SUCKER ROD PUMPING WITH PNEUMATIC SURFACE UNITS

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INTRODUCTION

The concept of pneumatic actuation of a sucker rod string in a pumping well is not new or revolutionary. There are records of patents and applications dating back to the late 1800's. These early units did not find wide acceptance due to problems of low efficiency, seal wear and leakage. Also, these early units were restricted in depth capacity to about 4000 feet maximum in most cases.

There are surface pneumatic pumping units available today that overcome the problems of low efficiency and seal failure by using new concepts in system control and entirely new seal materials and seal technology. This paper deals with the system design and field application of the most popular of the new generation of pneumatic oilwell pumping units. Applications discussed range from dewatering 1000-ft gas wells at 3 BPD to pumping 10,000-ft oil wells at 200 BPD.

HISTORY OF PNEUMATIC ROD PUMPING

Sucker rod pumping systems were in use at least as far back as the Egyptian era, when they were used to lift water from irrigation canals. The Romans lifted water from aqueducts with rod pumps; mine dewatering has made extensive use of rod pumps for over 2000 years.

The great majority of the oil wells being artificially lifted today are being pumped by sucker rod systems. Pneumatic actuation of a sucker rod string was initiated in the late 1800's to take advantage of existing field gas pressure to provide an economical source of pumping energy.

Figure 1 shows a patent issued in 1904 covering one of these early units. Some of them were wellhead-mounted while others were suspended from the derricks left on the wells.

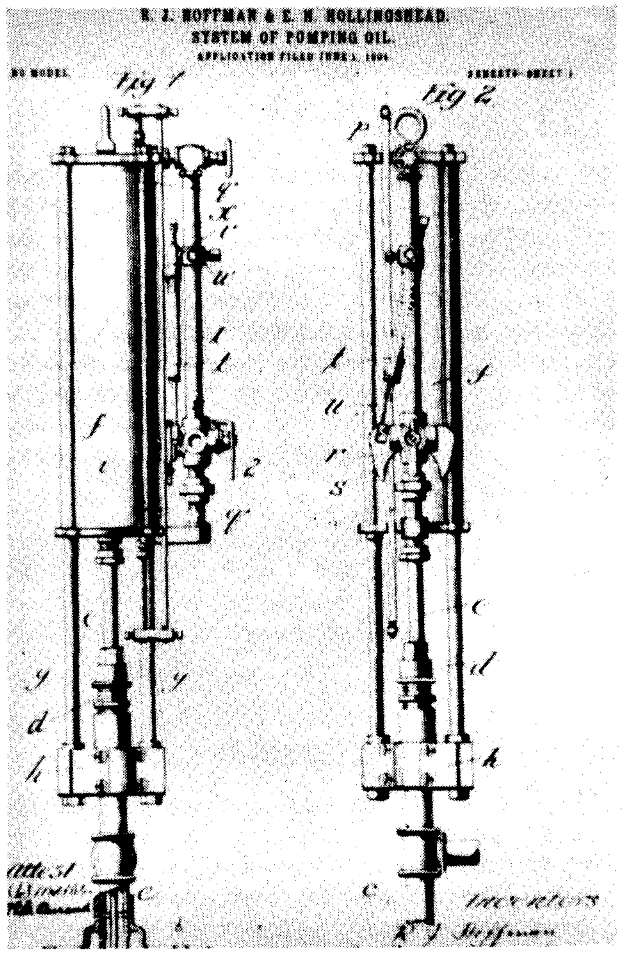


FIG. 1

Figure 2 is a typical installation of an early pneumatic unit pumping a well in 1900.

CURRENTLY AVAILABLE EQUIPMENT

Figure 3 is a typical installation of a modern pneumatic pumping unit installed on an oil well.

FIG. 2

The unit is basically a vertical pneumatic cylinder mounted rigidly to the wellhead, similar to the early units. From a distance, the pneumatic unit resembles a piece of pipe protruding above the wellhead. There is no visible evidence of motion, no beams, cranks, counterweights or foundations. All movement of the sucker rod string is imparted by air or gas pressure acting on the area of a piston inside the cylinder. There is no direct mechanical linkage between the prime mover and the sucker rod string.

All of the equipment description and application data presented in this paper pertains to the Klaeger Pneumatic Pumping Unit, which is manufactured and distributed by Mid-Continent Supply Co.

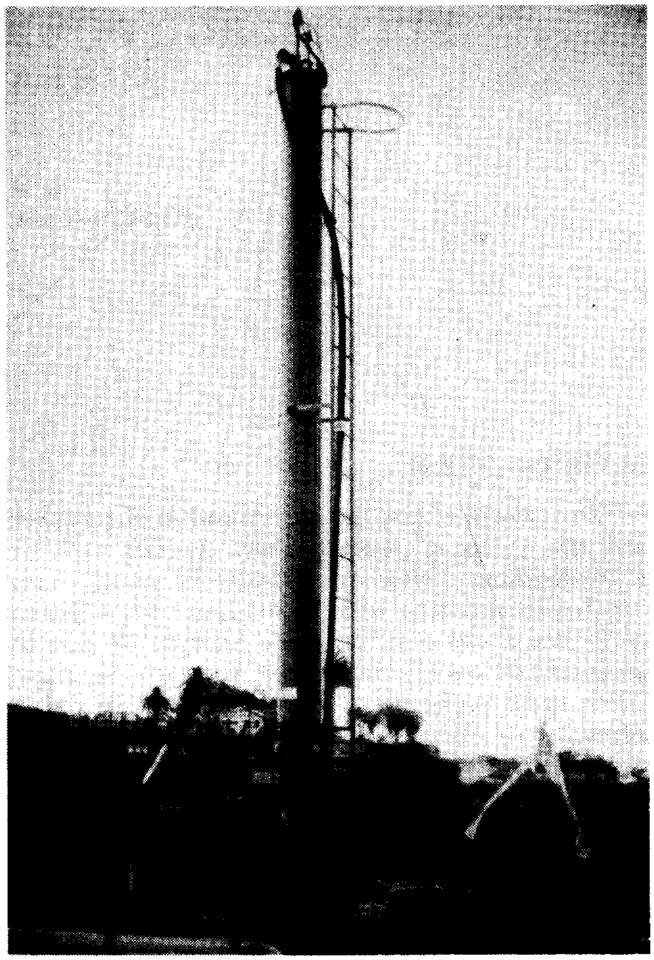


FIG. 3

BASIC PNEUMATIC THEORY

The first step in analyzing the operation of a pneumatic pumping unit is a study of the air flows and resultant forces involved in an air-actuated cylinder. The purpose of a fluid-actuated cylinder, hydraulic or pneumatic, is to convert the energy in a pressurized fluid to a linear force that can accomplish some form of useful work, such as lifting the sucker rods in a pumping oil well.

Figure 4 is a diagram of a simple pneumatic cylinder, in the vertical position as it would be mounted on a well. The basic components are the cylinder, piston, cylinder rod, and the inlet and outlet valves which control the flow of air into and out of the cylinder.

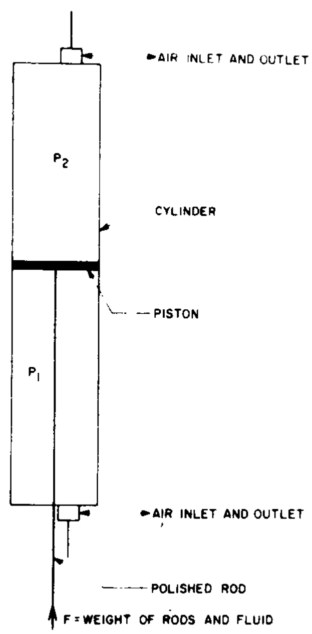


FIG. 4

The three primary parameters governing the amount of useful work available from this cylinder are: the piston area, the piston travel or stroke length, and the operating pressure level.

The piston area and stroke length are determined by the physical size of the cylinder.

The pressure level required to operate the cylinder is a function of the piston area and the load to be lifted.

$$P = F/A$$

In this case, the force to be lifted is the weight of the rods and fluid in the well, so that:

$$P_1 = \frac{\text{Rod wt.} + \text{Fluid wt.}}{\text{Piston Area}}$$

With a typical area of 100 in.^{2} and a maximum rod and fluid load of 30,000 lb, the operating pressures would be less than 300 psig. This pressure level is well within the range of readily available air-handling equipment, and within the range of many gas wells in dewatering applications which use wellhead gas as a source of pneumatic energy.

Pneumatic pumping units generally utilize a longer stroke and fewer SPM than a conventional unit in the same application. This longer, slower stroke results in lower air flow velocities which reduces losses due to pressure drop in lines, fittings, and valves to improve the overall system efficiency. In some cases, the longer slower stroke attained with a pneumatic unit may be of some advantage to bottomhole pump efficiency.

SOURCES OF OPERATING PRESSURE

Any pneumatic cylinder requires some source of pressurized gas or air for its operation. This source must have adequate volume and flow rate to enable the cylinder to operate at the rate required to meet the well's producing capacity.

In the case of a pneumatic cylinder being used to pump an oil well, there are two primary sources of energy—wellhead gas and auxiliary air compressors.

Operation on wellhead or lease gas requires a pressure level and a flow rate commensurate with the depth of the well and volume of fluid to be lifted. The use of ausiliary compressors is required lifted. The use of auxiliary compressors is required high enough to support operation. Some units have been operated from large field gathering compressors. In this mode, gas is taken from the discharge or interstage of a compressor, run through the pumping unit, and returned to the compressor suction at some lower pressure, where the gas is recompressed for sale or reuse.

Pneumatic units are also being operated with CO_2 and pipeline gas as the working fluid.

BRAKING AND REVERSING CONTROLS

Figure 5 shows a half scale model of a typical pneumatic pumping unit. The model is equipped with all of the operating components of an actual unit. The cylinder is constructed of plexiglass; this allows observation of the action of the piston and internal controls during the operating cycle.

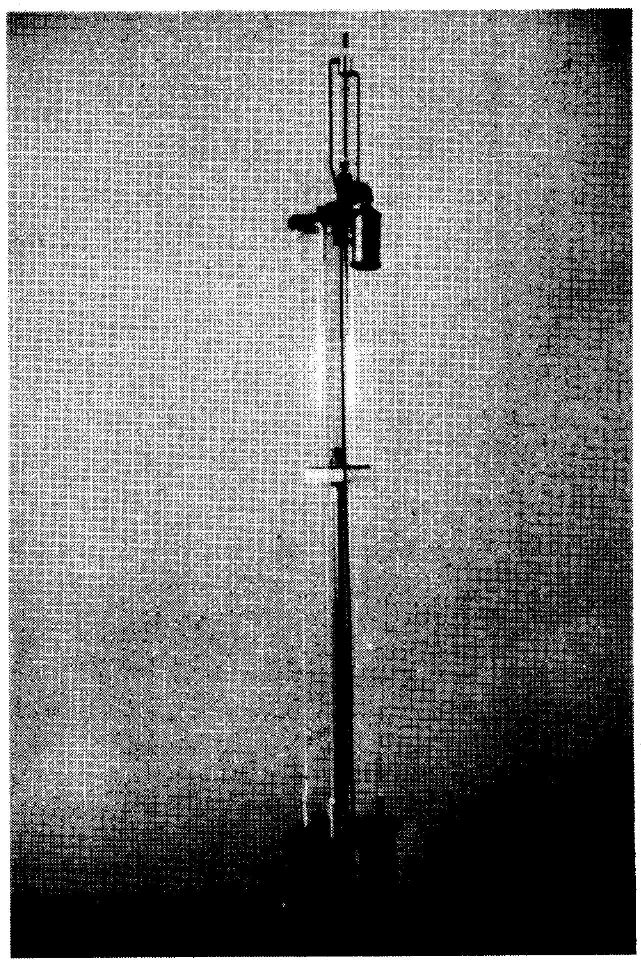


FIG. 5

The probe extending from the top of the unit is the upper control/braking probe; there is another identical probe on the lower end of the cylinder. The piston and polished rod can be seen inside the cylinder. At the lower end of the cylinder is a spool valve; this is the main air control valve used to switch the cylinder between a high pressure air reservoir for an upstroke and a low pressure air reservoir for the downstroke.

Figure 6 is an enlarged view of the lower section of the cylinder. The vertical rod next to the polished rod is the lower control/braking probe. This probe extends into the cylinder through the exhaust/inlet port. The brake disc just above the port opening is a slip fit on the probe to allow the probe to slip through the disc. When the piston hits the probe on the downstroke, the disc is pushed down to seat on the port.

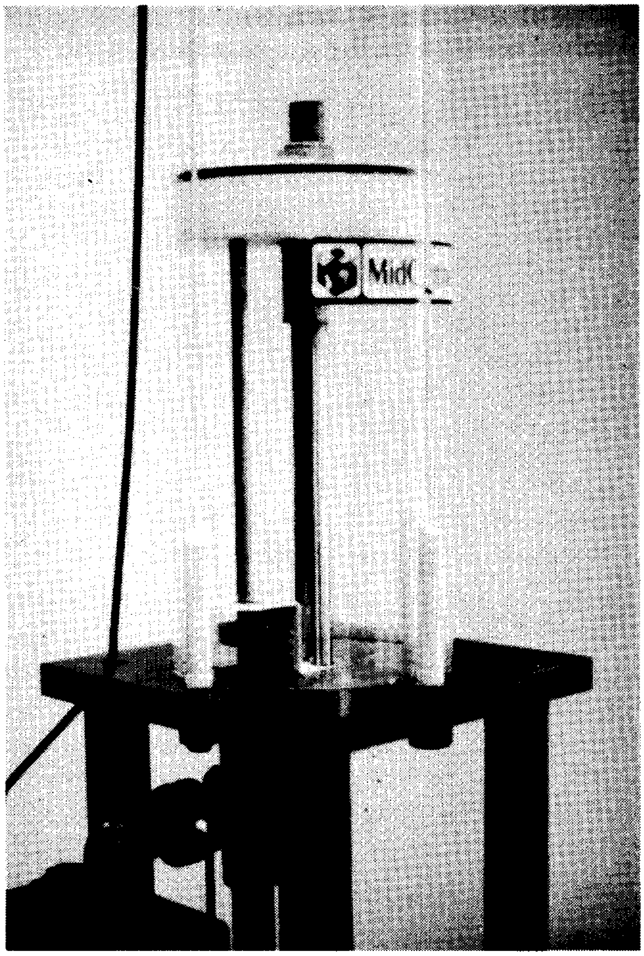


FIG. 6

Figure 7 shows the brake disc fully seated on the inlet/outlet port. The flow of air out of the cylinder is now blocked; however, the piston will continue downward, pulled by the inertia of the rod string. The brake probe is free to slip through the brake disc until the piston stops its downward movement. The piston and the sucker rod string are halted and reversed by the cushioning effect of this closed volume of air. At the same time the braking is being accomplished, the spool valve is being shifted to admit high pressure air back into the cylinder to begin the next upstroke.

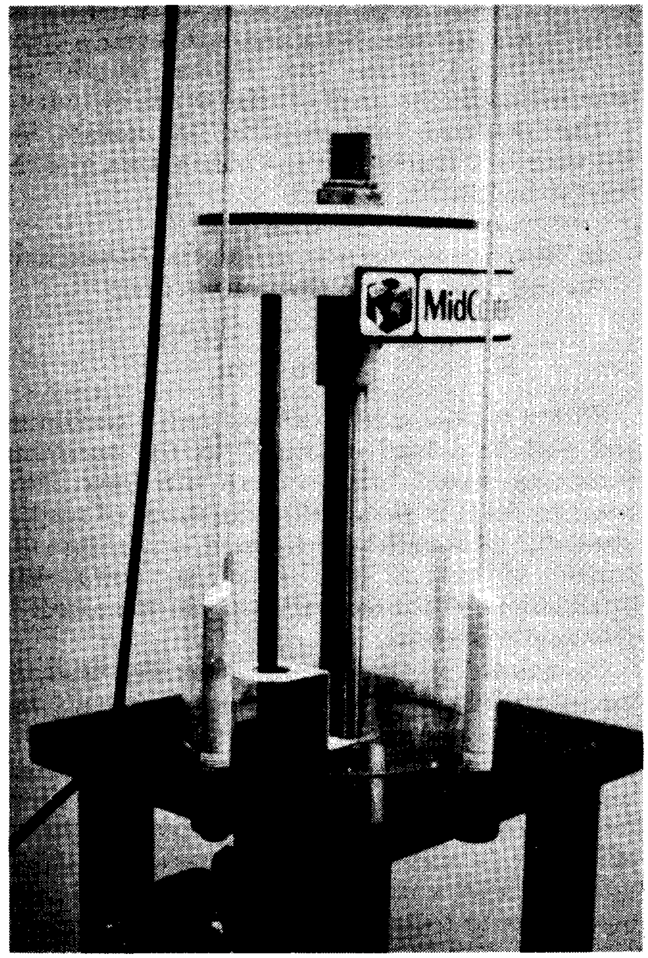


FIG. 7

Upstroke braking, reversal and control are accomplished in the same manner as on the downstroke. The upper brake probe and disc are exactly like the lower components, as shown in Fig. 8. The filter shown in Fig. 8 allows the volume above the piston in the cylinder to breathe filtered atmospheric air.

SYSTEM OPERATION USING WELLHEAD GAS PRESSURE

Figure 9 is a diagram showing a pneumatic pumping unit operating on wellhead or lease gas.

During the operating cycle, pressurized air or gas is admitted into the cylinder through the lower inlet; this pressure will force the piston to the top of the cylinder to complete an upstroke. During this upstroke, the upper part of the cylinder must be

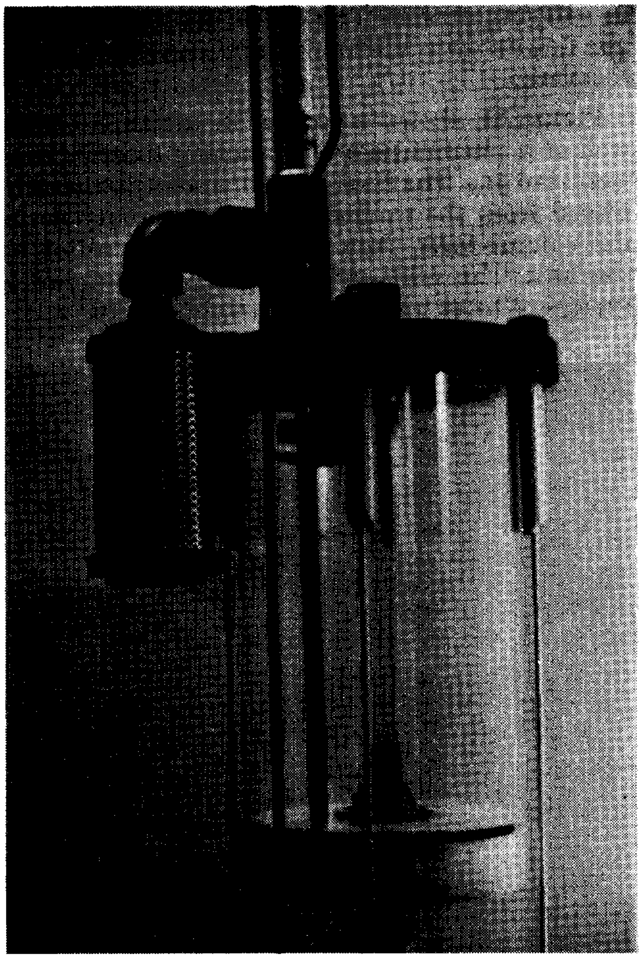


FIG. 8

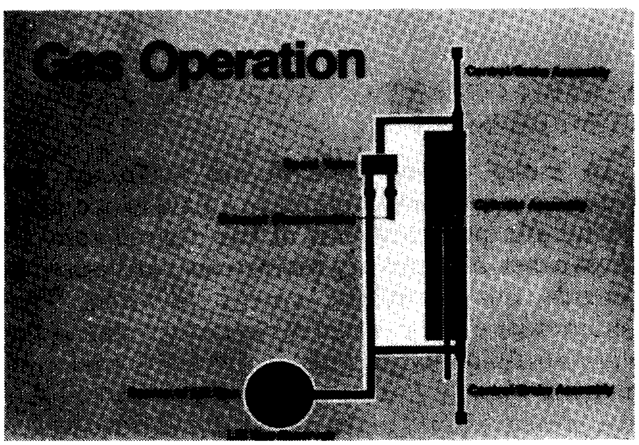


FIG. 9

vented, preferably in a manner which will allow the pressurizing medium to be recovered and reused.

The lift pressure can be expressed as

$$P_1 = \frac{\text{Rod wt.} + \text{Fluid wt.}}{\text{Piston Area}}$$

This pressure is present under the piston at the end of the upstroke.

In order to allow the rods to fall for a downstroke, the pressure beneath the piston must be reduced to slightly less than that given by the equation,

$$P_2 = \frac{\text{Rod wt.}}{\text{Piston Area}}$$

This pressure reduction can be accomplished by venting the gas under the piston in the cylinder until the pressure drops to P_2. The rods will then fall for the downstroke.

If we subtract P_2 from P_1, the difference is

$$P_3 = \frac{\text{Fluid wt.}}{\text{Piston Area}}$$

Therefore, another method of allowing a downstroke is to increase the pressure above the piston by an amount equal to the fluid weight divided by the piston area. Both methods give the same differential pressure across the piston, P_2 or the rod weight divided by the piston area.

The compressor-operated pneumatic units vent the cylinder to a lower pressure, while the wellhead-gas-operated units add pressure above the piston.

The source of lift gas shown on Fig. 9, wellhead or lease gas, feeds the lift gas reservoir through a pressure regulator. The gas is then admitted into the cylinder under the piston. Lift pressure is always present under the piston, it is never valved off. As the lift gas pushes the piston to the top of the stroke, the upper control/braking probe actuates the pneumatic control circuit to shift the spool valve to allow some of the lift gas in the reservoir into the upper part of the cylinder above the piston. This causes the pressure above the piston to increase to the level which will allow the rods to fall for the downstroke.

At the end of the downstroke, the lower control/braking probe again actuates the pneumatic control circuit to shift the spool valve to exhaust the volume above the piston. This reduces the pressure above the piston and allows the lift pressure to push the piston back up for another upstroke. The operating gas is expelled during the upstroke. This gas can be recovered at some pressure dependent on the difference between the required lift pressure and the 300 psig working pressure limitation imposed on the pneumatic cylinder.

FIG. 10

OPERATING CONTROLS—GAS OPERATED UNIT

Figure 10 shows the operating controls on a gas-operated unit. The valves are the upstroke and downstroke speed regulating valves. These valves are used to throttle the gas flow in the unit to provide a fast downstroke and slow upstroke over a wide range of speeds. The two pressure gauges indicate the pressures above and below the piston in the cylinder and give a direct indication of the loads being imposed on the unit by the rod string and fluid weight. The indicated pressures can be used for trouble-shooting by comparison with normal operating values. Pressures above or below the norm can indicate problems with the unit, the rod string or the downhole pump. The manual control button is used to interrupt the upstroke for purposes of dislodging foreign matter from the bottomhole pump.

TABLE 1

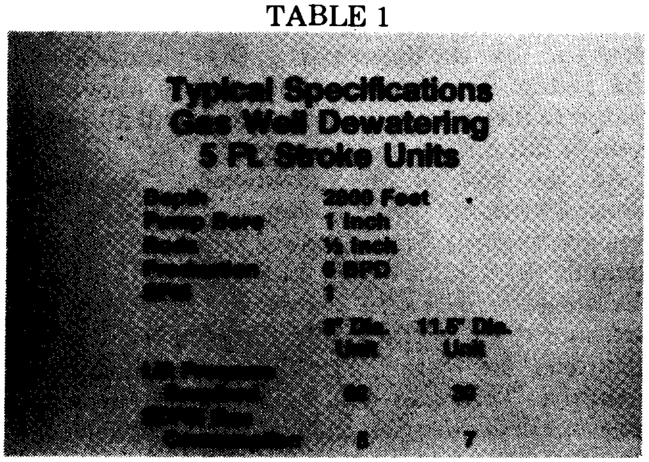


Table 1 shows the application data for a typical installation of a pneumatic unit in gas well dewatering service. The operating pressures and gas flows shown will be higher if the exhaust gas is recovered.

Figure 11 shows a typical installation on the well of a pneumatic unit operating directly from wellhead gas. The flow of the operating gas can be traced from the wellhead through a regulator to the volume tank, then to the inlet connection on the unit. The wellhead mounting of this unit is typical of most pneumatic pumping units.

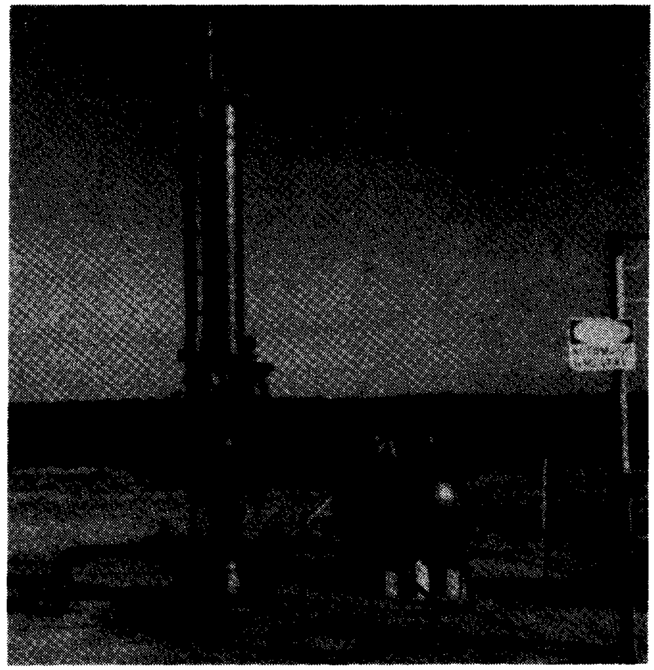


FIG. 11

SYSTEM OPERATION WITH AUXILIARY COMPRESSORS

In many cases, there is not sufficient gas pressure or volume available in a field to operate a pneumatic pumping unit at the desired rate. In these cases, an auxiliary compressor can be used to provide the pneumatic energy required. This compressor can use either air or natural gas as the working fluid. Natural gas is generally preferred in areas where a small quantity of gas is available at a pressure equal to the rod weight divided by the piston area, which is approximately the suction pressure of the operating compressor.

Figure 12 is an operating diagram of the equipment required to operate a pneumatic unit with auxiliary air compressors. The prime mover compressor is designated a "Booster" because of its function of boosting the pressure level of the working fluid. This compressor operates continuously with the discharge tank maintained at a pressure level just high enough to lift the weight of the rods and fluid to the top of the stroke. The suction tank is maintained at a pressure level just low enough to allow the rods to fall to complete a downstroke. These pressure levels result in booster compression ratios that are a function of the ratio of total load to rod load. Allowance must be made for pressure drop in the system piping, and for pressure fluctuation in the tanks due to the cyclic operation of the piston in the cylinder. The resultant compression ratios range from 1.2:1 to about 2.2:1 with most applications being less than 1.8:1. These low ratios mean a simple single-stage compressor can be used as the prime pneumatic energy source.

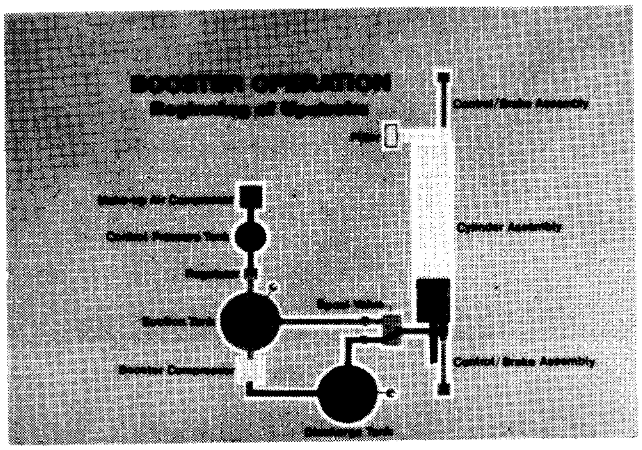


FIG. 12

During the cycle of operation, the cylinder volume under the piston is pressurized from the discharge tank. This pressure lifts the piston to the top of the cylinder to complete the upstroke. The upper control/braking probe then shifts the spool valve to open the cylinder volume to the low pressure suction tank as shown in Fig. 13. The pressure under the cylinder is then reduced to a level that will allow the rods to fall for the downstroke. The lower control/braking probe then shifts the spool valve to again admit high pressure air under the piston for the next upstroke. No pressurized air or gas is exhausted to the atmosphere during the operating cycle. The make-up compressor is a small (7 CFM) two-stage compressor which operates intermittently on pressure demand from the suction tank. Make-up air is required to compensate for pressure drops caused by sudden reductions in ambient temperatures. Use of natural gas as the working fluid allows elimination of the make-up compressor.

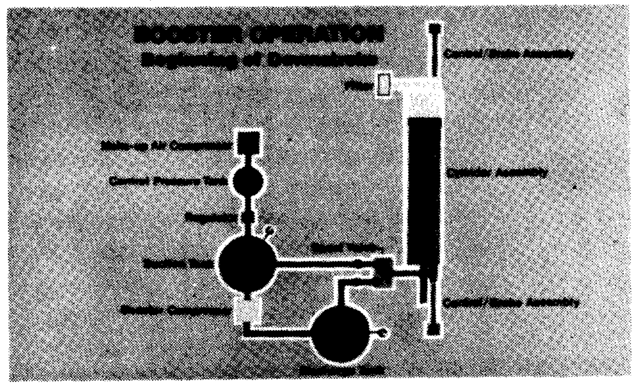
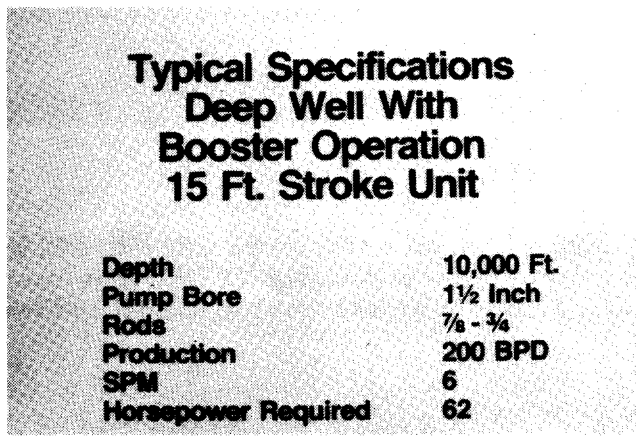


FIG. 13

Table 2 gives the application data for a typical installation fo a compressor-operated system. The depth range for units now in service is from 1000-11,600 ft. Production rates range from 3-850 BPD.



Typical Specifications Deep Well With Booster Operation 15 Ft. Stroke Unit

Depth	10,000 Ft.
Pump Bore	1½ Inch
Rods	⅞ - ¾
Production	200 BPD
SPM	6
Horsepower Required	62

TABLE 2

Figure 14 shows an installation of a 3-hp compressor-operated 5-ft stroke pneumatic pumping unit on a 1000-ft well producing about 9 BPD. This is the smallest compressor/unit combination currently in service.

Figure 15 shows a medium-sized 10-ft stroke, 40 hp system producing 200 BPD from 8800 ft. The tanks are the suction and discharge tanks for the booster compressor.

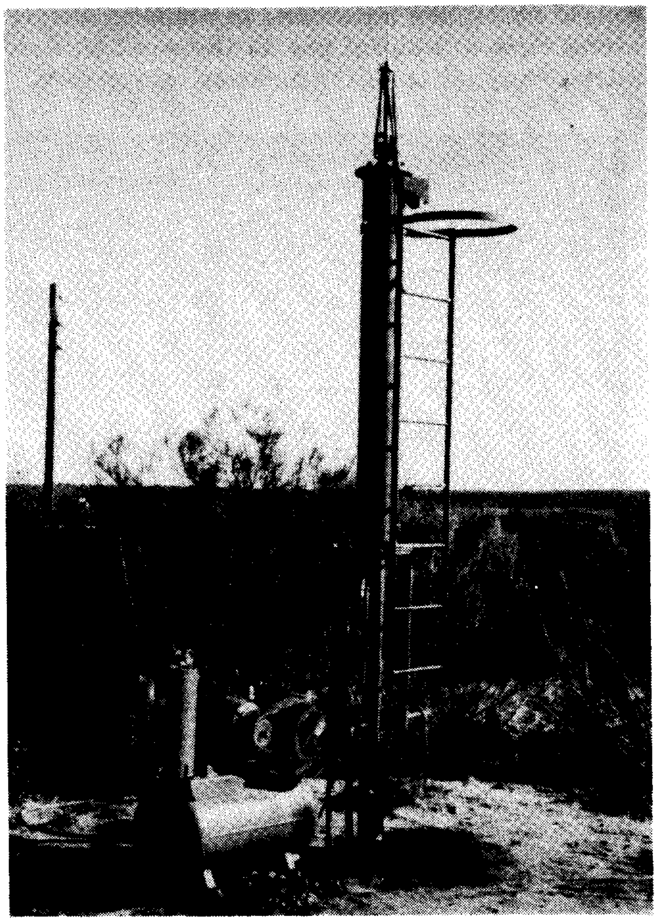


FIG. 14

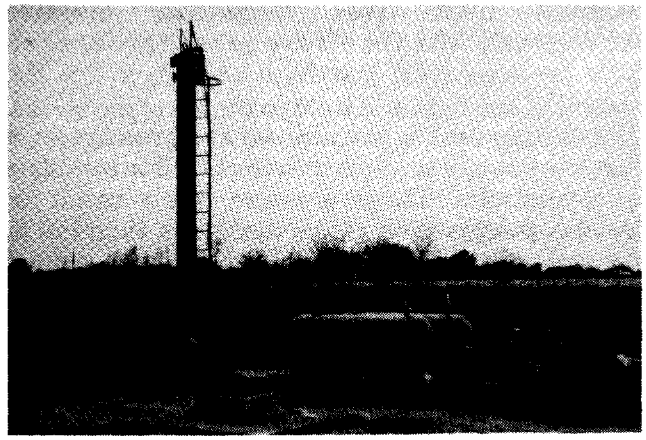


FIG. 15

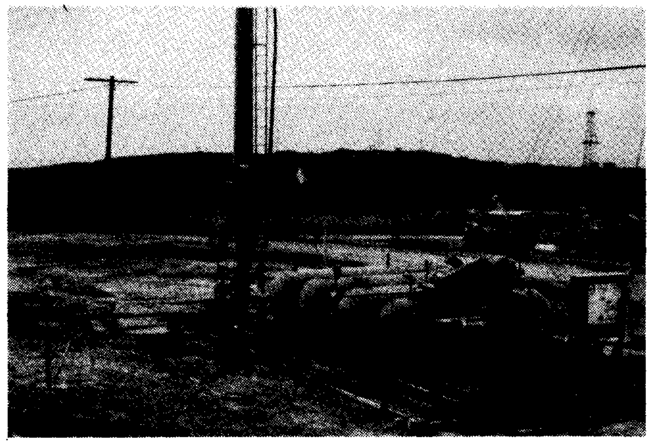


FIG. 16

Figure 16 shows a 15-ft stroke unit with a 60-hp booster compressor pumping 650 BPD from about 4000 ft. This large unit uses two suction and two discharge tanks to minimize pressure swings. The make-up compressor is visible on the top of the first tank.