in sandy soil. In its simplest form, a jetting setup for such work, often fabricated by the driller himself, may consist of just a piece of jet pipe connected to the pressure pump or some other water source. For example, a one inch pipe may be flattened to form a 1/4 inch slot at one end which in turn will produce a high velocity cutting stream of water. The top of the pipe may have a double elbow and union or hose adapter to provide a flexible joint so that the hose may be turned to one side as the jet is lowered into the hole being jetted. The water source for jetting may be a hand pump or power unit. A suitable amount of water needed to complete the well must of course be on hand, whether it's in tanks, drums, or a nearby water source. If the well is being jetted for a potable water supply, the water supply used for the jetting should have at least 50 parts per million (ppm) of chlorine. This is needed because during jetting, some of the water will enter the sands and water stratum and if it isn't pure, it may contaminate the water well supply you're trying to reach.

Jetting in sand is accomplished in the following manner. A post hole digger is used to start the hole and is dug approximately three feet deep. The jet pipe is raised in a vertical position over the hole. The water pressure is applied and the jet pipe begins cutting the formation and also washes the loosened earth up and over the sides of the hole. The jet is raised and lowered in a churning, up and down motion, lowering the jet pipe deeper and deeper until the desired depth is reached. The operator watches the materials washed up from the drill hole so that he can determine where the best sands or porous materials are located.

If this depth is not known before jetting, it may be advisable to make a test drill hole a few feet away to determine the proper depth to place the well screen. The actual jetting operation usually requires just a few minutes, so the well pipe and screen assembly must be prepared in advance.

When the driller has reached the proper depth, the well pipe, which is going down into the hole, must be standing by, ready to be placed into the hole. The water pressure is maintained while the driller raises the jetting pipe to the surface. The hole must be kept full of water until the well pipe is placed. As the retracting jet pipe reaches the top of the hole, the jet water flow is maintained until the well pipe is in position. The water is then shut off and the well pipe is lowered into place, and kept in proper elevation until the sands close around it.

If the sands cave in when the jet pipe is raised and the well strainer is stopped before reaching the desired depth, it may be necessary to place the jet by the side of the well pipe, and lower it until it is about even with the bottom of the screen. The cutting action of the jet will wash out the sands under the screen. In addition, turning the well pipe with a wrench will help seat the pipe in the sand. If this fails, the well pipe may have to be driven into position with a drive hammer or perhaps the hole will have to be started all over again.



Acker WB jetting rig with rotary drill head

Developing the well

A pump is hooked up to the well pipe and pumping is started — slowly, at first. If the well pipe happens to be loose in the hole, a bucket or two of clean, washed sand may be added around the well screen, filling the drilled hole with materials washed from the well and finally tamping the sand to eliminate any annular space around the well pipe.

Some development is desirable and this is usually accomplished by filling the pipe with water so as to make a back flow to the well, then pumping and repeating this until the sand is free and clear. As mentioned earlier, a potable water supply must be disinfected. A solution of 50 ppm chlorine poured into the well and left there for several hours will accomplish this. Simply pump off the well until the chlorine odor disappears. Finally, after completing the well, the ground should be graded so that it is higher at the well and sloping away from the well — so that no water stands around and near the well area.

When casing is required

Sometimes, well casing must be installed. Wells constructed in very porous materials or in beach sands, where the water table is some distance below the surface, may have to be cased into the water stratum in order to complete a proper well. This is because a much larger flow of water is needed due to water loss to the area surrounding the well — the deeper the well, the greater the water loss and the greater the pressure. The water fails to rise to the surface and loosened sands fall back on the jet, often locking it in place. Occasionally when jetting into the water stratum itself, the increased pressure, due to depth, coupled with the before mentioned losses, prevents the flow of jetting water to reach the top of the hole. When this happens, loosened sands in the pipe will settle and lock the jet pipe in the well. When this happens, block and tackle, or some other hoisting device, will be needed.

When installing this type of well, a device is needed to drive in the casing. This casing must be cut and threaded with couplings, in lengths to suit the installation's requirements. The same basic equipment for jetting is used. Drilling compounds (Kaolin, Bentonite, or other similar drilling compounds) are helpful. Even some form of drill as used in percussion-jet drilling attached to the jet pipe is sometimes desirable for the larger hole size needed or when drilling through harder sub-surfaces.

First, make a starting hole for the well. A starter casing may be used if desired. A settlement trench in needed from the well hole to a sizable work hole at least 30 inches deep for recirculating the work water. Add drilling compound to this work hole water. Put a pump strainer in the work hole about a foot below the water level but not on the bottom. Put a drill tool on the jet pipe slightly larger than the casing to be used. Attach a pressure hose to the drill pipe. Someone has to maintain the proper water level and add drilling compound as required plus keep the strainer clean to maintain continuous water flow to the jet. This is the helper's job. The driller will be busy working the jet pipe.

The operator will raise and drop the jet pipe, repeatedly, turning it at the same time to make a round hole. The jet action of the pressure water will raise the drilled mud and sand to the surface where it will flow through the settlement trench to the work hole and recirculate to the jet unit. Continue until the desired depth is reached. It must be below the static level of the ground water. While the jetting operation is taking place, the drilling compound will line and seal the walls of the drill hole. It is necessary to keep enough compound in the drilling water so water isn't lost when the drilling is stopped. The drill hole must be kept full of water even when the jet pipe is raised and kept full until the casing, which is prepared in advance, is installed in the drill hole and held in place until the sands close in around it.

While jetting the hole to the proper depth, the well screen and well pipe are being prepared for installation. After reaching the desired depth, the hole must be kept filled with water until the well screen and well pipe are installed. After this, the water can be turned off.

It is desirable to pour or pump some clean water down the well pipe and out through the well screen to wash out as much of the drilling mud as possible. The well should then be developed as described earlier. A well seal should be placed between the inner well pipe and the casing and any exterior annular space.

Percussion-jet drilling

This writer has drilled over 6,000 wells by the percussion-jet drilling method. It is fast and efficient and possibly the cheapest drilling method available for depths up to 200 feet or more in unconsolidated soils and even some rock.

Along with the usual equipment needed such as a derrick or well machine, block and tackle or power source, pressure pump, drive hammer, casing and other associated tools and material, a drill is needed. The drill is attached to the bottom of the drill pipe. This drill may be any of a number of designs, from flat chisels with jet holes on each side, to star drills with four jet holes. They might be "S" drills, or "stepped drills" which are longer at the center or longer on the outer cutting edges — but all with the necessary jet holes to allow water pressure to clear the drill and at the same time, force the cuttings up and out of the casing.

The equipment is set up as before including a 30 inch settlement trench. Dig a three foot deep starter hole. Raise the first section of drill pipe with the drill attached. Start the pump circulating the drilling water through the drill. Attach a turning clamp onto the drill pipe and start the percussion-drilling procedure. The drill is raised about two feet high and then dropped — repeatedly. A good operator will get 50 to 60 drops per minute. While the drilling is being done, the force pump is circulating water through the jet holes in the drill which wash out the cuttings and force them to the surface where they settle in the trench.

While doing this, the driller turns the pipe about an 1/8 of a turn per drop until he makes more than one-half a turn; then he turns the pipe 1/8 turn per drop in the other direction, repeating this over and over again until the hole is deeper than the first length of casing to be installed.

The drill is then removed from the hole and the first length of casing is attached and lowered into the hole opening. The casing is raised and dropped, as was the drill pipe, to place it into the drilled hole. The drive hammer is then inserted into the casing top and dropped onto it, repeatedly, until the casing is driven into the hole. A pipe wrench with extension is used to turn the casing, slightly, at each drop.

The driving is continued until the casing is just above ground level. The drill pipe is then attached once again and drilled through the first length of casing. When this point is reached, the drill pipe is clamped off on the installed casing and another length of drill pipe is added. Again, drill the length of this second pipe and remove drill pipe. Add another length of casing and drive it to ground level. Repeat drilling inside the casing, and driving more casing, until a solid formation or rock is reached. Set the casing firmly into the rock. Usually, no more casing is required.

Assemble the drill pipe in the casing and continue drilling until a water sand formation or porous water stratum is reached. The driller must watch and check his drilling mud many times to locate the water stratum. When this is reached, the well will usually start to lose water. The driller may want to drill deep enough into the stratum or through the stratum, if possible, to obtain the quantity of water desired. After removing the drill pipe, the well is developed until clear and free of sand.

Tubular deep wells

The equipment is the same as previously described but the process is slightly different. Install a short starter casing with side spout and prepare a settlement trench. Add drilling compound to the work water. Drill the hole a little larger than the outside of the well casing to the desired depth or rock formation. Have the casing ready to install and keep the water circulating. When ready to install the casing, disconnect the pressure hose from the drill pipe and place it where it will keep the drill hole full of water until the entire amount of casing needed is installed. While performing this operation, be sure to raise the drill pipe slowly so that the water level is not lowered while removing the drill pipe.

Attach lift fittings to the first section of casing with the drive shoe on the bottom end and place it in the drill hole and lower it to the work level. Clamp off casing at the work level. Add additional casing as required to the bottom of the drill hole. Insert the drive hammer and set casing securely, or cement or grout as required. The starter casing may be removed or left in place as the job requires. Now add a 50 ppm available chlorine solution to the work water and complete the drilling, the installation of screens and the development.

Jetting gravel-packed wells

In some areas, such as where this writer drills, the surface waters are usually within 20 feet from the surface, underlaid by an impervious limestone or marl stratum, then one or two muddy sand and shell formations from five to 25 feet thick, followed by an impervious stratum, 150 to 300 feet thick. This is practically ideal for gravel packed wells. Eight inch gravel packed wells with two inch slotted well screens are drilled for domestic supplies and irrigation work. Ten inch diameter gravel-packed wells with screens are drilled for public service and larger commercial-industrial applications. Some wells require casings, some do not. Also, some must be grouted while others need not.

Equipment used is the same as for tubular wells, plus an undercutting tool where required. A larger volume of water is usually needed and drilling compound is a must along with the proper screen and well pipe. Well casings, cement or clay grout, and grouting equipment are used as required. Where necessary, tremie pipes or pumping equipment are necessary for placing the gravel, plus a surge plunger, air compressor and pump. The gravel should be prechlorinated, graded and washed and of the proper size to suit the sands and stratum materials. Sometimes it is necessary to drill a pilot hole through the stratum to obtain sand size and stratum location and thickness. This usually requires a machine operator, a driller, a combination pipe-fitter and helper for small wells, plus another helper for larger wells. The process is as follows.

Place the machine at the well site. Start a hole for the starter well casing. The drill pipe is raised and dropped repeatedly about two feet, again, while the operator turns the drill pipe as in the percussion-jet procedure.

While drilling, a close check is kept on the circulation water and samples must be collected at regular intervals and whenever there is a change in formation. These samples must be marked and recorded because this is the only time the log data can be obtained. As the driller is holding the drill, he can feel the grinding or "holding" of the drill in certain formations — a skill acquired with experience. It is necessary to examine the cuttings every few feet as well as the drilling mud removed from the ditch.

Once a sand water stratum is reached, it is advisable to keep the drill hole full of water to prevent loss of head pressure on the walls of the unlined drill hole. Also, do not thin the work water too much with clear water or the clean water will wash out the compound that is holding up the walls, causing the walls to cave in.

When the driller is satisfied that he has reached and penetrated the water stratum deep enough, the drill pipe is removed from the hole. Keep the drill hole full of water while removing the drill pipe. Too fast a removal will drop the water level in the well and perhaps cave in the sand stratum.

After removing the drill, attach the undercutter if it is being used. The undercutter can be fabricated from a piece of four inch pipe, three feet long, with a flush welded plate in the bottom and a threaded coupling on the top. A jet orifice is drilled in the center of the bottom plate. Four jet nozzles are welded through a six inch coupling at the center of the four inch pipe. These are placed two inches apart at the center and at 90 degree angles of center of the four inch pipe. A one-half inch by two inch bar extends on four sides from the outer edge of the six inch coupling to the bottom end of the pipe and to just below the threads on the top part. The size of the four nozzles equals the work pump delivery at high pressure. This forms high pressure cutting jets operating sideways and below to enlarge the drill hole and wash out the cuttings in the area to be gravel packed.

Install the undercutter and necessary drill pipe in the drill hole and attach the circulation water hose. Lower the undercutter to the area to be worked and turn on the water pressure. A suitable amount of drilling compound must be kept in the work water. This tool is worked slowly up and down and turned back and forth to undercut the desired opening for the gravel pack.

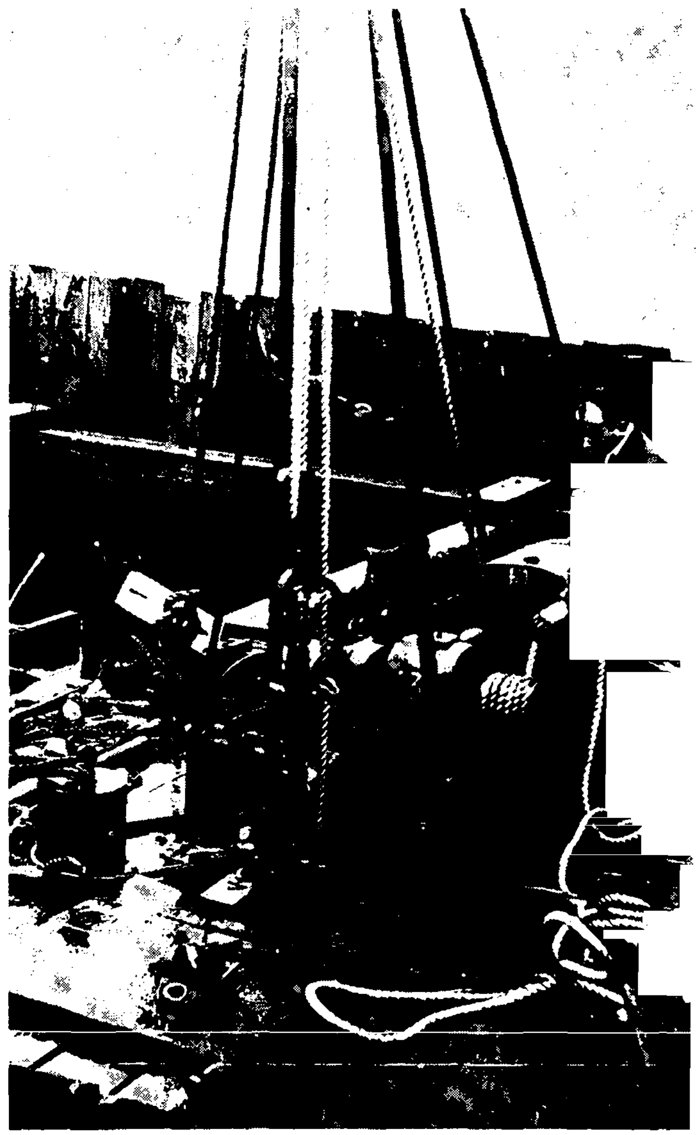
While this is being done, the well screen, well pipe and gravel are being prepared for installation. When the undercutting is complete, the pipe is removed slowly from the drill hole, at the same time, being sure to keep the drill hole filled with water.

Install the well screen and well pipe in the well and secure at proper placement. If the well is shallow, the water hose may be connected to the top of the well to slowly pump some water through the screen. Uniform gravel may be poured evenly down the side of the well or down a tremie pipe if deeper. It may be better to pump the gravel through the inner pipe and bottom valve until the desired level is reached some dimension above the screen area. Then remove the inner gravel pipe. It may be desirable to install a gravel fill pipe for future needs before filling the space between the well pipe and the drill hole.

If no casing is used, mix clay with the drilling mud from the well and pack the well between the well pipe and the drill hole — or fill the area with concrete mix to the surface. The starter casing may be removed if desired.

Next, pump some water from the well. It is desirable to wash the gravel and sides of the drill hole and start the flow of water as soon as possible. The amount of development needed varies, but it must cleanse the drill hole walls and the gravel to develop the flow. Development must be continued until the well is sand free. After pumping some water and cleaning the well with the pump, it is desirable to fill and pump the well several times.

A high-pressure water jet, made similar to the undercutter to fit in the well screen, is excellent for cleaning the sands and mud pack from the drill hole walls. This is repeatedly worked up and down and continuously turned to force high pressure water out through the screen and back in, above and below the tool. It is also helpful if some additional water is pumped from the well at the same time. An air jet blast through the same tool at the same time also aids the process.



One-man, self-contained jetting rig

If more development is needed, a surge plunger will help to set the sands and aid development. It is sometimes necessary to use chemicals to dissolve and help remove substances from the well and water veins. After development the well should be thoroughly disinfected with the 50 ppm chlorine solution and the well capped or plugged until the pump is installed.

There are many ways to employ jetting principles to water well work; these have been some of them. ■■

Chapter 8 — Bored Wells

By B. P. Ward

A rose may be a rose may be a rose, but augering is boring is rotary bucket drilling, a process for developing ground water sources in wide use in the southeastern U.S. Under any and all these terms, it is a method for providing relatively large diameter and relatively shallow wells. The author is B. P. Ward of Ward Drilling Co., Inc. Marietta, Georgia.

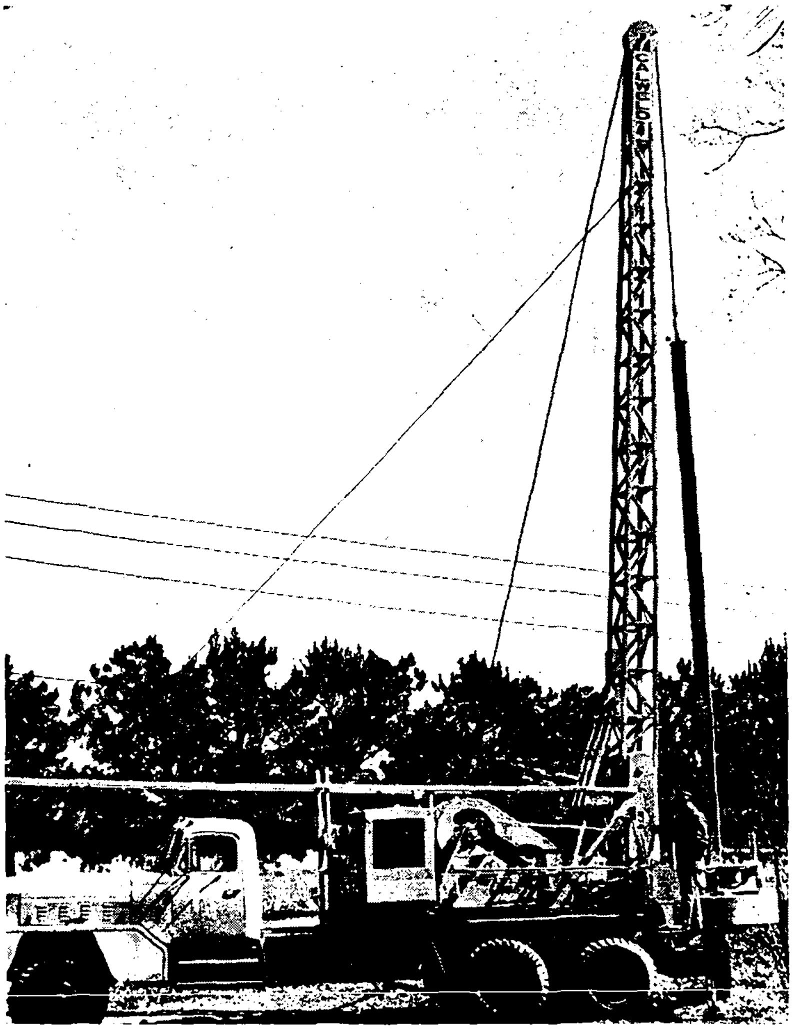
SOLID CORE from a bucket drill in hard-packed formation. Photo by Calweld.

FOR SEVERAL YEARS, the drilled deep well has been the basic source of supply off the mains for increased fresh water demands. As with everything else, however, inflation has taken its toll, and labor costs, taxes, and increased prices for fuel, machinery, and supplies have forced the cost of drilling up.

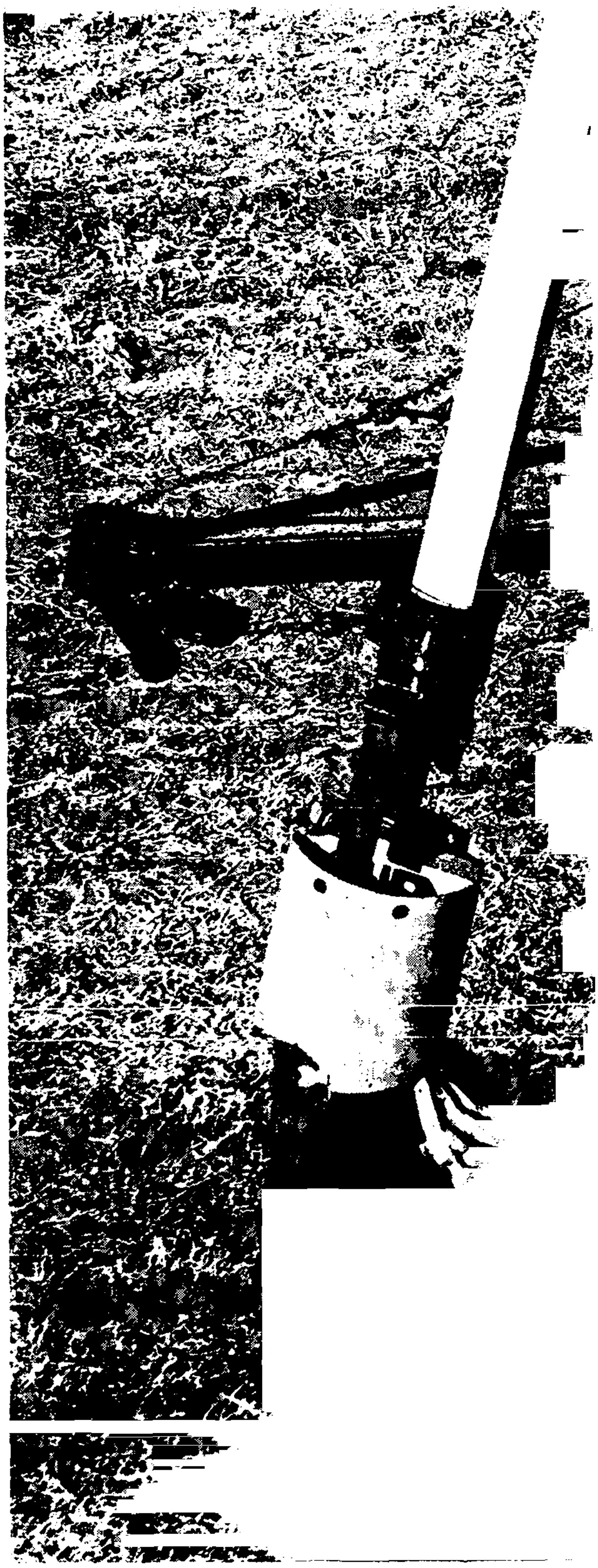
At the same time, while the average home has a greater need for fresh water, the southeastern part of the United States, in particular, has witnessed a great growth of wholesale production of poultry and other livestock which further increased water demands in rural areas. These demands, too, are sensitive to prices.

It can be seen, then, that more and more water is needed and that costs must be kept down as much as possible. Enter the "bored well."

As used in the southeastern U.S., the term



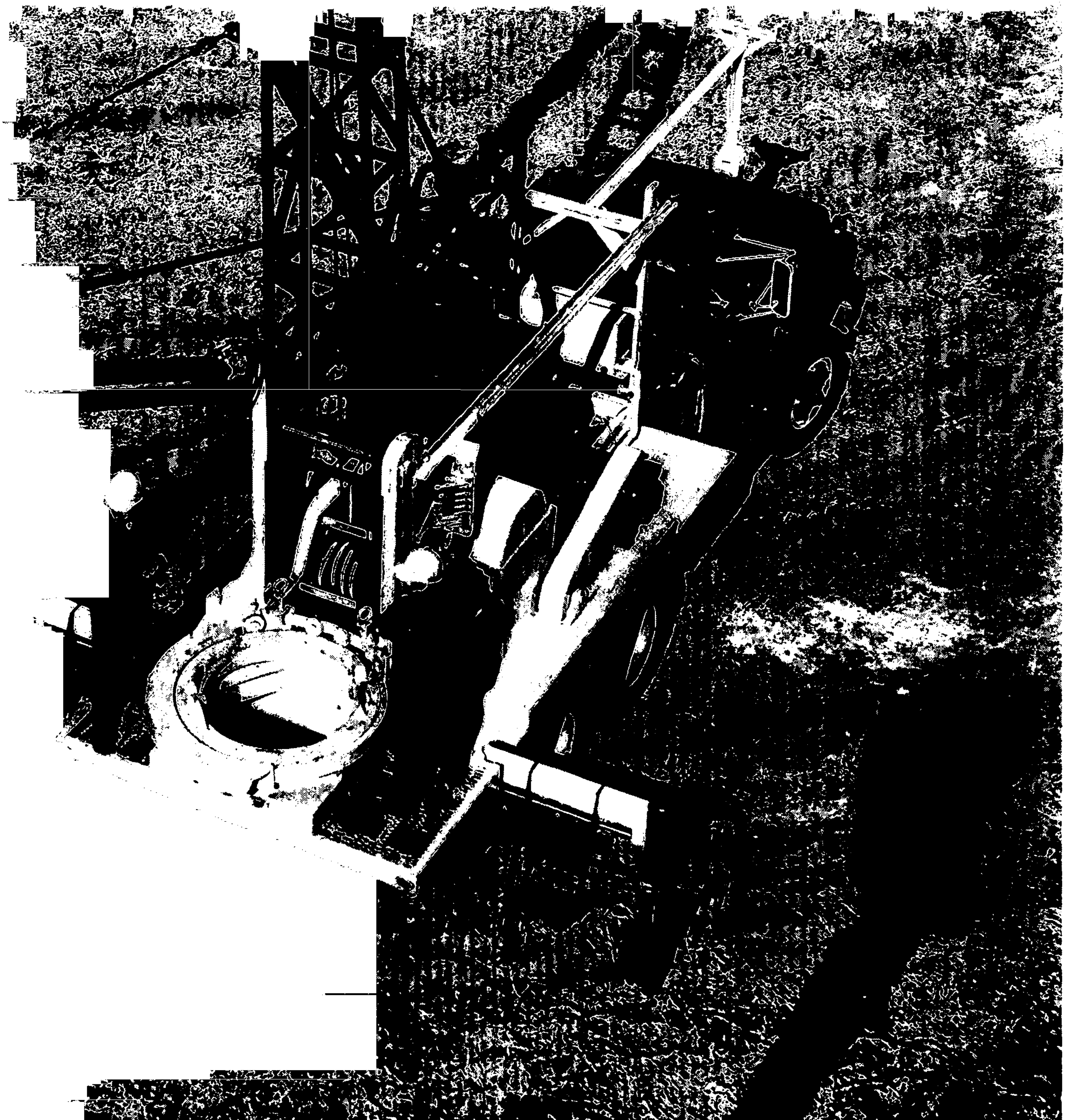
TRIPLE TELESCOPING kelly in the "dig" position. This rig, from Calweld Div. of Smith Industries, will handle 85 foot holes.



means the same as augering or rotary bucket drilling in other sections of the country. A bored well is one constructed by employing a bucket or auger type rotary machine. Such wells usually are about 30 inches in diameter and cased with 24-inch i.d. concrete pipe. The equipment is high-speed, volume-production machinery capable of making one to five wells per day, depending upon formations to be bored, well depths, travel distances, and so forth. This factor has helped hold the unit cost of boring relatively low compared with other methods.

To learn more about bored wells, let's follow the construction process from rig set-up to the water tap on the pump. First, however, a site is selected by agreement between the owner and driller. Several factors must be considered, but foremost is a location least likely to be or to become contaminated from any source of pollution, be it septic tank, barnyard, or other type of agricultural or industrial waste disposal. The site also must be as convenient as possible for the owner and (of course) within reach of the boring equipment. (The north Georgia mountains can produce some challenges in this regard.)

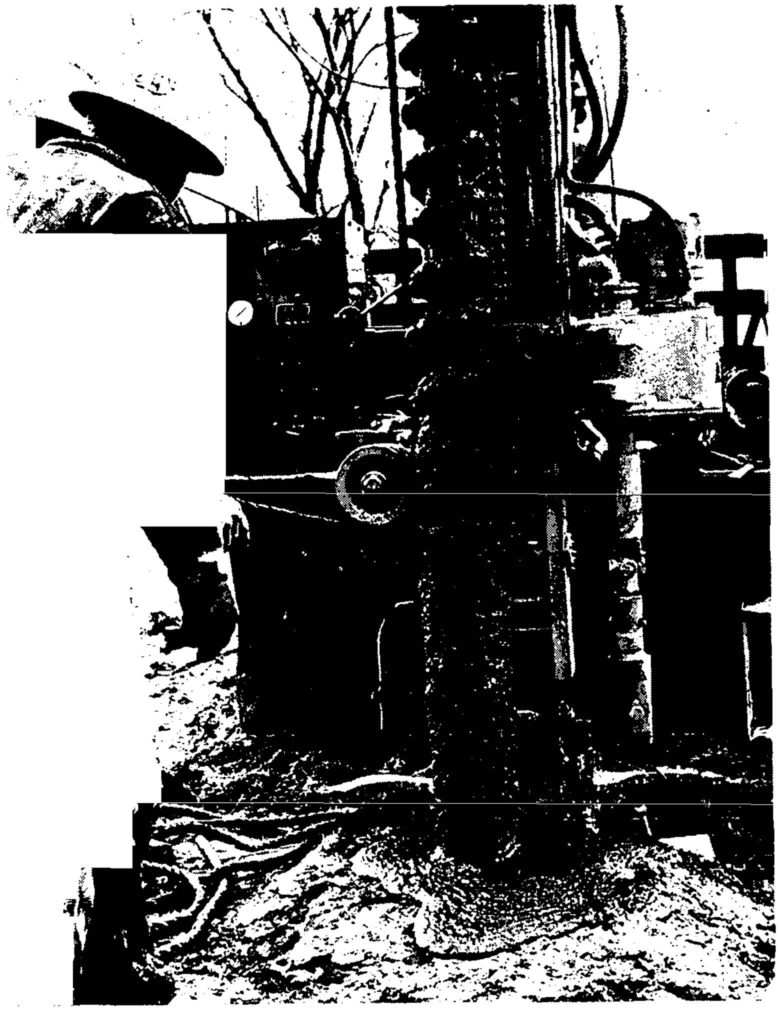
Once the site is selected, we put the rig in place and prepare to level it and to raise the mast, or derrick. Most boring rigs are equipped with hydraulic outriggers which lift both the machinery and the truck off the ground so that the rig can be levelled precisely for the boring oper-



ation. When this is done, the mast is raised into position, also hydraulically, carrying with it the kelly bar.

Today, this kelly is often of the telescoping type and quite heavy, in our area usually from 4,000 to 5,000 lbs and 75 to 100 feet long when extended in the hole. Greater depths can be reached by adding lengths of drill stem between the kelly and the bucket, but when the rig has a telescoping bar, this is a time-consuming chore. The kelly is supported by a steel cable connected to the machine draw works and is rotated by means of a large ring gear and pinion-type rotary table.

When the mast and kelly have been raised into position, and plumbed to the center of the ring gear opening, the boring bucket is attached to the kelly. This is a cylindrical device also known as an auger bucket. The entire kelly and bucket are then lowered to the surface of the ground



ACKER DRILL CO. augering rig which can be used for shallow wells and sand drains.

and rotated so that the bucket teeth bite into the soil and scoop it into the bucket. (Thus the other term for this method: rotary bucket drilling.) The teeth are set in the bucket bottom at such an angle as to force the soil through slots in the bottom until the bucket is filled.

The principal use of boring for water wells is in unconsolidated formations. Standard equipment will not work on hard rock, although some few special rigs are built to order for consolidated formations. The buckets on these have specially hardened cutting surfaces.

A full cycle has the bucket and kelly lowered into the hole; the truck-mounted ring gear rotates the kelly and bucket downward until the bucket is full; the full bucket is raised to the surface, swung either to one side or to the rear of the rig and dumped; the bucket and kelly are returned to the hole for the next bite. This process is repeated until the hole depth reaches a water-bearing strata, usually sand or gravel and hopefully mixed with clay. Drilling continues then to a depth which will create a proper reservoir of water for peak demand within the well.

There is surprisingly little variation in the penetration rate between formations, provided they can be bored in the first place. For best results, the formation must be homogeneous; the work goes much slower when buried obstructions exist. Boulders or cobbles must be picked out of the bottom with a special tool, such as an orange peel bucket or stone tongs. Naturally, it takes time to attach such tools, remove the obstruction, and then replace the bucket.

Generally speaking, if you can bulldoze a formation, you can bore it with a bucket rig. Most commonly, areas with clay formations find bored wells predominating. With clay, the formation is least likely to cave in. Caving can be quite a problem in pure sand, although some drillers report success with boring rigs in sand by keeping the hole filled with water at all times. This stiffens the sand and keeps the walls from collapsing. It also is possible to case the hole as you go down in soft formations where cave-ins are a threat. You use a bucket with a reamer attachment which creates a hole of larger diameter than the bucket.

In our area, an auxilliary hoist line is employed to set concrete casing into the hole. The casing setter is manually tripped by means of a rope to release the first 3-foot sections of pipe. This apparatus then automatically positions and releases each successive length of casing pipe. To complete the construction process, grout is placed around the casing from the top, and a reinforced concrete cap is installed. The well is now ready for installation of the pump and connection to the distribution lines for the owner's use.

Where the formation is suited, bored wells can go fairly deep, but most importantly, they go quickly. On speed rests their economic advantages. From 30 to 40 feet per hour is not unusual, and many drillers regularly go down 60 feet per hour. These speeds would involve the use of a kelly only, since addition of drill rods or use of special tools for obstructions will take time away from boring.

Boring or augering or rotary bucket drilling can be the most economically efficient method available for large holes to a certain depth. How large and how deep will depend on local conditions and the experience and equipment brought to the job by the driller. ■■

Chapter 9
Well Screens

by Charles J. Linck
Haslett, Mich.

WELL SCREENS ARE USED to draw water from aquifers located in unconsolidated materials — such as sand. Simply stated, well screens let the water into the bore hole and keep the sand out.

The well screen, or strainer, forms the "working end" of the water well. Through it flows water from the formation and its characteristics and placement in the bore hole wall in large part govern the efficiency and life of the well.

There are many types of well screens available. The most basic form is perhaps the field or knife slotted pipe still popular in some sections of the country. Its use is restricted, however, because of the lack of uniformity in slotting and the small available open area produced for water entry. Machine perforated pipe base screen (figure #1) produces uniformity in slotting but to be used as a screen, must be covered by wire gauze or wire rods as shown in figure #2. This type screen is used in many applications including temporary wells where it may be pulled and reused many times. It is very durable, hard to damage and a driller can easily repair the gauze or wire wrapping.

Machine perforated casing or in some instances sheet material which is rolled after perforating is a popular type of screen for applications where small slot or openings are not required. Figure #3 shows a "shutter screen" having closely spaced horizontal louvers. Figure #4 shows a vertical type louver with the louver open on two sides. Another type, a so-called "eye lid" louver, is shown in figure #5. In general these types of screens enjoy their greatest use in gravel wall type construction where small slot openings are not required.

Figure #6 shows another distinct type of screen; the vertical rodded wire wrapped screen. A cage of vertical rods are used around which continuous wire is wrapped horizontally. This type screen is available in almost any size slot opening and by varying the number and size of the vertical rods almost any degree of structural strength can be obtained.

In the selection of a screen four basic factors should be considered. These are: 1) a good screen should be structurally strong enough to support the bore hole; 2) it should be resistant to corrosion, 3) it should prevent excessive movement of sand into the well and 4) it should allow entry of water into the well with a minimum of friction.

Structural Strength of the Screen

Obviously a screen will generally only be required where the bore hole penetrates unconsolidated, poorly cemented, or broken formation. Except in unusual cases, this means you need to be concerned primarily with sand, gravel or mixtures of the two when considering the use of a well screen. The large variety of screens on the market offer all degrees of structural strength. Economics of the installation, regional practice, depth of the well and your own experience will dictate the type to select. The slotted pipe, wire or gauze wrapped pipe base screens and the heavy gage louvered type screens offer maximum structural strength at a minimum cost. They may not, however, always satisfactorily meet the other requirements of a good screen. For example, while a slotted pipe may prove satisfactory as a structural unit it may not prevent movement of sand into the well. The vertical rodded wire wrapped screen, on the other hand can provide for the structural requirements and is available with almost any size slot opening so that any size range of sand can be stabilized.

Corrosion Resistants

The ability of a screen to resist corrosion, electrolysis, and other types of chemical deterioration will play a large part in determining

Fig. 1

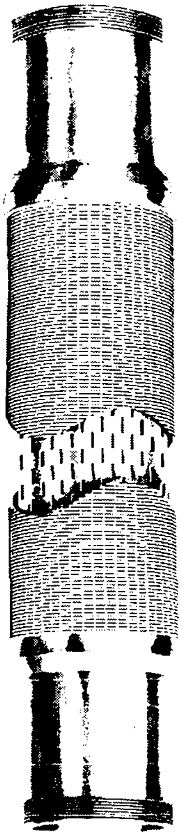


Fig. 2

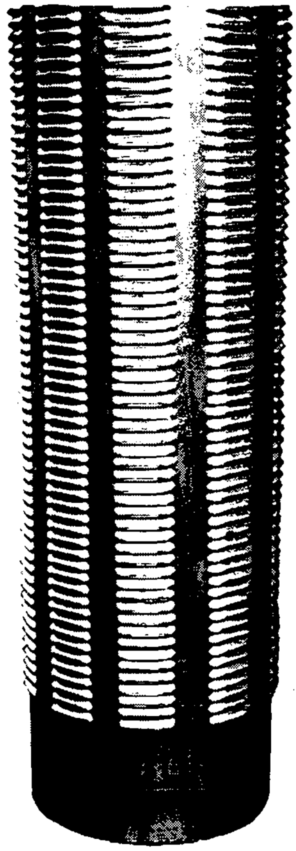


Fig. 3

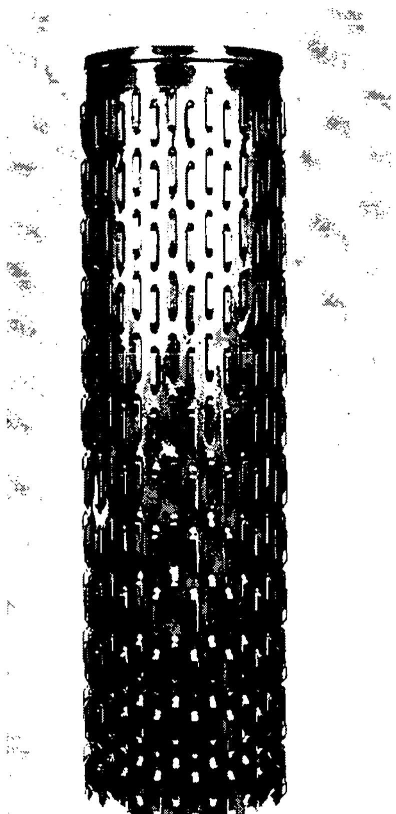


Fig. 4

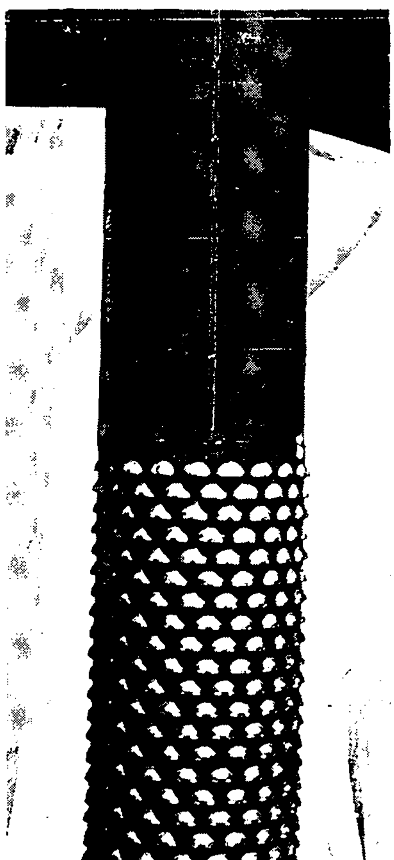


Fig. 5

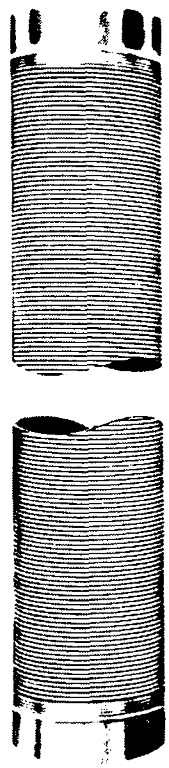


Fig. 6

the life of a well. Corrosion resistance is governed by the nature of the formation water and the type of material used to make the screen. Mild steel, stainless steel, red brass, bronze and various plastics are the most commonly available materials.

Mild steel screens in a few areas may perform satisfactorily for years thus providing both low initial cost plus long service. More commonly, however, experience has shown that the other materials provide longer life, are not affected by various types of well cleaning agents and hence provide a more satisfactory, although initially a more expensive installation.

Sand Control

A screen should prevent excessive movement of sand into the well. A well which is a "sand pumper" not only may eventually collapse, but the sand may cause excessive pump wear and limit the usefulness of the water produced. In tubular wells, where the screen is in direct contact with the native formation, the screen openings are usually selected so that they will retain from 50–90% of the formation. In a very uniform fine sand it may be necessary to design on the basis of 90% retention in order to insure stabilization. In the case of a graded formation, such as a mixture of sand and gravel, it may be possible to design on the basis of 50% retention and still achieve stabilization by proper well development.

In "gravel wall" wells, where special gravel or sand is placed between the screen and the wall of the bore hole, the gravel pack material is selected to provide stabilization of the formation. The screen slot in such cases is sized to retain the artificial gravel wall material, only. Since gravel wall material can generally be three to five times larger than the native formation, it is thus possible to use a much larger screen opening than in tubular type construction. In very fine formation this is a definite advantage. As the native formation becomes more coarse, and more graded, the advantages of gravel wall construction lessens.

Measuring samples

One of the most important factors in achieving a "sand free" well is that of obtaining representative samples of the native formation and having them accurately sieved (measured) to determine the size distribution of the material. The driller, by good sampling techniques, must obtain these representative samples. Most screen manufacturers provide a qualified mechanical analysis service. From this information the proper screen slot and, when called for, the artificial gravel wall material, can be selected to ensure a sand-free well.

Experience has shown that you should never compromise on the selection of slot size. The largest screen slot compatible with the formation should always be used. Studies and experience have shown that plugging is directly related to size of screen slot. All other factors being equal, one generally will find, for example, a 0.025 inch opening will plug twice as fast as a 0.050 inch opening screen. Similarly, redevelopment of a coarse opening screen is generally more successful than one with fine openings.

Hydraulic Design

A well screen should be so designed that there is a minimum of friction loss across the face of the screen. You have observed many times in the use of a garden hose, the longer the hose the less water you are able to obtain. This is because the flowing water develops friction with the walls of the hose. As a result you always have a loss of pressure across any given length of hose. Whether this drop in pressure is significant or not depends on the volume of water and the diameter and length of the hose. Basically, the same conditions hold true for a well screen. That is, to have an efficient hydraulic installation, the volume of flow and the total inlet area of the screen must be kept within a reasonable ratio.

The percentage of open area of screens vary from 1 to 5% for slotted pipe and pipe base types, 3 to 15% for louvered and punched types, and 12 to 30% for vertical rodded wire wrapped types. The variation being related to the size of the opening. A very fine slot screen, such as 0.010 inch, will have the lowest percent of open area with the larger slot sizes, such as 0.100 inch, having the highest percent of open area. As mentioned earlier you should always select the largest slot opening which will still provide a sand free well. You will thus have a screen with the greatest percentage of open area.

You must be concerned with "total" open area and not just "percentage". Hence, the length of the screen is also a critical factor. Double the length of screen and you will double the total open area. Three basic factors may limit the screen length: First, is cost. The customer will be unwilling to pay for more than is absolutely necessary. The second factor is the thickness of formation available. Obviously, if there is only five feet of formation, that is all the screen you should install. The third factor is the anticipated water level in the well when it is pumped. Good design requires that you set

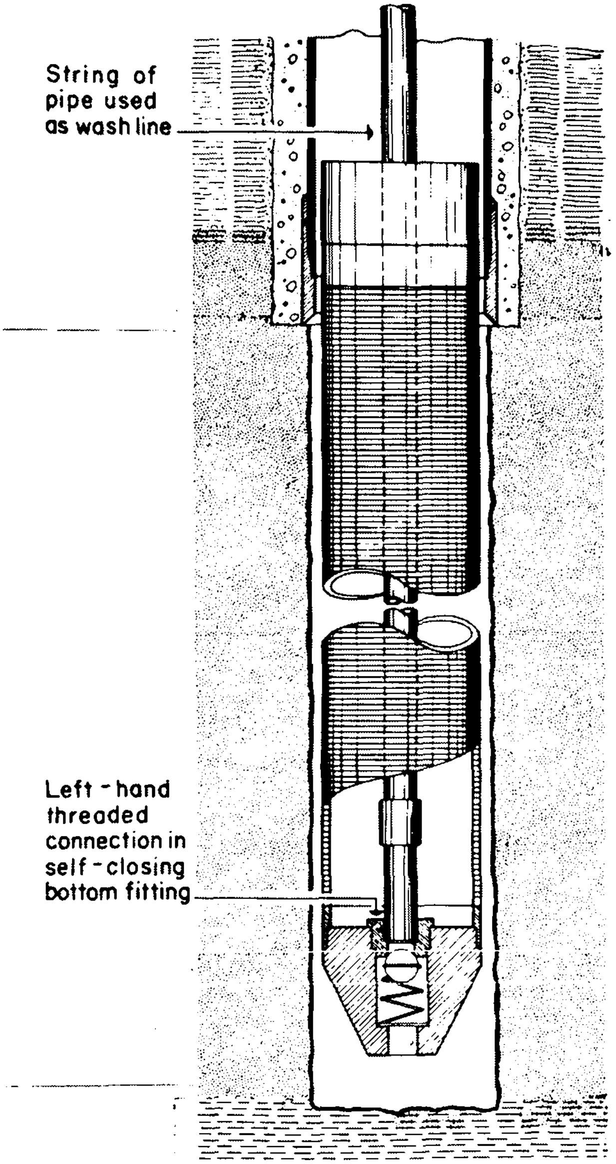


Fig. 7

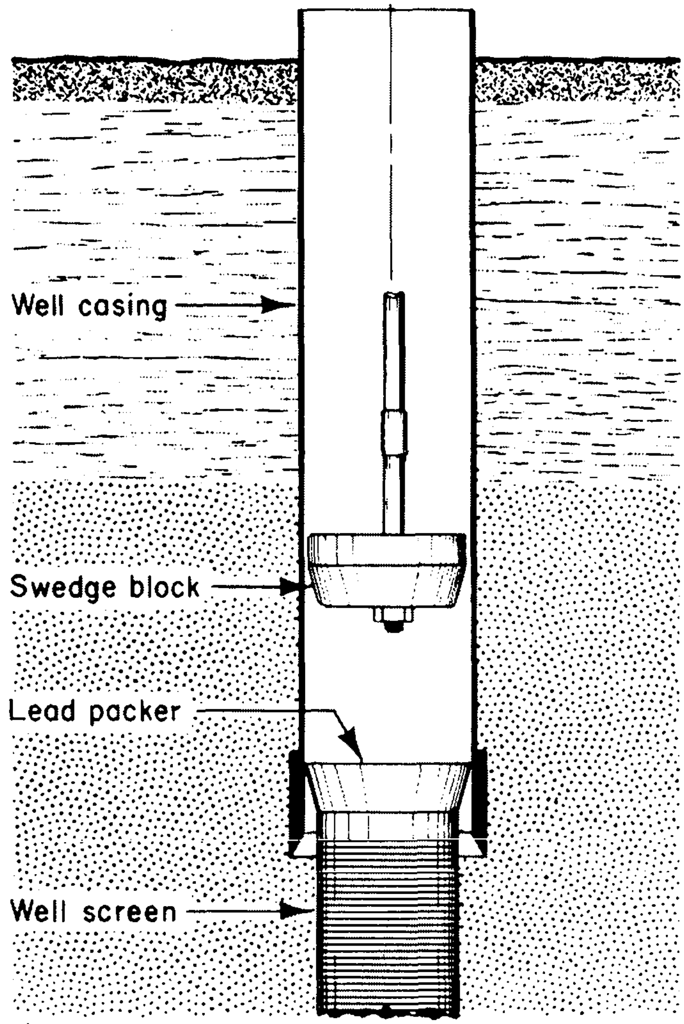


Fig. 8

the screen so that the top of it will always be below water.

Diameter of the screen also bears on the "total" open area and should be considered in the selection of a screen. Doubling the diameter, say from four to eight inches doubles the open area. Normally, however, the selection of screen diameter is based upon a variety of factors, such as minimum size needed for pumping equipment, and not only on available open area.

To provide a screen which will minimize friction loss you should: 1) select one having the greatest percentage of open area compatible with other design and economic factors, 2) select the longest length of screen which the formation and economics of the installation will justify and 3) select the largest diameter warranted by the particular installation.

In actual practice any of the three considerations given above can be compromised and compensated for by increasing one of the other factors. For example, where possible, one might use slotted pipe (one to five percent open area) instead of vertical rodded wire wrapped screen (12 to 30% open area) and compensate for the smaller percent open area by increasing the total length of screen. By proper design you could end up with the same total open area.

Summary-Design Factors

In your selection of a screen you must weigh each of the four major factors discussed above very carefully. Compromise is often necessary, but remember:

1) select a screen strong enough to resist collapse.

2) select a screen of the most durable material which the economics of the installation will allow.

3) select a screen which has openings that will stabilize the formation.

4) select a screen which will provide a minimum of friction loss for the anticipated flow. Balance percent of openings, length and diameter of screen to obtain the desired results.

Setting the Screen into the Well

The factors which are considered in selecting the best screen for a particular well, no matter how carefully considered, are to no avail if the screen is improperly placed in the well. Carelessness can result in the screen being damaged or being set at the wrong depth interval. Either can result in a poor well. Don't gamble, double check all measurements, be sure of your pipe tally and follow proper procedures when lowering the screen into the well.

Cased Holes

In screen setting methods first consider those used where the casing is advanced with the hole, as in cable tool, hollow rod or jetting work. The casing may only be taken to the depth where it is planned to have the top of the screen. The screen is then lowered into the hole and bailed or washed into place below the casing. In some cases an open hole may be drilled below the casing and mud or clay used to keep the hole open until the screen is lowered into place. In these procedures, it is necessary to know in advance the character of the formation. Such information is generally obtained by a test or pilot well which precedes the permanent construction. Figure #7 shows a typical "jetting down" arrangement.

Another, and perhaps the most often used, method of setting screen in a cased hole, is the so-called telescoping procedures. Here the casing is driven to the bottom of the formation or to the depth planned for the bottom of the screen. A screen is selected having a diameter which will fit inside the casing. It is then lowered to the bottom of the well and the casing bumped or jacked back to expose the screen.

In both of the above described methods the final step is to seal the top of the screen to the well casing. Traditionally, this is done by swedging out a lead seal at the top of the screen. A lead seal and a typical screen swedge are shown in figure #10. More recently at least one manufacturer has placed a rubber-type screen top seal on the market. It is said it will not only provide an effective seal but it will also lessen the possibility of electrolysis between, for example, steel well casing and bronze screen.

Rotary Drilled Holes

For rotary drilled wells, where the hole is drilled to its full depth before running the casing, the methods of completion with a screen are as numerous as drillers. Pipe and screen may be welded or screwed into a single string and lowered into the well.

The outer casing is not always used and if it is, the casing may either be cemented into place or removed after the screen and inner casing are set. Telescoping may also be utilized with the casing being set either before or after the final portion of the hole is drilled.

In most cases it is advisable to place stabilizing material (sand or gravel) between the screen and wall of the bore hole. The purpose of the stabilizing material is to fill the voids in the well and thus reduce the possibility of sudden shifting of the native formation which can cause collapse of the screen during development.

Construction techniques vary with each driller as do the large variety of screen setting tools. The methods and tools best adapted to a particular area can only be learned in the field. A few basic rules should be followed in all completion practices: 1) Be sure the casing is firmly anchored at its final position, 2) Know the size distribution of the formation in the interval to be screened, 3) Retain control of the screen while lowering it into the well, 4) Fill any large voids in the annular space between the screen and wall of the bore hole with stabilizing material, 5) Make a good seal between the screen top and well casing if they are not mechanically attached and 6) Place a good plug in the bottom of the screen if it was lowered into the well open-ended.

Conclusion

As a reader you may be disappointed that no charts, graphs or rules of "thumb" are given to guide you in the selection of a well screen or its installation for specific cases. However, as was pointed out in the introduction, the purpose here is to expose you to the basic principles involved. As you gain experience the details of selecting and setting a screen for specific installations will be unfolded. ■■

Chapter 10 - Sealing, grouting, and cementing casing

By William A. McEllhiney Sr.
Chairman of the Board
J. P. Miller Artesian Wells Co.
Brookfield, Ill.

THE USE OF CEMENT and the cementing of steel well casings in well bores dates back to the early twentieth century. Oil well drilling contractors needed a method to permanently separate water from oil producing zones. They found that grouting was the answer and that it was more permanent than packers which were then so commonly used. However, it was only a matter of a few years before water well contractors became aware of its desirability for the completion of water wells. For years its use was confined to large and deep wells.

The cementing equipment used then, and still used, for placing cement grout was heavy and expensive to operate. This fact made the well operators drilling home and farm wells reluctant to use it for their work, in spite of the fact that the proper use of cement could solve many problems.

Much has been published, catalogs are available, and cementing service companies stand ready to serve the needs of the contractor to do the bigger jobs, but the residential well driller who is confronted with cementing jobs is often at a loss to know just how to proceed. He knows how to pump water, and the kind of pump to handle drilling mud, but cement is something different. He may think that cementing a surface pipe or liner in place means a shut down period to allow the grout to set before drilling out. This spells loss of revenue. Cementing services are not available at his regular supply house, nor is he able to buy a cementing rig that is in the size range for his needs.

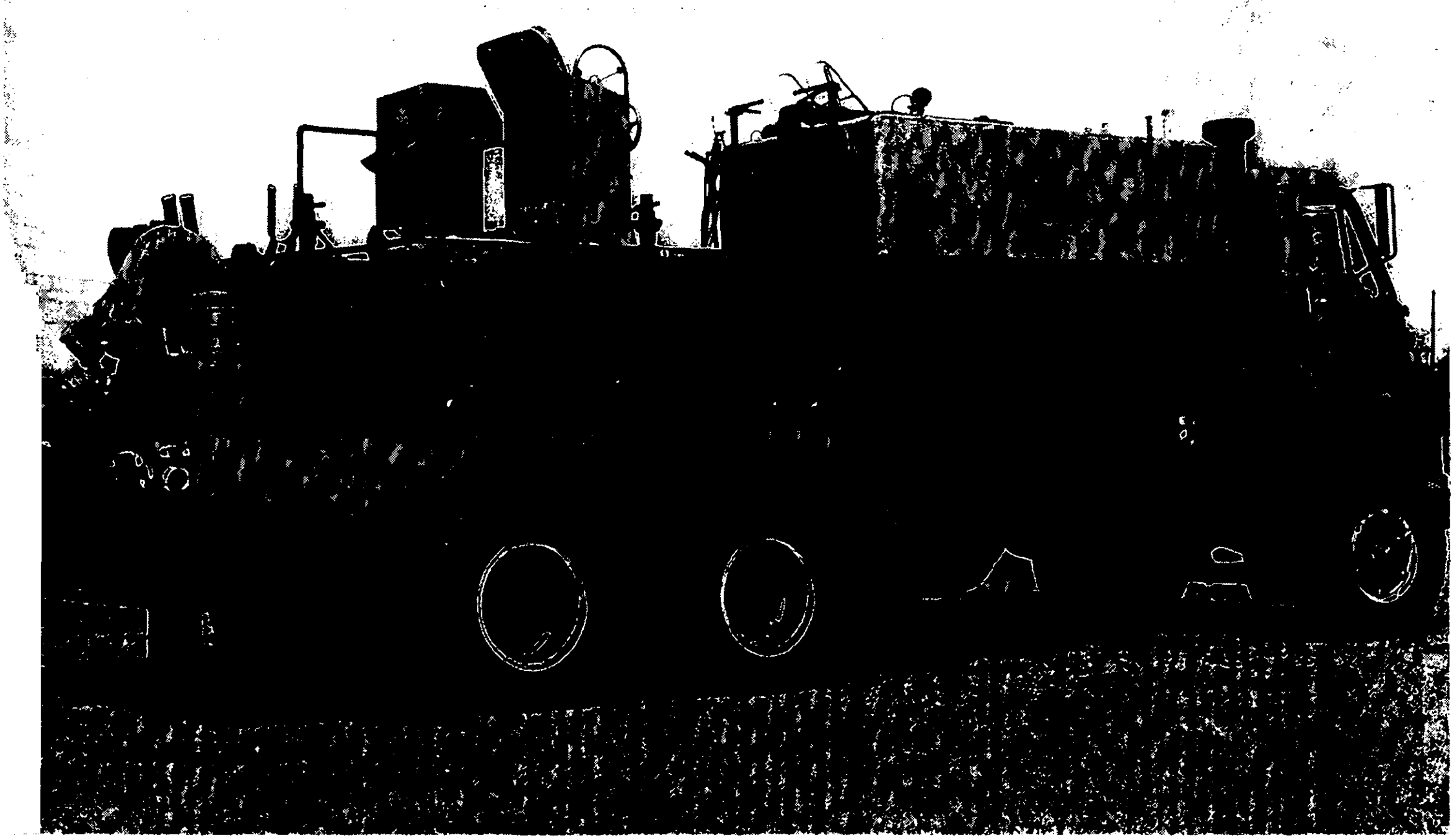
This chapter is not written to deal with the larger wells, but rather to offer some suggestions that may help a driller specializing in smaller wells to do a better job.

The whys

The common reasons why a well to be drilled might need cementing can be listed and described as follows:

▸ First, every well should be cased to a point below the level of possible contamination. In gravel and sand it is desirable to cement the well casing down to a point as close as possible to the top of the screen, or at least to the lowest possible pumping level. If you have impervious strata above the producing gravel or sand, the cement grout should extend from the surface down to the impervious barrier. The use of cement grout in such cases is superior to backfilling around the casing with drill cuttings or clay.

▸ Second, on a well producing from consolidated rock directly below "till" or "drift" formation, the surface formation above the pro-



LARGE SIZE DOWELL (*Div. of Dow Chemical*) "*Cementer Truck*". Smaller versions are used for pumping cement down into well hole.

ducing formation may be too thin or too porous, in which case the surface pipe driven into the rock is not sufficient protection against surface pollution. A driller must drill a sufficient depth into the consolidated rock, and below the zone of pollution and, there, install a permanent line of casing. The proven, safe way is to completely fill the annular space between the surface pipe, the drilled hole, and the permanent interline of casing with cement grout.

▶ Third, quite often, we must deal with man-made cases of pollution. Man-made quarries, filled with debris and garbage, septic tanks, and leaching fields, drainage wells, abandoned unplugged wells, nitrogen derivatives from modern fertilizers, are just a few possible contributors to pollution of a well to be drilled. Therefore, to make a well capable of producing potable drinking water, it is generally necessary to double-case a well and, at the same time, cement a liner well down into the producing aquifer and down below the possible pumping level.

▶ Fourth, it is often necessary to case-out an entire undesirable aquifer and to go to a lower formation for better quality water or for water less liable to be contaminated. Again, it is a situation requiring a cemented casing. Older wells often were cased with a packer at the bottom of the liner, and often, there was no real shut off. But if a seal was perfected, it was only as good as the casing which would be attacked by corrosion on the outside as well as the inside. The result usually was a leaky casing in a short time and a well repair job.

▶ Fifth, more and more attention is being given to the proper plugging of abandoned wells. Procedures have been established by state and local authorities and cementing has been an accepted practice.

▶ Sixth, usually the only repair work necessary on small-home wells is where the contact of the casing and rock has failed, or when a hole develops in the surface pipe. This generally calls for a liner extending below the original surface pipe and, here again, the safe procedure is to cement the annular space from top to bottom.

▸ Seventh, in drilling with a rotary machine, an open hole can be drilled down into bed rock, and the surface pipe installed in the open hole. When this is done, the annular space should be cemented.

The above list, of course, is not complete, but covers the common cementing jobs. The work can be done with rather simple equipment and a little ingenuity.

Equipment needed

The equipment necessary to do the grouting work on any of the above cases should be a pressure pump suitable to handle cement grout with a mixture of five and one-half to six gallons of water per 94-lb. bag of cement. The best pump for cementing jobs up to 50 to 75 sacks is a small power-driven reciprocating pump powered to deliver 100 pounds pressure.

For very small amounts of cement there is nothing wrong with using a hand force pump, commonly known as tank pumps.

The next essential piece of equipment necessary is a receiving tank or tub for cement. A common stock tank with a good heavy screen, with a one-quarter inch opening installed about one-third from one end, makes a satisfactory receptacle. It is necessary to keep lumps and any stringy material out of the pump. A short suction hose with quick-mate coupling should be used on the pump end.

The mixing of cement can be accomplished by any method: cement mixer, mortar mixer, by hand, or you can have a company deliver cement already mixed. It is well to remember that mix must be as free of lumps or any aggregate material as possible. The screen on the receiving tank will take care of just so much of the lumps and foreign material. It is discouraging to have valve and pump trouble while cementing. The cleaner the cement, the smoother the job.

It is essential to have an ample supply of good clean water available; above that required for mixing cement. Water under pressure is the only way you can remove cement if something goes wrong. A defective cement shoe or split casing, or bridged annular space, often develops after cementing has started and with ample water, the cement can be circulated to the surface or the cement can be diluted so that it will not harden. You then can remove the casing and correct the situation.

How far to cement

If we are to concede the premise that cementing is essential to make a safe well, it must then follow that we cement to a point below the zone of possible contamination, and, if possible, to a point below the lowest pumping level. This means that at least the lower part of the cemented area is below water. With this fact in mind you cannot make a satisfactory cementing operation by dumping cement grout into the annular opening. The proper method is to pump the cement into the hole or annular space through a pipe which has been installed to the bottom of the cemented area. Two possible procedures are available to a driller using the simple pump and tank. A pipe of any size, normally not less than 3/4 inch, can be run down the annular space to the bottom of the area to be cemented. Cement can then be pumped into the annulus until it returns to the surface. The alternate procedure is to install a cementing shoe on the bottom of the liner or surface pipe. This shoe will have a back pressure valve. A cementing tube, or pipe, is lowered inside the liner and attached to the cement shoe, usually by means of a right and left hand thread. Cement can be pumped down through the tube and out into the annular space until the annular space is completely filled. The tubing or pipe is unscrewed. The back pressure check valve will close. Surplus cement is then washed out of the tubing and it is removed from the well. This alternate method is particularly necessary where the annular space is restricted and where a pipe cannot be installed down the annular opening.

Cementing is not a complicated procedure. You can derive a great deal of satisfaction from the repetition of proven techniques of grouting which can add to the quality of your work.

Things to remember

Following are some more points about cementing:

1.) If your operation is limited to small wells (25 to 50 sacks of cement) you will probably be using small pumping equipment and a small cement tube. This being the case, you must be very careful to provide exceptionally good screening ahead of the pump and use well mixed grout, free of all lumps and foreign material. On larger pumps you can pass larger lumps and often can add to the mixture, loss circulating material such as seal flakes (shredded cellophane), Palco Seal (shredded redwood bark), etc. These additives are very essential in establishing circulation in heavily creviced zones. By being able to pump such material, you may be able to complete a cementing operation which a smaller pump would not have been able to handle.

2.) one advantage of pressure grouting is that you are not only cementing the annular space between a hole and a liner pipe, but you are also forcing grout back into cavities and crevices that contribute to possible contamination or bad corrosive water to the annular space. When this is done, even though you may have some voids and possible shrinkage cracks in the cement envelope, the chances are that the liner is amply protected. In the author's 30 years of experience with pressure grouted wells, I have never found a leaky casing where the casing was pressure-grouted in place.

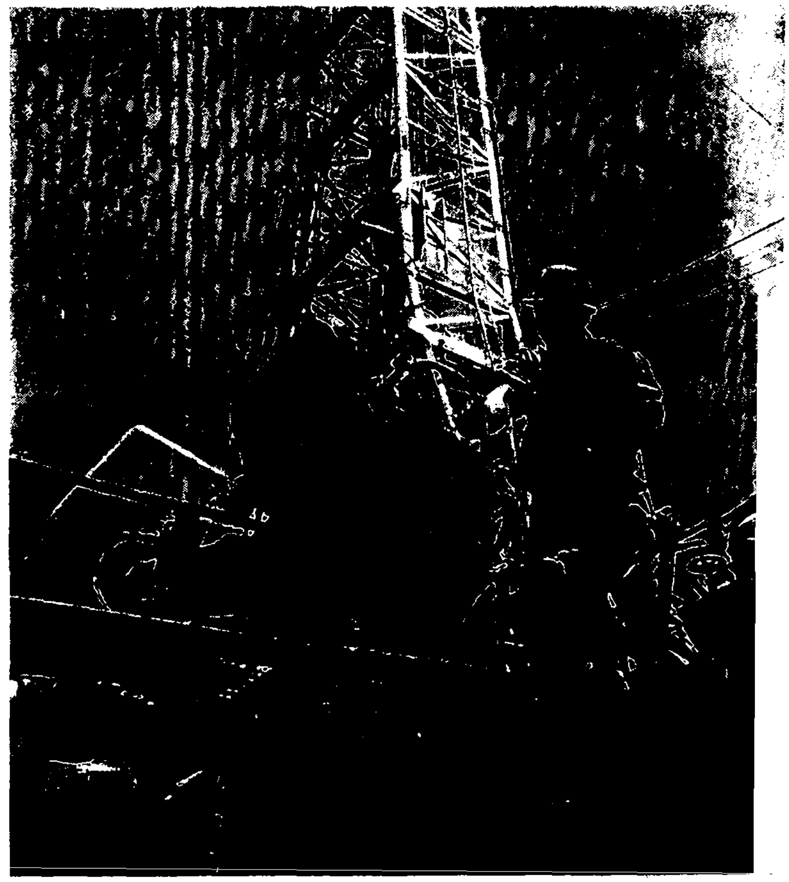
3.) In handling cement grout you must plan on "pacing" the cement and must finish all pumping of same within approximately four hours. The initial set of regular Portland cement takes place in about this time. If the time is more than this elapsed time, you will encounter increased resistance to pumping. So plan your work accordingly.

Watch your timing

On small well work this is seldom a factor. Conversely, you may want to decrease the initial setting time, which can be accomplished by adding two percent by volume of calcium chloride ($CaCl_2$) to your mixture. Not only will it reduce setting time, but the compressive strength (hardness) after 24 hours will be approximately equal to cement grout without calcium chloride at 48 hours. The use of "hi-early" cement can make possible further reduction in the setting time.

4.) Shrinkage of the grout envelope upon hardening is another problem. The accepted offset to this shrinkage is to use an additive of two to six percent finely-ground bentonite mixed with the slurry. Not only will it control shrinkage, but it will make the solution more fluid, thereby reducing pumping pressure. Bentonite is also a good loss circulation control material.

5.) Centering guides are often mentioned as being desirable when installing a liner in a drilled hole that is to be cemented. In the author's opinion, guides should not be used. It is rather naive to think that wells are drilled so straight that you end up with a concentric annular space between well bores and liners. It would take an infinite number of centralizers to hold a pipe concentrically in a normal bore. The fact that the casing may touch the well bore at one or more points will not result in any less an effective cement job. If you install a liner with a well bore below the bottom of a liner to be cemented in place, there is reason to align the liner and the well bore with a centralizer to eliminate an offset of the finished well.



OPERATOR AT THE CONTROLS of a Dowell mixer which blends dry cement, water and additives before pumping it down the hole.

6.) If you are cementing through a drillable cement shoe, do not crowd the tools, either with rotary or cable tools, when drilling up the shoe.

If you are running threaded and coupled pipe, and particularly if you are drilling with a rotary machine, be sure to tack-weld the shoe and the couplings on the bottom two or three joints of pipe. It is possible to unscrew a shoe or possibly a joint of pipe when drilling out a shoe. You can also knock a shoe off with cable tools. There's nothing worse than having a loose shoe in the bottom of the hole with the liner cemented in place.

Finally, there is no substitute for experience when it comes to improving the technique of cementing of wells. I have observed the operation and the equipment of many well drillers, and I know that you cannot under-estimate the ingenuity of the individual who decides he is going to equip himself to do first class pressure cementing. By repetition and refinement he will make better wells. This is the goal of all of us in the field of well work. ■ ■

Chapter 11 — Developing the well

By Vern Scoggins
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By now, it must be clear that there's more to providing a customer with a water well than simply making a hole in the ground and jamming some pipe down below the water table. Even after the borehole has been drilled, the casing set, and the proper screen selected and installed, it is the water well driller's responsibility to assure the owner that his well will deliver the maximum capacity over the longest possible time. Up to now, the driller's knowledge and his equipment have been enough to do the job. But for him to develop a well to the utmost and complete it, he needs skills that only talent and experience provide.

The concept of developing a well is not complicated. It simply involves those steps necessary to provide water in the aquifer the easiest possible path into the well. In unconsolidated formations, this means concentrating the coarsest sands and gravel right next to the well screen, with the degree of fineness gradually becoming greater as the distance from the well increases until it equals that of the aquifer generally. Water thus moves more freely the closer it gets to the well. In consolidated formations, wells are developed by assuring free flow from fractures or even by increasing the fractures artificially.

Well development methods

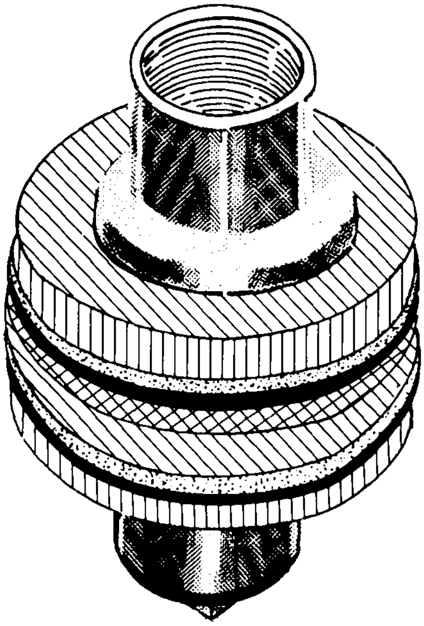
There are several methods of developing wells, either naturally developed or gravel-packed, some of which are more popular than others, and some of which suit only very special cases and formations. These include surging, either with a plunger or with air; overpumping; backwashing, by one of several methods; jetting; and the use of chemicals, explosives, and even dry ice.

Perhaps the most common method of developing wells, especially in sand and gravel aquifers, is surging with a plunger. It will serve best to show what results the driller hopes to get from natural development of the well since the largest number of people use this method. Gravel-packed wells will be considered later.

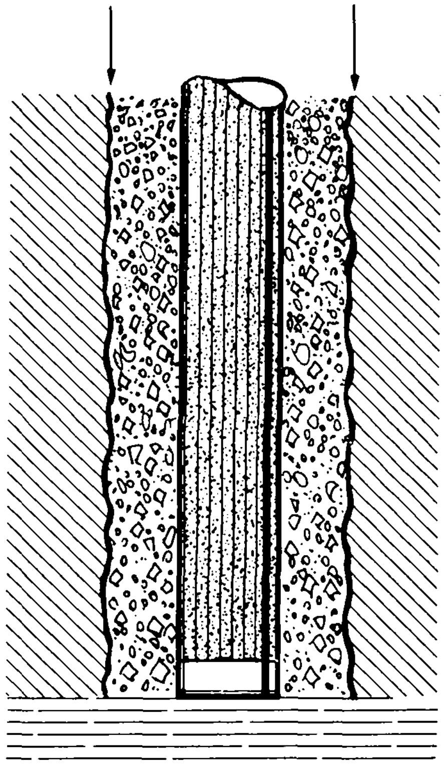
One tool used in this kind of surging is easily fabricated in almost any shop; the solid surge plunger consists of two rubber or leather discs between wooden discs on a heavy pipe nipple with steel plate washers under the end couplings. Different sizes can be assembled to fit reasonably well in different sizes of casing. Another type of plunger is equipped with valves to give a lighter surging action when desired.

The surge plunger is well adapted to cable tool operation. The downstroke forces water out of the well and into the surrounding formation. The upstroke then pulls water back into the well, and with it silt, sand, and anything fine enough to pass through the openings in the well screen. By forcing water out of the well, the surge breaks up "bridges" of sand particles as well as the "skin" created on the side of the borehole by the drilling process.

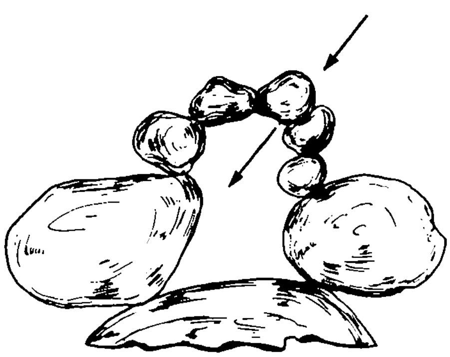
A bridge of sand particles can form between two coarser particles of gravel, thus providing an obstruction to water flow into the well, whenever water is pulled into the well only, and the flow is just in one direction. Forcing water out into the aquifer breaks up these bridges and creates a turbulence which tends to bring all fine



Solid-type surge plunger



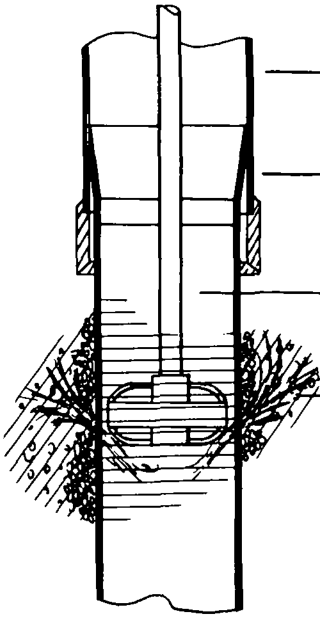
Skin effect (arrows)



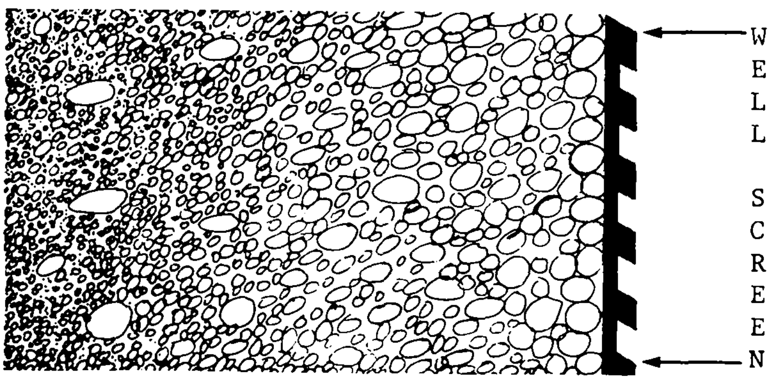
WHEN DEVELOPMENT is in one direction only, sand grains may form blockage.

particles into the well when the upstroke reverses the plunger's action. The skin is most often a result of rotary drilling when the mud fluid used in the drilling process clogs the formation and cakes into an impervious skin. All types of drilling, however, disturb the formation itself along the sides of the borehole to a point where some impediment to free flow of water is formed. Thus the out-and-in surging action is superior in most cases to those methods which only pull water into the well.

After the first few strokes of the plunger, a deposit of fine sand and silt will have entered the well. This is removed, usually by a sand bailer, and the amount carefully noted. As the length of time surging grows longer, and the amount of fines collected by the bailer grows smaller, the



JETTING TECHNIQUES using high velocity jetting generates turbulence around well screen which frees loose material and brings it into the well.



IN A NATURALLY DEVELOPED well, particles of fine sand are removed from the aquifer.

job of naturally developing a well in unconsolidated formations approaches its end. The action has increased the effective diameter of the well by spreading its zone of influence, and the amount of water which can be pumped from the well for each foot of drawdown (known as its specific capacity) also has increased.

High-velocity jetting

An even more effective method for developing the well is by pumping water through small nozzles at high velocities, or jetting. This allows the driller to treat each small area of well screen in turn, concentrating development wherever problems may be greatest, until the full depth has been cleared and prepared. Well screen openings which have been properly selected will direct the streams of water out into the surrounding formation and achieve complete development.

(Jetting has another advantage over surging with a plunger; it won't hurt to over-do the jetting, while improper surging can damage the well screen.)

A jetting tool, high-pressure hose, piping, and pump are all that jetting calls for. The tool is equipped with two, three or four nozzles spaced evenly around the side for hydraulically balanced horizontal discharge. Water is forced through the nozzles at a rate depending on the size of the openings and the pump pressure. If water is pumped from the well at the same time and at a rate slightly greater than that at which water is added through the nozzles, there will be movement of water from the aquifer into the well, bringing with it the fine particles loosened by the jet streams which will fit through the well screen openings. It won't always be possible to pump from the well at the same time you are using the jetting method of developing the well, but whenever it is possible, it is well worth while. (No pun intended.)

Air-surging

The other method of surging, through the use of an air lift, also can be effective. This is constructed by dropping two pipes into the well, each capable of being lifted or dropped independently. The larger, called the pumping or eductor pipe, is about 2″ less diameter than the well casing and contains the smaller air pipe, ranging from 1/2″ inside a 2″ eductor for a 4″ casing to 2-1/2″ inside an 8″ eductor for a well casing 10″ or larger.

An air compresser with its outlet connected to an air tank which is in turn connected by a goodly length of high-pressure hose to the air pipe and a quick opening valve connected at a convenient point complete the essentials. A tee at the top of the pumping pipe is fitted with a discharge pipe at the side.

Operations begin near the bottom of the well screen, with the pumping pipe lowered to within two feet of that point and the air pipe about a foot up inside. Water is then pumped slowly by conventional air lift method until the water is free of sand. Then the outlet from the tank is closed until the pressure builds up to about 150 psi, the air pipe drops below the pumping pipe outlet, and then the quick opening valve lets the air in the tank rush into the well. This surges water out through the well screen openings (as well as up through the casing and the pumping pipe to cause a predictable soaking at ground level), and then the pipe is brought back up inside the pumping pipe to continue the air lift and reverse the surging action by bringing water back out of the formation into the well, completing the cycle.

Backwashes and overpumping

As violent as the two methods of surging may seem, and as forceful as jetting may be, it is always best to begin development procedures gently, as with the simple air lift pumping action which precedes the first blast of air in the last method. Accordingly, some ways to develop wells remain rather gentle, as with backwashes created by pumping water to ground level of a deep well and then letting it fall back. A deep well turbine without a foot valve is often used for this purpose, although an air lift is applicable here, too. Or water can be pumped to fill a large tank from which it is all released at once to provide a stronger backwash. Generally, the surging action provided by backwash methods is not enough to develop a well to its full potential, although there are cases where they have proved satisfactory.

Similarly, overpumping is not apt to provide the best development, but this is the simplest way to remove fine particles from the aquifer. It does no harm, because any well which can be pumped at a high rate certainly can be pumped at the lower rate for which the well is designed. But it can leave bridges of sand grains and an only-partially-stabilized well. Its best application is a small well or one in a poor aquifer with few fine sands to cause problems. Large wells would call for pumps of capacities not always easily available.

Explosives, chemicals, and acids

Lest anyone think that only unconsolidated formations make it desirable to develop the well, it should be emphasized that all wells can benefit to an appreciable extent. As pointed out earlier, rotary drilling methods tend to leave a skin of caked clay and drilling mud on the surface of the borehole, and no well will produce its maximum capacity without this being broken up and removed. Polyphosphate dispersing agents added to water circulated to replace drilling fluids will give a good start on breaking these up, and the same materials work well where clay formations cause problems.

In hard rock, where the driller is at the mercy of faults and fractures, explosives are often used in attempts to develop greater capacities. Here, it is important to take into consideration the water pressures which must be overcome before the force of the blast can have any effect on the fractures.

Acids often work well in limestone, which is dissolved by acid. With fractures and crevices around the open borehole thus opened up, fine particles can be removed from openings more readily when water is pumped from the well.

Gravel-packed wells

Up to now, we've been discussing naturally developed wells, where the formation adjoining the well screen is the aquifer itself which must be arranged to our liking. It is possible, of course, to drill a wider borehole than our casing and fill this opening with just the sort of material we want to have next to the screen. A properly designed gravel pack will allow water to move through it very, very easily — and therein lies one problem with the development of a gravel-packed well.

When a well is packed with gravel, the skin of impervious material which resulted from the drilling process is not next to the well screen, but outside the gravel pack, acting as a barrier between the pack and the water-bearing formation. Surging action in attempts to develop this well must go first through the gravel, and since it is so easy to do so (and so difficult to go through the skin) water is apt to slosh up and down through the gravel and away from the skin which the surge is aimed at breaking down. Obviously, the thicker the gravel, the greater the problem; the thinner the gravel, the more effective the surge. The phosphates mentioned earlier can be especially useful in developing a gravel-packed well, assisting removal of silt and clay.

Summary

To close this chapter on well development, no comment would seem to be as appropriate as that which appears in the book, "Ground Water and Wells," published by UOP Johnson.

"Patience," it says, "intelligent observation and the right tools are required to complete a screened well correctly, whether it be naturally developed or artificially gravel-packed." ■ ■

Chapter 12 — Testing the well
Part I

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FOLLOWING THE construction of a water well it is desirable to test the well to determine the amount and from what pumping level the water will be produced. One would quickly recognize that the selection of the most efficient pump for the well must be based upon known pumping rates and depths and to the contractor these measurements are most important.

But it is also for other reasons that we test wells. The geologists and hydrologists are interested in the behavior of the ground water aquifer from which the water is drawn. Engineers and water agencies are interested in the safe yield of the aquifer, how the well will affect other wells, the water quality and how efficient the newly constructed well is.

Everyone engaged in the ground water industry enjoys a common interest in the measurements obtained during the proper testing of a well. The only significant difference between an aquifer evaluation study and a test "to find out what she will do" is the accuracy of the measurements taken and recorded.

In order to understand the procedures for testing a well we shall define the terms commonly used by the water well industry.

Definition of terms

1. **Static Level.** This is the level at which water stands in a well that is not being pumped. It is generally expressed as the distance from the ground surface (or from a measuring point near the ground surface such as the top of the well casing) to the water level in the well. For a well which flows at the ground surface, the static water level is above the ground surface. It is measured by valving off or shutting off the flow of the well and measuring the head in feet. This is sometimes referred to as the shut-in head.

When we say the static level in a well is 80 feet, it means that the water stands 80 feet below the measuring point in the well when there is no pumping. When we say that a well has shut-in head of 10 feet we mean that the water would rise 10 feet above the measuring point in a pipe extended above that point. Static water levels should always be made before pumping a well.

2. **Pumping Level.** This is the level to which the water is lowered during pumping. It is generally expressed as the distance from the measuring point at the ground surface to the water level in the well.

3. **Drawdown.** Drawdown in a well means the extent of lowering of the water level during pumping operations. It is simply the difference between *Static Level* and the *Pumping Level* in the well. We should understand that the drawdown represents the head in feet of water, that causes water to flow through the aquifer material toward a well at the rate that water is being taken from the aquifer. A highly permeable sand and gravel formation would require less head or "drawdown" to produce a given quantity of water than a less permeable sand which contained streaks of clay — both formations being of the same thickness.

4. **Residual Drawdown.** After pumping is stopped, water levels rise and approach the static water level observed before pumping started. During such a recovery period, the distance that the water level is found to be below the initial

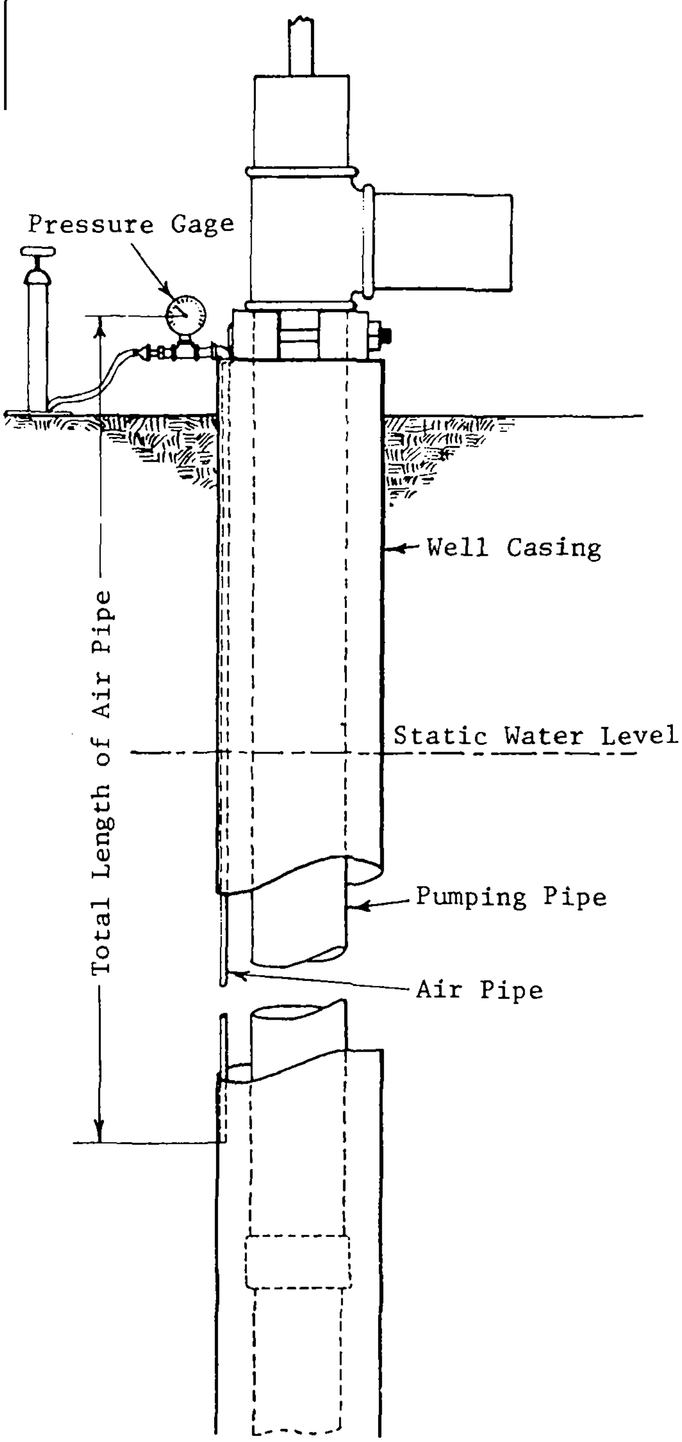

Fig. 1—Well with air line installed to accurately determine the static level, pumping level, and drawdown.

static water level is called residual drawdown.

5. **Well Yield.** Yield is the volume of water per unit of time discharged from a well, either by pumping or by free flow. It is measured commonly as the pumping rate in gallons per minute (gpm). Other units employed are gallons per hour (gph) for small yields, and cubic feet per second (cfs) for large yields. The well yield is sometimes referred to as the *Pumping Rate.*

6. **Specific Capacity.** The specific capacity of a well is its yield per unit of drawdown. It is commonly expressed as the "gallons per minute per foot of drawdown." For example: If a well was producing 200 gallons per minute and had a drawndown of 10 feet after a period of pumping, the specific capacity would be 200 divided by 10 or 20 gallons per minute per foot of drawdown. Since normal wells will continue to drawdown with time, it is well to determine the specific capacity from measurements taken after a given period of time. A commonly used period of time is 24 hours.

Instruments Used

Time, water levels and *capacity* flow rates are three measurements to make during a pumping test. Making accurate measurements together with the planned program of testing procedures will not only allow the contractor to properly select the pump best suited for the well, but also provide valuable information about the ground water aquifer below. To measure these values the following instruments can be used:

1. **Time.** In the measurement of time, the common watch is all that is required for successful well testing. It is important to record time during a well test since pumping levels change as a function of time. This is more fully explained in the section "Conducting Well Tests."

2. **Water Levels.** To make readings to any water level, the simplest and also the crudest way is to use a heavy weight or float on the end of a steel tape or chalk line. Readings taken in this manner often vary from two to six inches from true readings depending on the kind of line and whether or not the weighted end will float. The most satisfactory method is to use either an air line or an electric circuit. Measurements to the static or pumping level are always important and the use of an air line (or some other means more accurate than a weighted tape) are generally required.

Measurements to the pumping level are particularly important because they not only furnish the basis for estimating pumping levels for various capacities, but they also determine the power costs and the proper setting of the pump bowls if they are of the deep well turbine type.

The illustration (Figure 1) shows a well in which an air line is installed to determine accurately the static level, pumping level and drawdown. This apparatus is inexpensive, easy to install and remove and is generally accepted for all but the most accurate tests. It consists essentially of enough small diameter pipe or tubing to extend from the surface well to a point below the static or pumping level depending on which is being measured.

On top of the tubing or pipe is an ordinary altitude or pressure gauge to which is attached a tire pump or air pressure when it is available. Any small size of iron, brass or copper, 1/8 or 1/4 inch in diameter, may be used.

If the air line is to be left in the well for permanent use, it should be of some non-corroding metal; if jointed and coupled, the joints must be absolutely air tight. Tubing is now commonly used for air lines. Two things are necessary to make accurate readings with this device.

First, the exact vertical distance between the center of the pressure or altitude gauge and the open end of the air line as it is installed in the well must be determined. This measurement is obtained by carefully measuring the air line as it is placed in the well. With pipe this can be done accurately; with tubing it sometimes becomes a problem since the tubing has a tendency to curl. For this reason it is necessary to take special pains with tubing to get the vertical distance accurately.

Second, the air line must be air tight from one end to the other, including the connections at the gauge and air pump.

Using air line to test wells

Be sure all joints and connections are airtight, then pump air into the line until the maximum possible pressure is reached. Air forced into the line creates pressure which forces the water out the lower end, leaving the line full of air. Readings should not be taken, of course, while the air is being pumped in. The head of water above the end of the line maintains the pressure and the gauge registers the actual pressure or head above the end of the line. A gauge graduated in feet shows directly the amount of submergence of the end of the line.

Subtract this figure from the length of the line and you have the water level. Just as drawdown is measured, so is recovery measured after pumping has stopped. In fact, recovery can be observed directly from the action of the needle as it moves to the right due to the column of water in the well rising to the static level when pumping is stopped. For active wells in good, open aquifers this rise is very rapid, occurring in

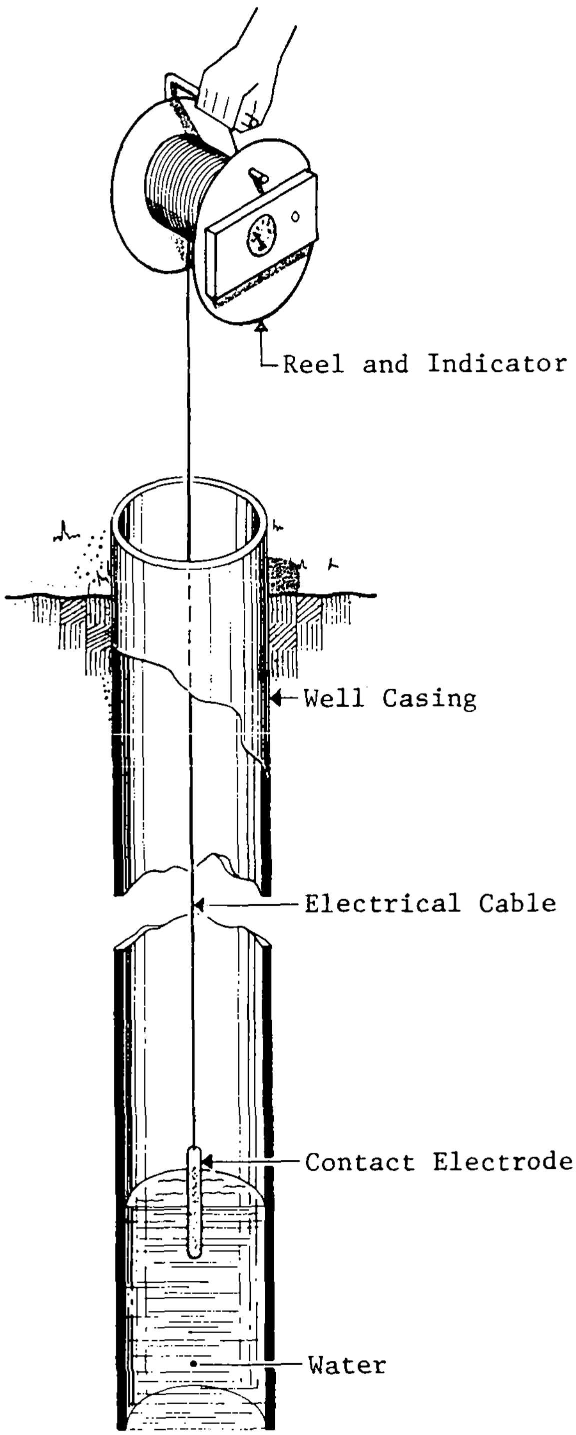

Fig. 2—Electric Sounder to measure water levels.

a few minutes. In poorer formations the recovery of static level may be a matter of hours. In any case, no well ever recovers the last few inches until a period of from 24 to 72 hours has elapsed.

For a practical example, let us say that the gauge is an altitude gauge reading in feet and it takes 46 feet of head or pressure equivalent to this amount of head to force all of the water out of the air line. We have created a condition whereby the air pressure inside the air line is just sufficient to balance the pressure of the water on the outside of the line. In this case it is 46 feet by direct reading on the altitude gauge.

If the distance from the center of the gauge to the open end of the air line is 95 feet, then the distance from the gauge to the static level is the difference between 95 feet and 46 feet, or 49 feet. If the gauge is above or below the ground surface, this must be considered if measurements are being referred to the surface.

Suppose now we start our test pump. It will be noticed that the pressure on the gauge drops as the water is lowered in the well. This is as it should be since the water in the well is lowering and there is not as much water pressure above the open end of the air pipe as there was before pumping started. In most gauges the needle actually moves to the left, or counter clockwise, to indicate a drop in pressure. Most altitude gauges have two needles, one red and the other black.

It is customary to set one needle, usually the red one, at the first reading — the reading taken before starting to pump the well. Then by reading the movable, or black, needle, the difference between the two needles can be read directly and the drawdown determined instantly.

Let us say our movable needle reads 22 feet after pumping has started. The difference between 46, our first reading, and 22 is 24 feet, or the drawdown at the quantity being pumped. A few trials will be sufficient for anyone to become familiar with the use of an altitude gauge and air line. If a pressure gauge is used, it operates exactly the same way except that the readings are in pounds per square inch and must be converted into feet of head for practical use. To do this, multiply the readings in pounds by 2.31 to obtain feet in head. For example, if the gauge reads 40 psi, then the head in feet would be 40 $\times$ 2.31 or 92.4 feet.

Electrical methods for measuring

Perhaps the most popular device for measuring water levels is the electrical depth gauge or electric sounder. (See Fig. 2.) This tool is available from several manufacturers. A shielded electrode is suspended by a pair of insulated wires and a volt meter indicates a flow of current when the electrode touches the water surface. Flashlight batteries supply the current.

To get accurate readings, the electrode and cable should be left hanging in the well between readings. This eliminates any errors from kinks or bends in the wires which may change the length slightly when the device is pulled up and let down.

For greater accuracy, the change in water level should be measured along the cable with a steel tape rather than using the metal markers which are usually attached to the cable by the manufacturer. One fixed mark may be used to indicate the static level and to serve as a base mark for subsequent measurements with the tape.

Wetted tape method

The wetted tape method is a very accurate way of measuring depth to water and can be used readily for depths up to 80 or 90 feet. First, a lead weight is attached to a steel measuring tape. The lower two or three feet of the tape is wiped dry and coated with carpenter's chalk or keel before taking a reading. The tape is let down in the well until a part of the chalked section is below water, with one of the foot marks held exactly at the top of the casing or other measuring point. The tape is then pulled up.

The wetted line on the tape can be read to a fraction of an inch and this reading is subtracted from the foot mark held at the measuring point to get the actual depth to the water level. A disadvantage of this method is that the approximate depth to water must be known so that a portion of the chalked section is submerged each time to produce a "wetting line."

References

1. UOP Johnson, "Testing Water Wells for Drawdown and Yield," Bulletin No. 1245.
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3. UOP Johnson "Ground Water and Wells," 1st Edition, (1966).
4. Illustrations courtesy UOP Johnson.

Testing the well
Part II

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PART I of Chapter 13 (Sept., GWA), introduced some of the terminology used in the testing of wells, plus some mechanical and electrical methods of testing static level, pumping level, and drawdown. This month's Part II explains flow rates and then gets into the actual step by step procedure for testing a well.

Flow rates

While the vertical measurements to water levels are being made, the measurements of quantity being pumped at those levels is also being made. The most accurate and fundamental method of measuring the rate of flow of a steady continuous stream of water is by collecting it in a container of known size and measuring the time required to collect it. Since this method is inconvenient and impractical for the average well job other methods are employed. These involve the use of Venturi meters, pilot tubes, current meters, orifices, flow gauges, weirs and similar devices. A description of the use of all these instruments is beyond the scope of this chapter. Three of the most commonly used methods are as follows:

1. Circular Orifice Weir. The circular orifice weir consists of a steel plate centered over the end of a discharge pipe in which there is a perfectly circular hole with clean edges, smaller in diameter than the discharge pipe. Back two feet from this plate is a small pipe tapped smoothly at right angles into the discharge pipe at the horizontal center line. The discharge pipe should be at least six feet long overall. A clear plastic tube is installed over the small (1/8 inch pipe nipple) pipe and is held vertically during the testing.

The pressure caused by the restriction of the water passing through the orifice plate causes water to rise in the tubing. The water level in this Piezometer tube is measured from the center of the discharge pipe to the top of the water column. The amount of water being pumped is a function of this height and is determined from Table No. 1. The accuracy of this method is dependent upon how carefully the well tester observes and understands certain limitations of the instruments. First, the pipe on which the orifice is used must be horizontal and the discharge must be allowed to fall freely.

Second, the edges of the orifice opening must be sharp and clean, preferably chamfered to 45° with the sharp edge upstream.

Third, combinations of pipe and orifice diameters must be such that the head built up will be at least three times the diameter of the orifice.

Table 1 — Table of Flow Rates Through Circular Orifice Weirs

Head of Water in Tube Above Center of Orifice	4-inch Pipe 2½-inch Opening	4-inch Pipe 3-inch Opening	6-inch Pipe 3-inch Opening	6-inch Pipe 4-inch Opening	8-inch Pipe 4-inch Opening	8-inch Pipe 5-inch Opening	8-inch Pipe 6-inch Opening	10-inch Pipe 6-inch Opening	10-inch Pipe 7-inch Opening	10-inch Pipe 8-inch Opening
5 inches	55 gpm	89 gpm	....	....	....	....	....	....	....	....
6 "	60 "	97 "	82 gpm	158 gpm	144 gpm	240 gpm	390 gpm	....	....	....
7 "	65 "	105 "	88 "	171 "	156 "	260 "	420 "	370 gpm	540 gpm	830 gpm
8 "	69 "	112 "	94 "	182 "	166 "	275 "	450 "	395 "	580 "	880 "
9 "	73 "	119 "	100 "	193 "	176 "	295 "	475 "	420 "	610 "	940 "
10 "	77 "	126 "	106 "	204 "	186 "	310 "	500 "	440 "	640 "	990 "
12 "	85 "	138 "	115 "	223 "	205 "	340 "	550 "	480 "	700 "	1080 "
14 "	92 "	149 "	125 "	241 "	220 "	365 "	595 "	520 "	760 "	1170 "
16 "	98 "	159 "	132 "	258 "	235 "	390 "	635 "	555 "	810 "	1250 "
18 "	104 "	168 "	140 "	273 "	250 "	415 "	675 "	590 "	860 "	1330 "
20 "	110 "	178 "	150 "	288 "	265 "	440 "	710 "	620 "	910 "	1400 "
22 "	115 "	186 "	158 "	302 "	275 "	460 "	745 "	650 "	950 "	1470 "
25 "	122 "	198 "	168 "	322 "	295 "	490 "	795 "	690 "	1020 "	1560 "
30 "	134 "	217 "	182 "	353 "	325 "	540 "	870 "	760 "	1120 "	1710 "
35 "	145 "	235 "	198 "	380 "	355 "	580 "	940 "	820 "	1210 "	1850 "
40 "	155 "	251 "	210 "	405 "	370 "	620 "	1000 "	880 "	1290 "	1980 "
45 "	164 "	267 "	223 "	430 "	395 "	660 "	1060 "	930 "	1370 "	....
50 "	173 "	280 "	235 "	455 "	415 "	690 "	1120 "	980 "	1440 "	....
60 "	190 "	310 "	260 "	500 "	455 "	760 "	1230 "	1080 "	1580 "	....

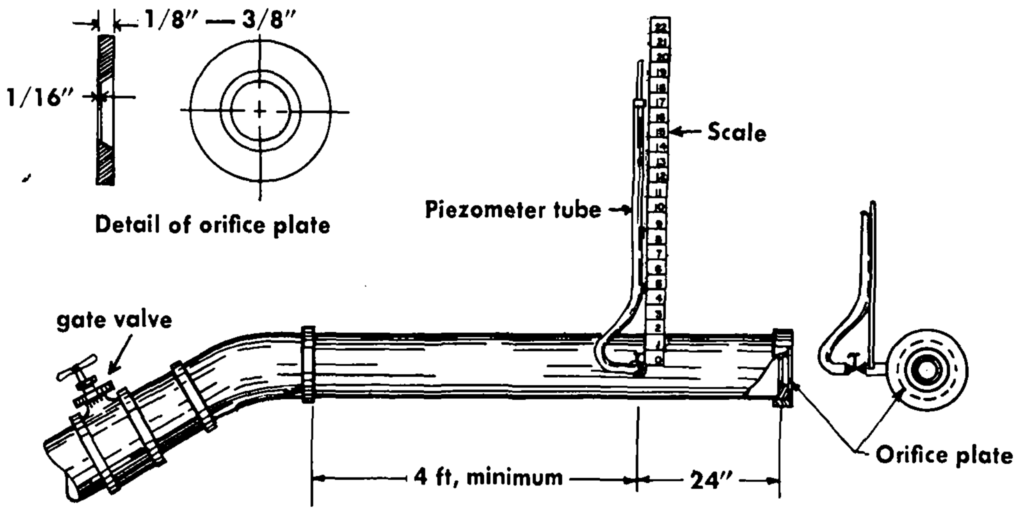
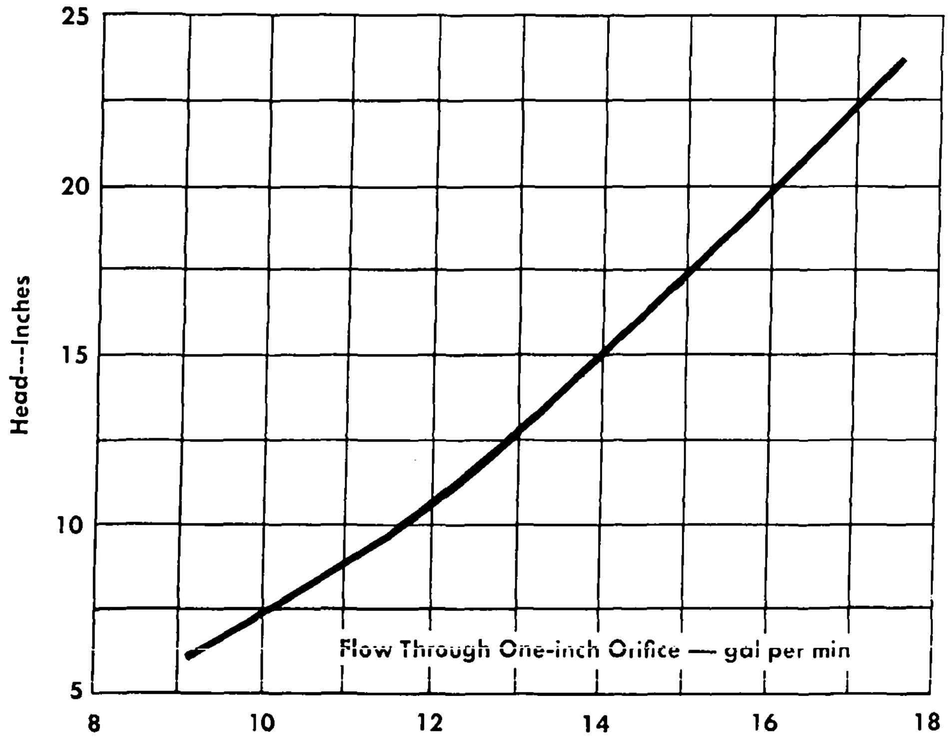


Figure 1. Essential details of the circular orifice weir commonly used for measuring pumping rates when pumping by means of a turbine pump. Discharge pipe must be level.

TABLE 2.

Rating curve for one-inch-diameter orifice in orifice bucket. Multiply values from this curve by number of orifices to get total rate of flow.



Fourth, the orifice must be vertical and centered in the discharge pipe.

Fifth, the head measuring tube must be free from air bubbles and not protrude beyond the inside surface of the pipe.

The apparatus and setup are shown in Figure 1 for all ordinary tests.

Orifice bucket

2. Orifice Bucket. The Illinois State Water Survey has developed a device termed an "orifice bucket" for readily measuring limited rates of flow up to about 180 gpm. It consists of a small cylindrical tank or container with one or more one-inch holes accurately bored through the bottom. The water to be measured flows into the tank and discharges through the one-inch orifices. The container fills with water to a level where the pressure head causes the discharge through the orifices to just equal the inflow.

A gauge glass or a simple Piezometer tube is connected into the wall of the container near the bottom. A suitable vertical scale is fastened to the outside so that the orifices can be read accurately. A calibration curve shows the rate of discharge through a single one-inch orifice for various values of the pressure head.

The flow rate taken from this curve multiplied by the number of orifices used gives the total rate of discharge through the device.

Table 2 shows the rating curve for a one-inch orifice as determined in the Water Survey laboratory. It shows, for example, that when the water is 16 inches deep in the container, the flow through one hole is 14.4 gpm. If the bucket used is made with five holes, the total rate of flow with 16 inches of pressure head would be 72 gpm. One of the practical uses of the orifice bucket is for measuring the discharge from a plunger pump or rig-operated pump where the flow is not constant.

3. Drop Measurement. One of the least accurate measurements of flow that can be employed is that of the "drop method." The principle employed in this method relates to the velocity of the water passing through a discharge pipe either in full or partial flow. While not a desirable means of measuring the capacity, there will be times in every well and pump installer's employment that a measurement of capacity is desirable at a time when no field instruments are available.

In such instances, measure the horizontal distance from the end of the discharge pipe that is required to allow the center of the discharge stream to fall 12 inches. (See Fig. 2) The horizontal measurement in inches can then be converted to gallons per minute by entering Table 3 when the diameter of the discharge pipe is known. Limitation in the use of this table is to measuring only discharge pipes that are full. Tables are available for partially filled discharge pipe and can be found in many water well handbooks.

In addition to the "Drop Method" of measuring capacity, other approximating methods of measuring flows and well yields are common to the industry. Among them is the "Bailer Test" which involves rapid bailing of the well, measuring the drawdown and by counting the bailer loads over a measured time period, calculating the average flow.

Conducting well tests

We have examined the terms used and the instruments employed by the water well industry in conducting well tests. The practical application of these tools comes from experience and a fundamental understanding of the behavior of ground water flows. It should be kept in mind that a pump test is a test of the finished well as a structure and not necessarily a test of the yielding ability of the formation in which the well is constructed.

Various contractors, engineers, geologists, etc., have certain procedures for testing wells which are based upon their specific needs in evaluating the well. The contractor may desire to know at what pumping level a given quantity of water is obtained after a specified number of hours of pumping. In this case, the measurement of capacity and pumping level would be made after the prescribed passage of time. The geologist may desire to measure the transmissibility of the aquifer supplying the ground water and would require several measurements of pumping levels at specified times during which the capacity of the pump is held constant.

I cannot emphasize enough that regardless of the type of test employed, the accuracy of the test is most important.

Procedure

An excellent procedure for anyone to follow in well testing which will answer both the contractor's needs and provide some geological data is as follows:

1. During preliminary well pumping, establish the maximum rate that can be pumped from the well with the equipment employed. For example, assume a well can be pumped at 100 gallons per minute for several hours without breaking suction with the test pump or dewatering the aquifer below the screen.

2. By use of a discharge valve (such as a gate valve) throttle the pump to about 80 percent of the maximum capacity.

3. Stop the pump and allow the well to recover to its *static level.* Normally this requires an overnight shutdown.

4. Measure (prior to testing) the static level of the well.

5. Noting the time, commence pumping at the established flow rate.

6. Measure the drawdown every minute for the first ten minutes, thence every five minutes for the first two hours of pumping being careful to maintain exactly the same pumping rate by adjusting the gate valve.

Measurements of pumping levels after the initial two hours can then be spaced every thirty minutes as the test continues. What will be observed is that the water level will fall rapidly during the early period of pumping (thus the reason for frequent measurements) then less rapidly as the test continues.

What you will be observing is the general behavior of most wells drilled in artesian basins. Subject to the accuracy of the measurements and to special conditions found in some wells you will observe that the change in pumping levels during the first ten minutes of pumping will be nearly the same as that observed from ten to 100 minutes. Or the change from five minutes to fifty minutes will also be the same as that observed from 10 to 100 minutes and from 4 to 40 or 8 to 80, etc. More importantly, if this value is for example 25 feet, then one might anticipate that the well will continue to lower another 25 feet in the time period measured from 100 to 1000 minutes, and another 25 feet in the time period from 1000 to 10,000 minutes, etc. In more meaningful terms we can say that the pumping level would lower 25 feet in the first 10 minutes, 50 feet after 1 hour and 40 minutes, 75 feet after 16 hours 40 minutes and to 100 feet after nearly seven days of continuous pumping.

The test should be conducted for at least 10 hours and preferably 24 hours.

will convince any well tester that he stands on dangerous grounds if he attempts to base pump selections on tests conducted after short periods of pumping.

A discussion of the procedures for testing wells to obtain data for calculating the principal factors of aquifer performance is beyond the scope of this chapter. In such tests, the variations of drawndown with time of pumping as discussed above together with the measurement of one or more observation wells is required. Instructions on how to perform these tests are discussed in Chapter 5 of "Ground Waters and Wells" (Edward E. Johnson, Inc. 1966).

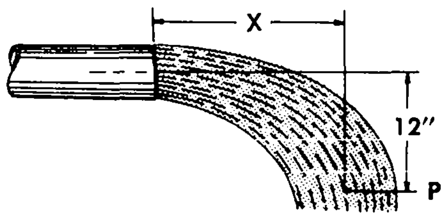


Figure 2. Rate of flow from a horizontal pipe can be estimated from the distance X.

Table 3 — Discharge from Horizontal Pipe Flowing Full, in gpm

Distance, X, in inches, at 12" drop	Pipe diameter					
	2"	3"	4"	5"	6"	8"
6	21	46	80	125	181	312
7	24	54	93	146	211	364
8	28	61	106	167	242	416
9	31	69	119	188	272	468
10	35	77	133	208	302	520
11	38	84	146	229	332	572
12	42	92	159	250	362	624
15	52	115	199	313	453	780
20	70	154	265	417	604	1040

7. If convenient, plot the test data on semilog graph paper which is available from most stationary supply houses. You will observe that the points will fall on nearly a straight line.

8. Calculate the specific capacity of the well based upon the measured or calculated pumping level at 1440 minutes (24 hours).

9. The desired pumping level for other flow rates lower than the tested capacity may be safely calculated from the specific capacity obtained. With an understanding of how rapidly the water level is dropping during the test a more meaningful selection of pumping equipment can be made for the well. Conducting this "Constant Rate Pump Test" a few times

Summary

The performance of any well is a function of its design, its construction, its development and finally its supplying aquifer. Initial well tests become the foundation for evaluating its performance as a hydraulic structure over the useful life of the well. If future tests indicate a decline in specific capacity with little change in static level then the water well contractor should recognize the need for well servicing. Proper well testing is an important avenue of service to the well user. The technician assigned the responsibility of well testing serves a vital role in the ground water industry.

Chapter 13

Types of Pumping equipment

by Edwin A. Scott, Jr.
President, Scott Periodicals Corp.

TWO BASIC PRINCIPLES underlie the workings of virtually all pumps now being installed for private water systems. The first, often referred to as suction pressure or suction force, actually is the result of atmospheric pressure. The second, known as centrifugal force is a factor in the operation of every type of rotary pump.

Atmospheric Pressure: At sea level, the atmosphere has a weight (or pressure) of about 14.7 pounds per square inch (psi). The weight of this air is responsible for operation of all types of suction pumps.

Visualize a drinking straw in a glass of soda or a pipe inserted in a body of water. If a partial vacuum is created inside the straw or pipe, liquid will flow into it. While this action is commonly called "suction," it is actually the result of atmospheric pressure *pushing* the liquid into the space where a vacuum exists.

How high can such a vacuum lift a column of water? If the suction were perfect, i.e., a complete vacuum, there would be no force whatever to counteract the 14.7 psi of atmospheric pressure. One psi can lift a column of water 2.3 ft. Therefore in a perfect vacuum, suction force could theoretically lift a column 2.3 x 14.7 or 33.9 ft. However, for a variety of reasons, including the impossibility of a perfect vacuum, 25 ft is the accepted maximum lift of suction-type pumps.

In shallow wells, pumps can operate on the basis of suction pressure alone. But in wells deeper than 25 ft, this force must be coupled with some other action to bring water to the surface.

Centrifugal Force: The second mechanical principle involved in pumping is centrifugal force. This is nothing more than the tendency of any rotating object to move outward from the axis or center of rotation.

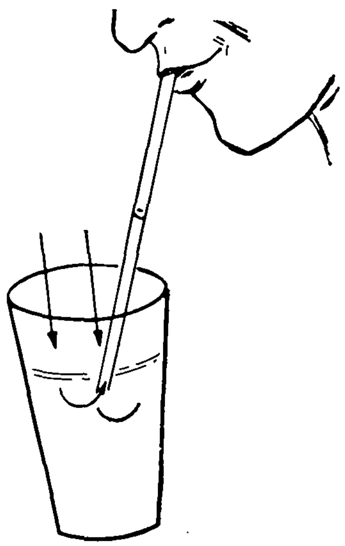
Again, a common experience is illustrative. Consider a pail of water being swung in a circle. Although the pail may be tipped almost horizontal to the earth's surface, the water doesn't spill out because centrifugal force keeps it in place. Now imagine that a hole is punched in the bottom of the pail. The water flows out in a steady stream. If there were a means of replenishing the water by suction, you would have what amounts to a centrifugal pump.

In practice, the pump creates centrifugal force with a bladed wheel known as an *impeller*. Water enters the pump housing at the hub of the wheel. The rotating impeller creates a centrifugal effect which causes the water to flow outward from the axis. This flow in turn creates a partial vacuum or suction, which brings additional water in through the intake.

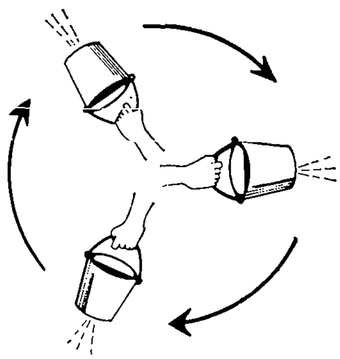
In one form or another, centrifugal force underlies the operation of all common water systems pumps—jets, submersibles, turbines. In simplest form, the intake for a plain centrifugal pump is simply connected to the drop pipe into the well. When the pump is turned on, centrifugal force and suction cause water to flow up the drop pipe. Such an arrangement, however, is suitable only for very shallow wells—15 ft or less. For greater depths, a special type of centrifugal unit known as the *jet* pump is commonly used.

Jets

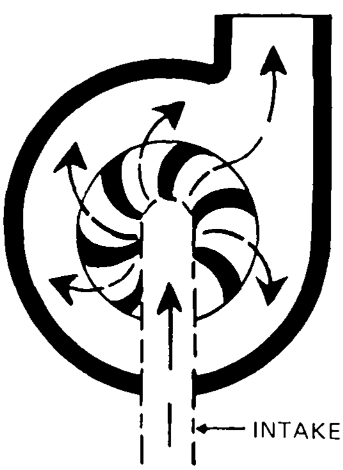
THE JET PRINCIPLE: Jet pumps operate on the basis of the ejection principle. According to this phenomenon, a partial vacuum is created when the velocity of a stream of water is increased by passing it through a constricted noz-



ATMOSPHERIC PRESSURE AND SUCTION



CENTRIFUGAL FORCE



CENTRIFUGAL PUMP

zle. The action is identical to that of a garden hose.

In jet pumps, this principle is adapted by means of a device known as ejector. This unit has three main parts: Body, nozzle and venturi tube, arranged as illustrated. Water supplied by a centrifugal pump flows through the nozzle, creating a partial vacuum. Atmospheric pressure then forces well water into the system through the side opening of the nozzle. This "pumped" water, together with the "drive" water from above, then flows through the venturi tube where the velocity is reduced and the pressure increased.

As adapted to private water systems, this opperating principle has numerous advantages. The action is smooth and continuous, without the surges associated with older types of pump. An unlimited amount of air can be handled. And, as noted above, the action is simple, with the pump impeller the only moving part.

Jet pumps are classified into various types according to the location of the ejector and the arrangement of the pumping unit.

SHALLOW-WELL JETS: As indicated earlier, 25 ft is the practical lift limit for any type of pump operating on pure suction. While straight centrifugal pumps are not efficient to this depth, a unit employing the ejector principle can function efficiently down to 25 ft. Such a pump, known as a shallow-well jet, has the ejector unit mounted directly on the pump body. Water from the centrifugal pump is driven through the nozzle. This creates sufficient vacuum to suck water from depths up to the full 25 ft.

DEEP-WELL JETS: When water must be pumped from depths of greater than 25 ft, the ejector unit is submerged in the well. In this arrangement, known as the deep-well jet, water enters the ejector as the result of suction. However, suction is only partially responsible for its ability to travel to the surface. The principal factor involved is the force of the "drive" water being pumped by the centrifugal unit. Because deep-well jets force, rather than suck water to the surface, there is no theoretical limit to the depth at which they can be used. However, submersible pumps (see below) normally provide greater cost-efficiency at depths much over 200 ft or even less.

CONVERTIBLE JETS: Some jet pumps are built witn ejectors that can be used either mounted on the pump (shallow-well) or removed for installation in the bore hole (deep-well). Such units are known as convertible jets. Because of their great flexibility, they have become increasingly popular in recent years.

MULTI-STAGE JETS: A jet with one impeller is known as a single-stage unit. If greater pressure is desired, it can be obtained by adding one or more additional impellers on the same rotor. In such an arrangement, the first impeller pumps water into the housing of the second impeller, increasing its pressure in the process. Water then passes through the additional impeller(s), finally arriving at the ejector at higher pressure than if a single stage had been used. The additional pressure thus created permits the jet to function in a deeper well or to pump water to a greater pressure above the wellhead.

VERTICAL JETS. A special type of single- or multi-stage jet has the impeller(s) arranged pancake-fashion on a vertical rotor directly over the well. There are no major efficiencies gained by such a configuration, and pumps of this design are marketed primarily to satisfy regional preferences.

Submersibles

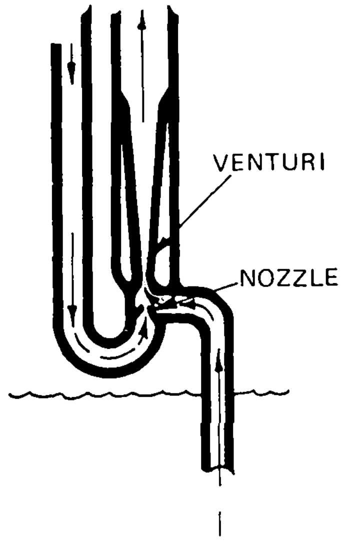
The multi-stage jet demonstrates the principle that a greater number of stages increases the pressure that the pump is capable of delivering. This same concept underlies the design of the submersible pump, by far the fastest growing type used for water systems.

Every submersible has a series of stages arranged on a common shaft. Each stage consists of an impeller, very similar to those used on basic centrifugal pumps, and a diffuser. The diffuser's function is to convert water velocity into higher pressure and to channel the flow into the next stage. Thus, a submersible pump consists of a series of stages connected to a single motor. What distinguishes this type of pump from others is that *the motor is submerged in the well, along with the pump.*

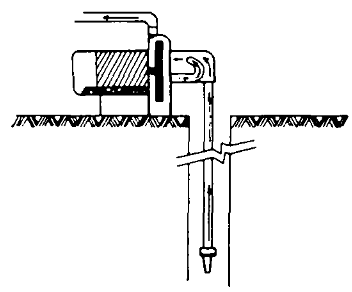
By virtue of its multiple stages, the submersible pump generally delivers higher pressures than jet pumps of the same horsepower. Consequently, such units are favored for deeper wells. However, their high capacity (in terms of flow) and quiet operation—all moving parts are down in the well—offer advantages at any depth.

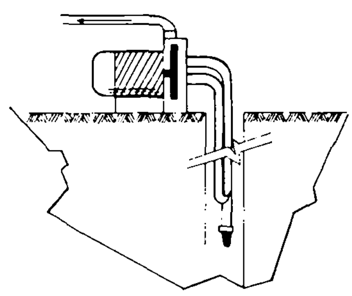
There are numerous ways to classify submersible pumps. The most common are as follows:

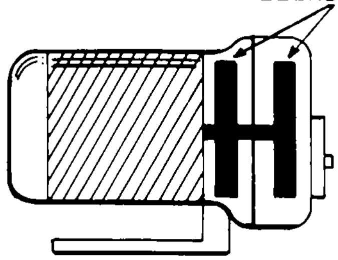
Diameter: Since a submersible must fit down in the well, it must obviously have a diameter no greater than the well in which it is installed. Thus submersible pumps can be classified as 4-in., 6-in., etc. While pressure increases with the number of stages, delivery—i.e., output in terms



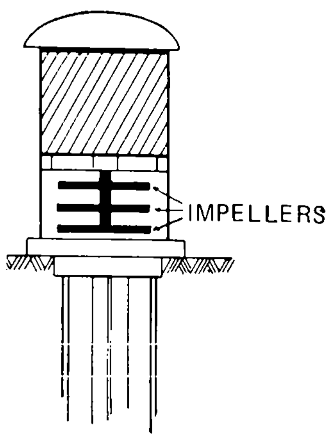
JET PUMP EJECTOR


SHALLOW-WELL JET

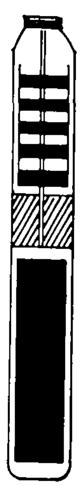

DEEP-WELL JET



MULTI-STAGE PUMP



VERTICAL JET


SUBMERSIBLE PUMP

of flow—is determined in part by the pump diameter. For household use, most submersibles are of the 4-in. type.

Number of Wires: To operate submersible pumps, electrical cable must be run from the power source to the pump motor in the well. Thus, these units can also be described by the number of wires used in the power cable. *Three-wire submersibles* have the starting device (start capacitor and switch) in a control box above the ground. The same is true of overload protection. *Two-wire subs* have the starting controls and sometimes the overload protection built into the pump motor.

Motor Design: Submersibles are also classified according to the design of the pump motor. There are three basic types:

HERMETIC MOTORS: In this design, the stator and rotor windings are made of conventional wire, then sealed in a plastic matrix. The entire part is then hermetically sealed in metal, giving rise to the terms "canned" or "potted" for the windings of these hermetic motors. With the electrical parts so sealed, the motor can run freely under water; indeed, well water flowing through the motor serves as both lubricant and coolant.

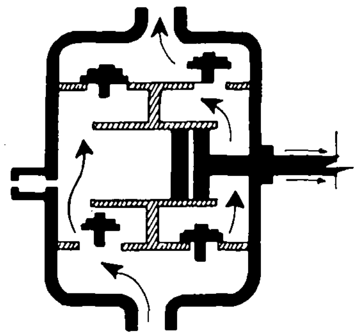
OIL FILLED MOTORS: A second design involves "open" or unsealed motor windings—rotor and stator—which are lubricated by oil. A reservoir of oil, kept under pressure either by spring loading or by gravity, keeps water from leaking into the motor spaces.

NON-HERMETIC WATER-FILLED: A third design involves "open" or non-hermetic windings similar to the oil-filled motor. In this case, however, the windings are insulated with a waterproof, flexible material. In this design water serves as both lubricant and coolant. However, because of the insulation on the windings, it cannot short out the electrical circuits.

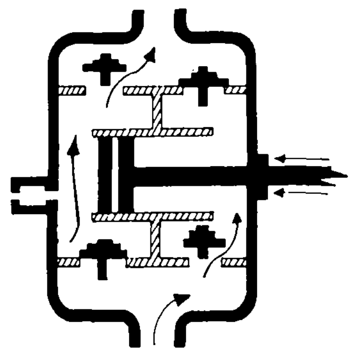
Piston Pump: This is a form of reciprocating pump in which the action of a piston alternately sucks water into a pumping chamber and then forces it out into the system. The accompanying diagrams illustrate its operation. In the first one, the piston is moving from left to right. This creates pressure in the right-hand chamber, forcing water out of the right-hand discharge valve. It also creates suction in the left-hand chamber, drawing water in through the left-hand suction valve. When the piston reverses direction, as in the second illustration, the operations are reversed.

Working Head: A second type of reciprocating pump, designed primarily for deep wells, involves a plunger and cylinder located below the water level in the well. The vertical action of the plunger forces water up through the cylinder and drop pipe to the surface. Power for these pumps, which are also called "sucker rod pumps" or "stroke pumps," is provided by an electric motor or gasoline engine at the surface. Rotation of the prime mover is transformed into an up-and-down motion by a gear box and lever or walking beam.

Vertical Turbines: Superficially similar in design to the submersible, the vertical turbine differs in details of the stage configuration. Turbines are easily recognized by their distinctive bowl units. These contain long tapered passages which facilitate water flow and permit maximum impeller size within a given pump diameter. This configuration permits vertical turbines to pump large volumes of water. As a consequence they tend to be used for farm irrigation, community water supply and high-volume industrial work. Vertical turbines are normally powered by an electric motor at the surface and connected to the pump by a long shaft.



PISTON PUMP
RIGHT-HAND STROKE



PISTON PUMP
LEFT-HAND STROKE

Accessories

Pressure Tank: Water is almost never pumped directly from the well into the household piping system. Instead it flows from the pump to a storage tank. The tank has a cushion of air which is compressed as water flows, thereby keeping the system under pressure.

Air Controls: Air is partially soluble in water. Hence air in a pressure tank would gradually dissolve, "waterlogging" the tank, unless precautions are taken. There are three methods of accomplishing this control of air in the pressure tank.

AIR VOLUME CONTROL: This is a valve which fits directly on the pressure tank. Depending on the water level and system pressure, this device either bleeds air from the tank or allows air to enter it.

TANK FLOAT: A second device prevents tank air from being absorbed by the water simply by separating the two. This device is a circular float which rides on the water in the tank. Some designs have a special edge which "wipes" the tank walls, thereby improving the seal. Even with such designs, some air is dissolved over a period of time. Hence, tanks equipped with floats must be recharged every few years.

DIAPHRAGM TANKS: A third approach involves tanks equipped with a flexible diaphragm which is permanently sealed to the tank. As the water level rises and falls in the tank, the air chamber—separated by the diaphragm—contracts and expands accordingly.

Pressure Switch: Water systems are normally designed so that the pump starts when the pressure falls to a given level, usually 20 or 30 psi. Then the pump is allowed to run until the pressure increases a given increment, generally 20 psi. The device that controls this on-off action of the pump is a pressure switch. A switch that starts the pump at 20 psi pressure and cuts it off at 40 psi is said to have a "20-40 setting." Other common settings are 30-50 and 40-60.

Pressure Gage: It is often desirable to use a gage to determine the pressure at which the pump is operating. With jet pumps the pressure gage is commonly mounted on the unit itself. With submersibles it is located somewhere in the surface piping system.

Relief Valve: Many pumps are capable of delivering surges of extremely high pressure. To protect the system from such surges, relief valves are often installed in the piping. These valves open when a predetermined pressure is reached.

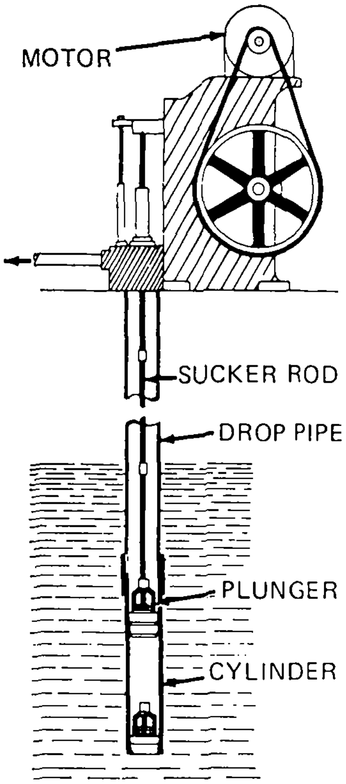
Liquid Level Control: If a submersible were to pump a well down to the level where little or no water was entering the pump, severe motor damage could result. To prevent this, a liquid level control may be installed in the system. Such a device senses the low water level in the well and shuts off the pump.

Foot Valve: For a jet pump to retain its prime, water must remain in the drop pipe after the pump shuts off. This is true whether the ejector is in the well (deep-well jets) or mounted on the pump (shallow-well units). Water is held in the pipe by a foot valve, which is nothing more than a check valve mounted at the end of a drop pipe, or on the ejector, in the case of deep-well jets.

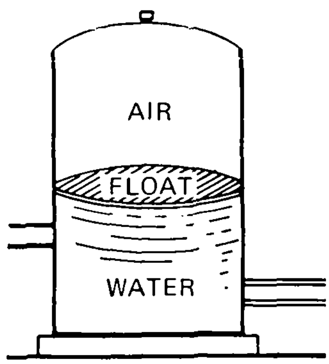
Well Seal: To keep out dirt and contamination, a well seal is often used where the casing emerges from the ground. This device consists of two steel plates on either side of a soft rubber disk. As the plates are drawn together, the rubber expands, forming a waterproof seal between the casing and the drop pipe(s).

Pitless Adapter: Another device for sealing off the well is the pitless adapter. With this, the well casing extends above ground, but the piping connection to the drop pipe is below grade. Such a layout provides an extremely sanitary means of connecting the well piping to the surface piping.

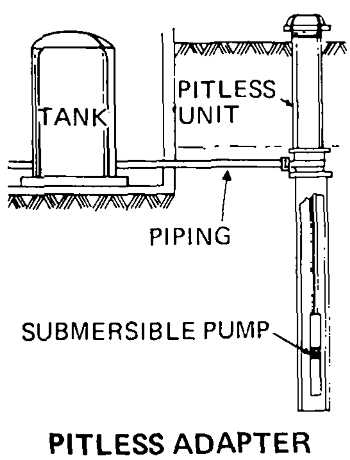
Lightning Arrester: If lightning strikes a pump or the piping connected directly to it, the pump will probably be ruined beyond repair. However, lesser damage can be caused during electrical storms by what is known as "induced" surges of high voltage. This can be caused either by nearby lightning bolts or merely the high voltage conditions that may prevail during thunderstorms. Such surges can damage the pump motor windings severely. Lightning arresters provide protection from this hazard. Wired across the pump power line, the lightning arrester is an efficient conductor of electricity at normal voltages. However, when a surge of high voltage current passes through it, the arrester becomes a nonconductor. Thereby, it prevents the surge from reaching the pump windings. ■ ■



WORKING HEAD PUMP



AIR FLOAT TANK



PITLESS ADAPTER

Chapter 14 – Water system sizing and selection

by Edwin A. Scott, Jr.
President, Scott Periodicals Corp.

"PLENTY OF WATER, plenty of pressure" is the time-honored definition of an adequate private water system. But this summary can be refined further and translated into specific quantities. Doing so requires familiarity with the basic criteria by which water systems performance is measured. Among these, the most important considerations include the following:

TOTAL DEMAND: This is the sum of the water requirements of all users of the system, generally expressed as gallons per day (gpd). For residential jobs it is usually based on the number of occupants of the home. Total demand of farm systems is often geared to the amount and kind of livestock. In the case of nonfarm, nonresidential installations, many different means are used for arriving at total demand.

PEAK DEMAND: Rarely, if ever, is the total demand of a private water system spread equally over the day. In homes, for example, there are periods of peak demand — each lasting about an hour — in the morning and again in the evening. Restaurants, farms, motels and most other water users likewise have periods of peak demand.

SYSTEM CAPACITY: In order to function properly, the system must be able to meet the peak demand over the entire period during which it may be experienced. Thus, the peak demand for a household lasts about an hour. If that demand is 30 gpm for a full hour, this means first that the pump must be capable of pumping at that rate. It also means that the well must be able to produce 30 gpm for a full hour, or that the storage tank has sufficient capacity to make up for any shortfall in well production.

In designing systems it is important to determine the period over which peak demand will last. In schools, for example, it exists only during the recess or lunch period, say 15 minutes to half an hour. In hotels and motels, where the activities of guests are not as precisely regulated, morning and evening peak demand periods generally run two hours, on the average.

PRESSURE REQUIREMENTS: The basic purpose of the pump is to provide the energy to lift water from the well, push it through the piping system and deliver it to outlets at an adequate pressure. But what constitutes "adequate" pressure is sometimes arguable. In the majority of existing systems, the pumps are set to start when pressure in the storage tank falls to 20 pounds per square inch (psi) and shut off when it rises to 40 psi. This so-called 20-40 setting may be ample if the piping is large enough, of short length and free of scale. However, the governing factor is the pressure *at the outlet,* not at the pump. Therefore, with undersized or scaled piping, or long piping runs, a 20-40 setting may be unsatisfactory.

In any event, appliances are usually the governing factor in determining outlet pressure needs. Dishwashers and washing machines will not operate without at least 10 psi at the inlet. Lawn sprinklers need at least 20 psi, often more. And it must be remembered that when a water conditioner is on the line, a significant pressure drop—sometimes as much as 20 psi—can occur.

According to The Water Systems Council, a several feet submergence below the pumping level. This allows for a possible fall in the water table. However, the pump or foot valve should never be located at the very bottom of the well. To do so would risk fouling the pump with sediment or binding it with sand.

ELEVATION: This characteristic is the opposite of submergence. It is the distance between the ground level at the wellhead and the ground level where the pump is located. If the pump is installed in the well, or immediately at the wellhead, there is no elevation.

SPECIFIC CAPACITY: When drawdown level is reached, equilibrium exists between the amount of water flowing into the well and the amount being pumped out. At this point the pump should not be delivering more water than the well can produce. The numbers of gallons of water produced per minute at this point of equilibrium is known as the *specific capacity* of the well. An important criterion in system sizing.

Water needs

Assume now, that the well had adeqate capacity to meet reasonable water needs. Pump selection then depends on two basic criteria: (a) the water needs of the customer, expressed in terms of both total demand and peak demand; and (b) the pressure requirements of the system. These criteria cannot be considered separately in sizing a pump. They must be taken together. Following is the procedure for determining water needs in various applications.

Residential Installations: In sizing water systems for homes, total demand is not normally the governing criterion. Studies of domestic water usage put the average daily requirements of a household at 50-75 gpd per person, with houses in the luxury class using perhaps as much as 100-150 gpd. Even at this higher figure, daily consumption for a family of five would come to only 750 gpd. Translated into average flow rate, this comes to about half a gallon per minute, which almost any well can produce and any pump deliver.

Rather than total demand, *peak demand* is what counts in residential jobs. A simple but accurate method for determining normal peak demand is to count all of the water outlets or fixtures in the house and allow 1 gpm for each outlet. Thus, in a modest vacation home there would be a bathroom with water closet, tub or shower and lavatory (3 outlets), a kitchen sink (1 outlet) and possibly an outdoor hose bib (1 outlet). Using the formula of 1 gpm per outlet, safe method of determining the best pressure setting is to go by the fixture or outlet of greatest elevation and farthest from the pump. When water flows through this fixture at full capacity, the pressure should be at least 10 psi on the *inlet* side of the unit. If this is the case, there is almost a 100 percent chance that pressure will be adequate throughout the system.

The well

Obviously, to meet the various capacity requirements discussed above, the well must be adequate. This is basically the driller's job. But the pump installer must be at least conversant with the usual measures of well performance so he can discuss them intelligently with the customer and/or driller. In this connection, the pump installer should secure a *well log* whenever possible. This is a written "profile" of the well, detailing its depth, rate of production, type of casting, etc. The most common well characteristics include the following:

DIAMETER: It might seem obvious that a 4-in. submersible pump can't fit in a 3-in. well. Yet occasionally an installer will order a new submersible from his wholesaler without checking the well diameter. It's also a good idea to check well *straightness* or plumbness if a submersible is being installed to replace a jet. A well that's adequate in size but crooked may not permit installation of a submersible.

DEPTH TO WATER: Also known as the "standing water level" or "static water level", this is the number of feet from the surface to the water level when no water is being withdrawn and the well has reached equilibrium. In other words this is the *highest* level water reaches in the well, and of course the pump or drop pipe must be set considerably below it.

PUMPING LEVEL: Once the pump starts, the water level tends to fall because, presumably, the pump is removing water faster than it can flow into the well. However, a steady-state point is eventually reached at which water flows into the well at the same rate at which it is being pumped out. The water level at this point is known as the pumping level.

DRAWDOWN: The difference between the depth to water or static water level and the pumping level is known as drawdown. This is not to be confused with "submergence," which is the depth below the pumping level (at full drawdown) where the pump or foot valve is located. As a practical matter, there should always be this system would need pump capacity of 5 gpm. For a larger home with 2½ baths (8 outlets), kitchen sink and dishwasher (2 outlets), washing machine and laundry tub (2 outlets) and two outdoor bibs, 14 gpm would be required.

The accompanying table on page 36 shows the average rate of flow for various household fixtures. It's evident that unless all or most fixtures are used simultaneously — which is improbable — the "outlet count" method of sizing works.

Farms: Sizing water systems for farms — especially where livestock is involved — presents a different problem. In this case both total demand and peak demand must be figured. The table at right shows total demand requirements for various types of livestock. The system should be sized to accommodate this demand within two hours (120 minutes). To the gpm thus arrived at must be added the needs of the farm household, plus all water outlets in the farm building.

To illustrate: Take a dairy farm with 70 milking cows, 30 dry cows and a flock of 500 chickens. From the table at right, total demand for livestock would be 35 x 70 gpd (milking cows) plus 30 x 15 gpd (dry cows) plus 5 x 6 gpd (chickens) or 2,930 gpd. Since the system must be sized to deliver this demand in two hours, required capacity is 2,930 ÷ 120 = 24.4 gpm. Assume also that there are 12 outlets in the farm-house and an additional four in the milk house. Then the total capacity would be:

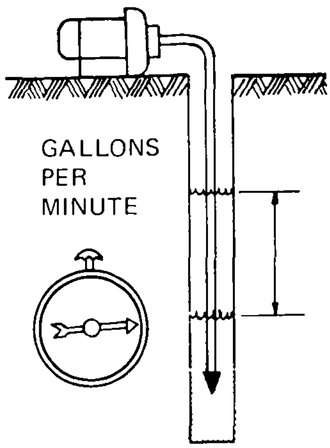
Livestock	*24.4 gpm*
Farmhouse	*12.0*
Milk House	*4.0*
Total capacity	*40.0 gpm*

The pump would have to be sized to deliver this flow rate.

Commercial Establishments: There are no hard and fast rules for sizing commercial jobs because requirements vary so widely. The best procedure is to determine total daily requirements and then estimate the approximate time span over which this demand must be met. The table on page 36 (lower) shows average daily water needs for numerous nonresidential applications. Schools, as we have seen, must meet this demand in half an hour or less. Motels, on the other hand, can extend it over a two-hour period. In the absence of any specific information, it is best to size nonresidential jobs by dividing total daily demand by two hours or 120 minutes.

Pressure

It is erroneous to think of a pump as having a



SPECIFIC CAPACITY

DAILY WATER NEEDS
of livestock (GPD)

MILK COW	35
DRY COW	15
STEER	12
MULE	12
HORSE	12
HOG	4
SHEEP	2
CHICKENS/100	6
TURKEYS/100	12

SIZING FARM SYSTEMS

LIVESTOCK REQUIREMENTS
120 MINUTES

+

FARMHOUSE OUTLETS

+

FARM BUILDING OUTLETS

=

FLOW RATE NEEDED (GPM)

SIZING COMMERCIAL SYSTEMS

DAILY REQUIREMENTS

PEAK DEMAND PERIOD

FLOW RATE NEEDED (GPM)

USAGE CHARACTERISTICS OF PLUMBING FIXTURES

	FLOW RATE (GPM)	INLET PRESSURE (PSI)	GALLONS PER USAGE
WATER CLOSET—TANK TYPE	4	8	4-7
WATER CLOSET—FLUSHOMETER	15-40	15	3-7
BATHTUB	5	8	35
SHOWER	5	8	25-60
LAVATORY	4	8	1-2
KITCHEN SINK	5	8	2-4
LAUNDRY TUB	7	8	6-8
AUTOMATIC WASHER	5	10	40-50
DISHWASHER	2	10	10-20
WATER SOFTENER BACKWASH	7	20	100-150
GARDEN HOSE—1/2-IN.	3	15	—
GARDEN HOSE—1/3-IN.	6	20	—
LAWN SPRINKLER	3-7	20	—
FIRE HOSE—1 1/2-IN.	40	30	—

DAILY WATER USAGE OF COMMERCIAL ESTABLISHMENTS (GPD)

AIRPORTS (per passenger)	3-5
BATH HOUSES (per bather)	10
CAMPS (trailer, tourist, etc., per camper)	50
FACTORIES (for personal use only, per employee)	15-35
HOTELS & MOTELS (per guest)	60
HOSPITALS (per bed)	250-400
LAUNDRIES, COIN-OPERATED (per cycle)	50
RESTAURANTS (per patron)	10
SERVICE STATIONS (per customer)	10
STORES (per public toilet room)	400
SWIMMING POOLS (per swimmer)	10
THEATERS (per seat)	5

single capacity expressed in gpm. The pump has, rather, a range of capacities determined by the pressure or "head" required in the system. Capacity (or delivery) varies inversely with the head, and both must be taken into consideration when sizing a pump.

In water systems work, pressure is expressed either in terms of pounds per square inch (psi) or feet of water. Either term may be used, so long as it's used consistently. For conversion purposes, 1 psi equals 2.31 ft of water.

Pumps are normally selected in terms of pressure and capacity directly from the manufacturer's catalog. Among various terms used in selection tables, the following are most common:

DISCHARGE PRESSURE: This is the pressure of the water as it leaves the pump or well. In the case of jets, it is the pressure on the discharge side of the pump. In the case of subs, it is the pressure at the wellhead.

TANK PRESSURE: Some catalogs also specify pump capacity in terms of tank pressure or pressure switch setting range. In most cases the "tank pressure" refers to the higher end of the pressure switch setting. However this should be checked out in the individual catalog being used.

TOTAL HEAD: The more elaborate catalogs show performance curves for various pumps. These are plots of pump output (in gpm) vs. "total head," usually expressed in feet of water. The total head represents the sum of all pressure requirements on the system, including the following:

Suction lift, the pressure necessary to get water from the pumping level to the surface.

Elevation, the pressure (if any) needed to get water from the surface to the pump level.

Friction loss, the pressure needed to push water through the piping, valves, fittings, etc. It's possible to calculate the friction loss through a given piping network for any rate of flow. However, the simplest procedure is to take friction loss downstream from the tank into consideration when determining pressure switch settings.

Service pressure, the component of pressure required to operate the water-using outlet. As indicated earlier this ranges from 10 psi for most fixtures to 20 psi or more for lawn sprinklers.

It is not always necessary to compute total head in order to size a pump. Most catalogs are set up to show pump capacity at various depths and discharge or tank pressures. The usual procedure is to read down to the necessary depth, then across to the desired capacity at the discharge or tank pressure needed for adequate system performance.

PEAK DEMAND PERIOD IN NONRESIDENTIAL SYSTEMS (MIN.)

HOSPITAL	60
HOTEL	120
MOTEL	120
OFFICE BUILDING	60
RESTAURANT	120
SCHOOL	15-30
STORE	120
THEATER	15

Pump selection

The procedures outlined above enable the installer to select a pump according to the performance characteristics needed. It then remains to ascertain the *kind* of unit best suited to a given installation. Arriving at this decision involves consideration of many factors: cost, performance, noise, well depth and other advantages and disadvantages which may make one type of pump preferable to the other.

The accompanying table outlines some of the more important features of the major types of pump. In addition to these, the following factors should be considered:

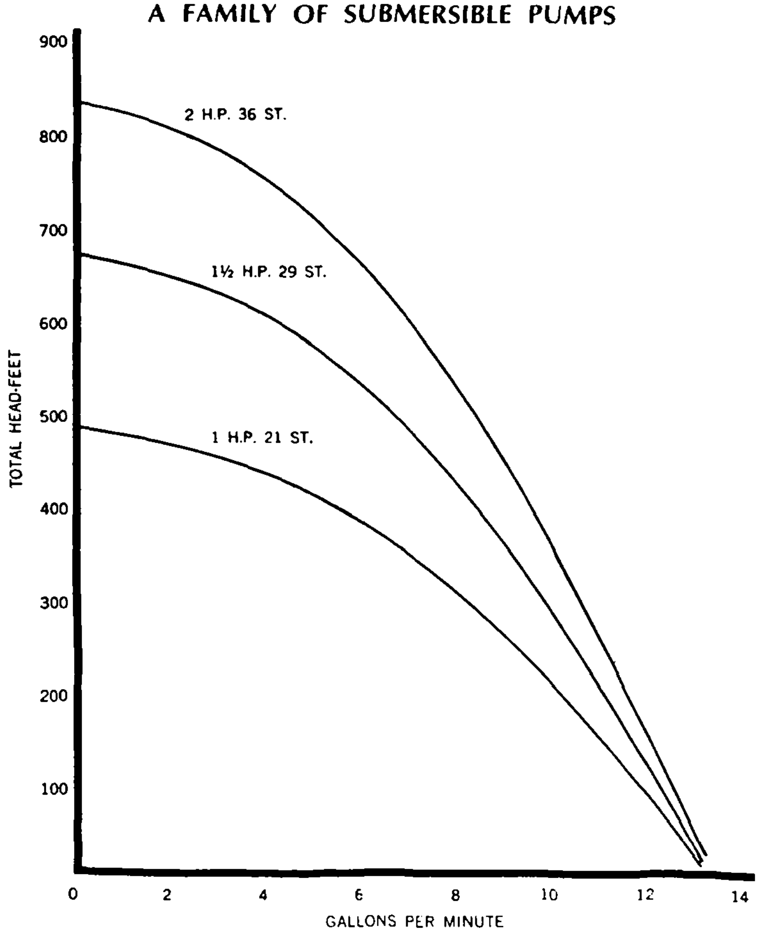
- How much reserve capacity does the unit have in case peak demand increases?
- How much labor is involved (a) in installing the pump; and (b) in servicing it after installation?
- If over an extended drought, the standing water level drops sharply, will the unit have capacity to pump from greater depths.

Wiring

When installing jet and submersible pumps one step common to both units is electrical wiring. Whether or not an electrician is involved, it is the responsibility of the pump installer to see that the job is done properly. Otherwise, trouble with the unit may develop and, in many cases, the manufacturer's warranty may be voided.

Controls and Overload Protection: The basic pump controls, i.e., start switch and capacitors, are normally packaged either in the pump or in the control box. The installer doesn't have to worry about their being included in the wiring job. However, he does have to make sure that overload protection is provided. This can take the form of either fuses or circuit breakers. In either case, the manufacturer's recommendations as to maximum amperage of the overload device must be followed.

TYPICAL PERFORMANCE CURVES FOR A FAMILY OF SUBMERSIBLE PUMPS



Wire Sizing: It is vitally important that the electrical wire from the control box to the pump be of adequate size. Undersized wire will result in an inadequate flow of current to the pump, just as undersized piping restricts water flow. Not only will the pump malfunction, but in the majority of cases the manufacturer's warranty is void if improper wiring practices are followed.

Electrical wire is described by American Wire Gauge number — the smaller the number the larger the wire. The size wire needed depends on the power requirements of the pump and the length of the wire run. The table below shows the maximum length of run for power lines of various gauge.

Lightning Protection: As noted earlier lightning can do severe damage to water systems, even when there is no direct hit. Much of this damage can be prevented by using a lightning arrester. Some pump and motor manufacturers supply control boxes with the lightning arrester already wired in place. But if the installation is being made where there is even a fair incidence of electrical storms, an arrester should be added if it is not included with the basic pump package. ■■

MAXIMUM WIRE LENGTH (FT) BY SIZE OF MOTOR

PHASE & VOLTAGE	MOTOR H.P.	WIRE SIZE (A.W.G.)						
		#14	#12	#10	#8	#6	#4	
THREE Ø 115 VOLT	1/4	115	175	280	—	—	—	-
	1/3	110	165	260	—	—	—	-
	1/2	80	130	195	310	—	—	-
THREE Ø 230 VOLT	1/4	450	705	—	—	—	—	-
	1/3	410	665	—	—	—	—	-
	1/2	315	490	775	1230	—	—	-
	3/4	190	300	475	760	1205	—	-
	1	165	260	415	660	1050	—	-
	1-1/2	130	200	315	500	800	1270	-
	2	95	150	240	380	600	960	-
	3	—	100	155	245	395	625	9
	5	—	—	125	195	315	500	7
SINGLE Ø 220 VOLT	1-1/2	695	1100	1750	—	—	—	-
	2	480	760	1210	1930	—	—	-
	3	350	550	875	1385	2220	—	-
	5	225	355	565	900	1430	2280	-
SINGLE Ø 440 VOLT	5	900	1420	2260	—	—	—	-

PUMP SELECTION GUIDE

	SHALLOW-WELL JET	DEEP-WELL JET	SUBMERSIBLE
MAXIMUM PRACTICAL DEPTH	25 ft.	200 ft.	500-1,000 ft.
PRESSURE CAPABILITY	Moderate	Single-stage: moderate Multi-stage: high	High
CAPACITY	Moderate to high	Moderate to high	High
NOISE CHARACTERISTICS	Moderate	Moderate	Little or none
ADVANTAGES	1. High capacity at low head. 2. Simplicity of operation. 3. Easy to service. 4. Low cost. 5. No moving parts in well. 6. Can be remote from well. 7. Some sand tolerance.	1. High capacity at low head. 2. Simplicity of operation. 3. Easy to service. 4. Low cost. 5. No moving parts in well. 6. Can be remote from well. 7. Some sand tolerance.	1. High capacity at high head. 2. Good pressure performance. 3. Frostproof installation easy. 4. No pumphouse needed. 5. Quiet operation. 6. Almost unlimited in depth. 7. Cannot be airbound.
DISADVANTAGES	1. Capacity decreases with depth. 2. Can become airbound. 3. Limited depth (25 ft.).	1. Capacity decreases with depth. 2. Can become airbound. 3. Moderate depth limitations.	1. No sand tolerance. 2. Service may require pulling pump. 3. Hoist needed to install.

Chapter 15—Records and Reports

by Richard Berkholtz, president
Berkholtz Drilling Co., Inc.
Brookfield, Wisc.

RECORDS — REPORTS — FILES — INVOICES, these are the words that can easily bring curses to the lips of any well drilling contractor. However, if we are going to be realistic, we must face the bitter facts of life — certain things must be written down, and it then follows, if they are going to be of any value to us, we must be able to find them again. Happy is the man who keeps his records simple (but accurate) and easy to find.

This chapter makes no effort to deal with the economics of water well construction. It hopes only to point out the minimum records that should be used and retained with the goal of making our future easier and more profitable.

Well Logs

A study of history will help blueprint the future. By developing a usable history of our work, estimating future jobs becomes easier, and many expensive pitfalls can be avoided. Job location, customer, sizes of drillhole, grout or seal, geological formations encountered, pumping data, dates, material costs, time consumed and any unusual conditions should be recorded. One suggested format for use by the driller is shown in Illustration #1. Drilling conditions, state requirements or personal preference may move you to enlarge upon some sections. Many municipalities (state or county) require some form of report from the driller. Adoption of their form will save time and expense and probably give the driller all the information he will require. If not, collect samples of well logs and develop a form to suit your needs. Our illustration can have the location information filled in before giving to the driller with his work instructions. The balance is easily filled in as the job progresses, and is then turned back when the job is completed. A thumb nail sketch of this report is put on a location record index which is described later.

Contracts

A signed contract with your customer is a safeguard against future misunderstandings. The original quotation can be converted to a contract by simply having a provision for the customer to accept your proposal. If a forced collection becomes necessary, the procedures you must follow are usually spelled out by law, so printing pages of fine print into the contract does little more than confuse everyone concerned. A few words of caution here however. Payment terms should be included. Know the laws of your state regarding mechanic liens, if any, and the collection of accounts. Be sure the person ordering the drilling has the authority to speak for the owner regarding that particular piece of property; for instance, a renter may order a well the owner may not want and will have to be persuaded to pay for.

Work Order Register

Assign each contract a number. The register from which this number is taken should contain at a minimum: work order number, name, loca-

WELL CONSTRUCTOR'S REPORT

1. COUNTY	CHECK ONE	NAME	
Washington	☐ Town ☒ Village ☐ City	Germantown	W.O.8090

2. LOCATION (Number and Street or ¼ section, section, township and range. Also give subdivision name, lot and block numbers when available.)
W210 N13646 Woodside Lane - NE¼ Sec 7, T 9N R 20E

3. OWNER AT TIME OF DRILLING
Jeffery Construction Corporation

4. OWNER'S COMPLETE MAIL ADDRESS
2274 North Calhoun Road, Brookfield, Wis. 53005

5. Distance in feet from well to nearest: (Record answer in appropriate block)

BUILDING	SANITARY SEWER C. I.	SANITARY SEWER TILE	FLOOR DRAIN C. I.	FLOOR DRAIN TILE	FOUNDATION DRAIN SEWER CONNECTED	FOUNDATION DRAIN INDEPENDENT	WASTE WATER DRAIN C. I.	WASTE WATER DRAIN TILE
15	-	-	-	20	-	-	-	-

CLEAR WATER DRAIN C. I.	CLEAR WATER DRAIN TILE	SEPTIC TANK	PRIVY	SEEPAGE PIT	ABSORPTION FIELD	BARN	SILO	ABANDONED WELL	SINK HOLE
-	-	not in	-	not in	-	-	-	-	-

OTHER POLLUTION SOURCES (Give description such as dump, quarry, drainage well, stream, pond, lake, etc.)
- above indicates none

6. Well is intended to supply water for:
home

7. DRILLHOLE

Dia. (in.)	From (ft.)	To (ft.)	Dia. (in.)	From (ft.)	To (ft.)
7-7/8	Surface	83			
6	83	188			

8. CASING, LINER, CURBING, AND SCREEN

Dia. (in.)	Kind and Weight	From (ft.)	To (ft.)
6	New Std. Black Steel	Surface	
	P.E. 18.97#		83

9. GROUT OR OTHER SEALING MATERIAL

Kind	From (ft.)	To (ft.)

10. FORMATIONS

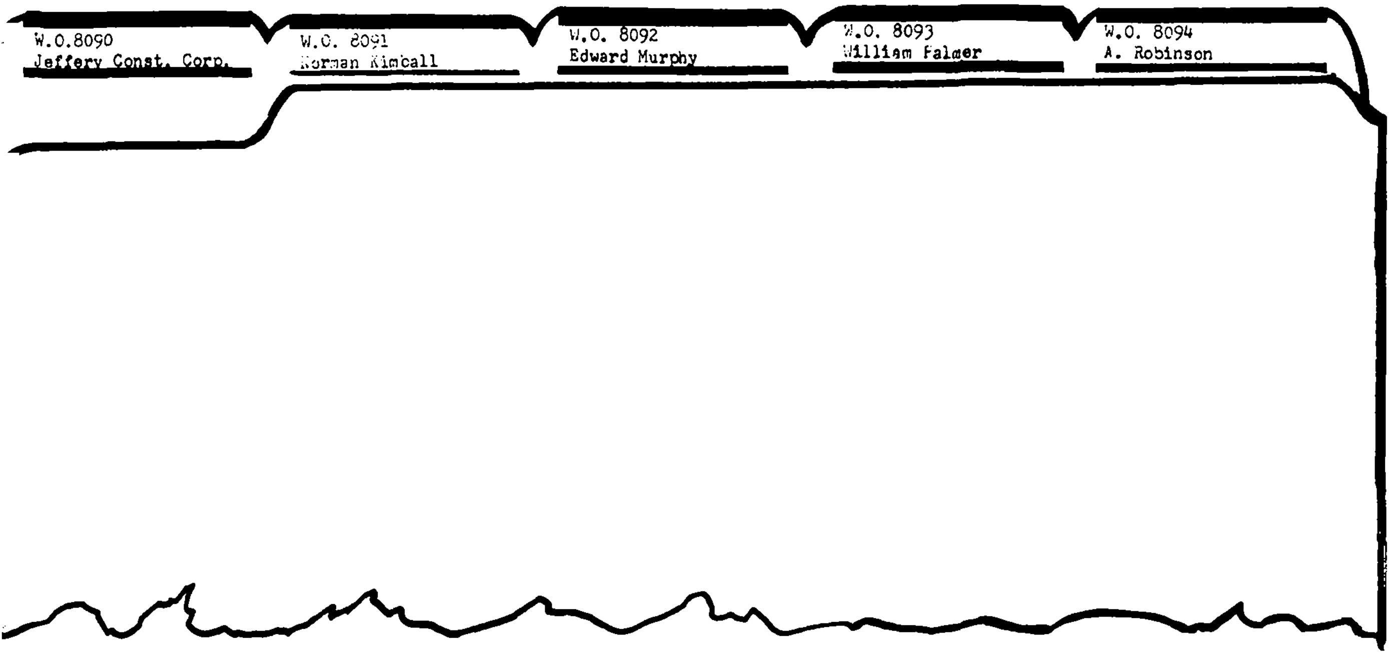
Kind	From (ft.)	To (ft.)
stony red clay	Surface	16
blue stony clay	16	58
shelfrock & gumbo	58	82
limerock	82	188

Illus. 1

WORK ORDER REGISTER - 1968

W.O. NUMBER	CUSTOMER NAME	ADDRESS	DRILLER	BILLED	STARTED	COMPLETED
8090	Jeffery Const. Corp.	German Town.	J	✓	7-7-68	7-9-68
8091	Norman Kimball	1800 Canon Dr.	B	✓	7-2-68	
8092	Edward Murphy.	Sun Prairie				7-3-68
8093	William Palmer	Excelsior, Sauk Cty.	B		7-4-68	
8094	A. Robinson	N70 W4745 Tansdale.				
8095	David Weiss	12278 Luther	A	✓	7-2-68	7-4-68
8096						
8097						
8098						
8099						
8100						
8101						
8102						
8103						
8104						
8105						
8106						

Illus. 2



Illus. 3

tion, date drilled. It can also have space for driller identification, and the date on which the job was begun. This register also tells you at a glance the number of open or uncompleted jobs you have, plus it is a check point to be sure they have been billed. See illustration #2.

Work Order File

Every job should have its own file folder into which is put all information having any bearing on that job. Number and label a folder for each contract. See illustration #3. Keep contract, well constructor's log, well permits and all other paper work regarding this well in this folder. The only exception is the unpaid invoice. While the billing computations can be made directly on the original quotation or contract, the unpaid invoice will not arrive in this folder until it becomes paid in full. However, paid invoices should be filed here only if your accountant approves this practice. In any event, there should be a notation on the work order indicating that billing is completed, and the date payment is made. A driller, just starting out, may find it convenient to file according to customer name. However, it is suggested that numbered folders be used with an accompanying alphabetical index. After a sizable number of wells have been drilled (and the file drawers are full) you need only remove to inactive storage the early numbers in order to update your files. Be sure both number and name are entered on original file tab.

Arranging the file by number will put wells into chronological order, so that old records can be transferred and new records kept in the most accessible drawer.

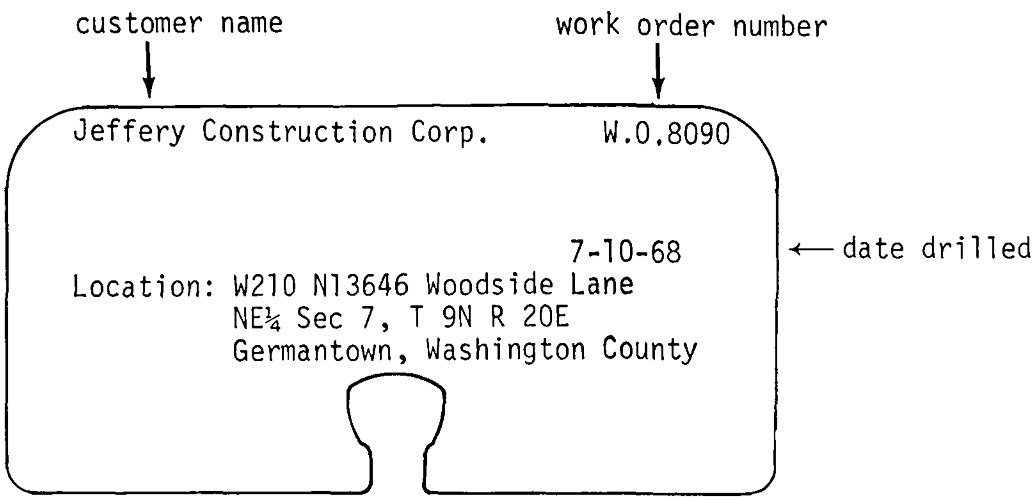
Customer Index

Normally you will be directed to the work order file by one of two means. You have taken the work order number from the location file (description below) or you have the customer's name. The customer index is kept on a small card and filed alphabetically. A 3″ x 5″ index card file is the least expensive and serves very well. Investigate equipment sold under trade names: Kardex, Wheeldex and others. See illustration #4.

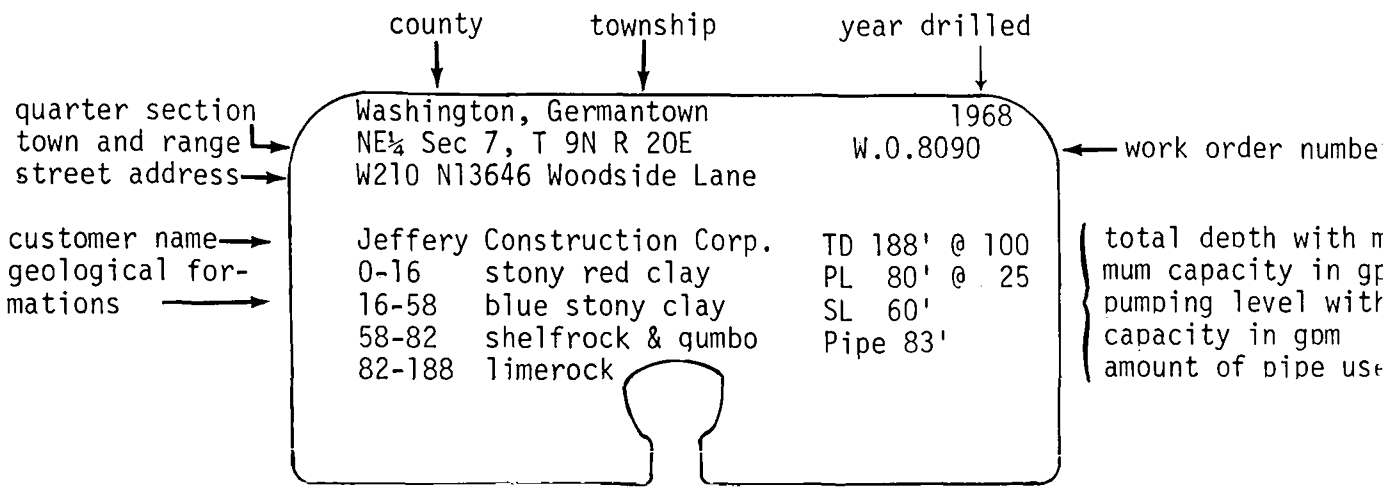
Location Record

The most valuable aid to a successful driller is his own experience. After thousands (or hundreds) of wells have crossed your desk, your brain is not an efficient index to the various areas in which you have worked. A record of the geological formations by quarter section number can be of inestimable help for quoting and drilling. Many states require this information on your reports to them. Required or not, include it on all well construction logs.

The Location Record should cover 1) county name; 2) township name; 3) section, quarter



Illus. 4



Illus. 5

section, township and range numbers; 4) year and work order number as cross reference to files; 5) customer name; 6) geological formations; 7) total depth, pumping level, static level and pipe used. See illustration #5. File by county, township and section.

Map File

Speaking of section numbers, start a map file. Good maps useful to the driller are not easy to find. Label them and keep them organized by county. The maps, together with plat books where available, are necessary to operate the foregoing Location File. A hinged wall mounted index is ideal for quick access and easy viewing.

Property Records

Each and every piece of equipment should have its own file folder. As you acquire each piece of equipment of value, label a folder to house all information regarding that item. The original invoice is a good starting item to the file, for it is useful when depreciating or selling. Prints, maintenance reports, license information and any other facts relating to the item should end up here. If the original invoice is put here, be sure a copy or cross reference goes into the Accounts Payable file. Check with your accountant on the best practice for you.

The above are your office files on property records. A shop file with a folder to hold operation instructions and catalogs on each item will save time and be handy where it is used.

Accounting Records

Consult a good accountant. Follow his advice. The money spent here will be saved many times over. Time saved when the revenue agents audit your income tax will reduce your own personal burden of seek and find.

There are many ways in which you will profit from a good record system, but experience has taught that the greatest bonus is this: The more complete your records and the more available they are to you, the easier it is to prove your point or substantiate your position. Be it customer, judge, or Uncle Sam. ■ ■