Selection of High Pressure and High Capacity Pumps for Waterflood Service

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Basically, two types of pumps are used for high pressure waterflood service. These are the positive displacement and kinetic energy types. This paper will deal with plunger pumps which are a reciprocating variety of positive displacement pumps and horizontal and vertical centrifugal pumps of the kinetic energy classification. Examples of installations of these pumps are shown in Figs. 1-4.

PUMP CHARACTERISTICS

Each of these pumps has its own set of characteristics which may be classified as either an advantage or disadvantage for its use in a particular project. Some of the major advantages are listed:

Centrifugal Pumps

(1) Initial cost is less than for a plunger pump at certain rates and pressures.

(2) May be directly connected to high speed prime movers such as turbines with built-in speed reducers or electric motors without the use of gears or belts.

(3) Have no reciprocating parts.

(4) Contain no valves requiring inspection and maintenance.

(5) Produce a non-pulsating discharge.

(6) Require a lesser amount of floor space than plunger pumps with the same capacity.

(7) Require less attendance than plunger pumps.

(8) Handle large volumes of fluid.

Plunger Pumps

(1) Have greater flexibility than centrifugals in reference to speed, discharge pressure and capacity.

(2) Maintain higher uniform efficiencies than centrifugal pumps.

(3) Are better adaptable to high pressure conditions than centrifugal pumps.

(4) Are particularly suitable to the handling of small and medium fluid volumes.

(5) May be used with most low speed prime movers without speed changes.

ECONOMIC EVALUATION

In order to make a complete economic evaluation of pumps to be used in a specific injection system, one must consider all conditions which are anticipated throughout the life of the project. Several of these fundamental considerations should be:

(1) Anticipated system injection rate and pressure.
(2) Quality of source water.
(3) Location and space available for the injection plant.
(4) Selection of prime movers.
(5) Pump efficiencies.
(6) Initial investment.
(7) Effect of flood performance upon injection equipment requirements.
(8) Flexibility of injection facilities.
(9) Operating costs.
(10) Project life.

Anticipated Injection Rate and Pressure

The selection of the required number of injection wells and the total daily injection rate influence the type of injection pumps to be used. Obviously, if a few wells are to be put on injection status initially with the addition of several wells later in the project, the basic requirements should provide for a future expansion of injection equipment to accommodate these additional wells. The most economical approach to a problem of this nature would probably be to install sufficient pumps to meet these initial requirements and install additional pumps when needed.

An estimation of the initial and maximum injection pressure is of primary importance. Prior to the fillup phase of a flooding operation, the injection pressure should probably be kept below the formation fracturing pressure in order to obtain the best possible sweep efficiency, thereby increasing ultimate recovery.

With a reciprocating pump, injection volumes and pressures can be varied within certain limits by changing plungers and liners without altering horsepower requirements for the same pump RPM. Centrifugal pump discharge pressure and volume may be altered by varying the number of pump stages and the size and shape of the impellers. The shape of the impeller is normally fixed and not variable. These changes affect horsepower requirements necessitating either a change in prime movers or the original installation of a prime mover of sufficient size to meet the maximum discharge conditions. If a decision is made to use the larger prime mover, the unused excess horsepower represents a monetary loss to the operator.

Quality of Source Water

Prior to the selection of injection equipment, the quality of source water must be known. A complete chemical and mineral analysis of the water should be obtained. If possible the corrosive nature of water should also be determined. Steps should be taken to remedy an existing corrosive condition by chemical means and/or by maintaining a closed injection system and using corrosion resistant materials. If abrasive particles or excessive turbidity are present in the source water, filtering systems should be installed to protect the pumps.

Past experience has indicated that plunger pumps tolerate entrained solids better than centrifugal pumps. Manufacturers claim the vertical turbine pumps can handle slightly greater amounts of abrasive materials than the horizontal centrifugals.

Location of Injection Plant

In areas where available space presents a problem, the operator is interested in installing adequate injection equipment utilizing the least amount of floor space. For an installation with this limitation centrifugals have a distinct advantage over horizontal and vertical plunger pumps.

Selection of Prime Movers

The desired use of specific prime movers will often influence the pump selection. If an operator wishes to commence flooding operations on a lease where electric power is readily available, it is conceivable that the additional power requirements would enable him to receive the benefit of a lower power rate for artificially lifting his producing wells. This could possibly favor the use of electric motors in lieu of gas engines.

On the other hand, many times lease gas may be used for either single or multicylinder engines and gas turbines at a nominal cost to the operator.

Centrifugal pumps may be directly coupled to constant high speed electric motors whereas gear reducers or belt drives should be used with plunger pumps to utilize the electric motors. Electric motors have the disadvantage of one constant speed. Variable speed drives are available; however, lower efficiency and increase in electric motor investment are involved.

Plunger pumps are especially adaptable for use with slow speed gas engines. The pumps may be coupled directly to the engine shaft and will operate with a uniform efficiency over a wide range of speeds.

Speed increasers are necessary when driving centrifugal pumps with multicylinder engines. A disadvantage is that these increasers are expensive, thereby increasing the overall price of the injection equipment. The prime mover must operate at a relatively constant speed as the pump's efficiency for constant discharge pressure or volume is affected by fluctuations in RPM.

Pump Efficiencies

It is an established fact that centrifugal pumps operate at lower efficiencies than plunger pumps. Plunger pump volumetric efficiencies range from about 92 to 97 per cent and 95 per cent is an acceptable design basis. The plunger pump mechanical efficiency is around 90 per cent. Poor efficiency can be improved by the use of an inexpensive charge pump piped into the suction of an injection pump.

Centrifugal pumps are generally rated on the basis of capacity and head at the point of maximum efficiency.

The volute-type centrifugal pump is essentially a velocity machine. Liquid enters the impeller axially to the shaft and has energy imparted to it by rotating vanes of the impeller. The design of this type of pump follows the well known affinity laws which may be stated as follows:

(1) At a constant impeller diameter -
(a) The capacity varies directly as the speed.
(b) The head varies as the square of the speed
(c) The horsepower varies as the cube of the speed.
(2) At a constant speed -
(a) The capacity varies directly with the impeller diameter.
(b) The head varies as the square of the impeller diameter.
(c) The horsepower varies as the cube of the impeller diameter.

The input horsepower may be determined from the following formula:

$$HP = \frac{\text{Gallons per Minute X Total Head in Feet}}{\text{3960 X Pump Efficiency Expressed as a Decimal}} \text{ X Specific Gravity of Liquid}$$

Efficiencies of approximately 47 - 74 per cent are obtainable for fluid volumes ranging from 3500 to 10,000 BWPD. As the capacity increases to 100,000 BWPD a maximum efficiency of about 87 per cent is reached. From this information it can be seen that centrifugal pumps are designed for large volume requirements. If these pumps are used for medium capacity installations, the additional power expense due to their low efficiency can quickly overshadow their low initial cost.

Initial Investment

Every operator is concerned with the initial costs related to an injection project. The immediate expense of buying and installing injection equipment has a significant bearing upon pump selection. Obviously, an operator doesn't want to buy extra equipment that will not be used for several months. Also, he will be against sizing injection pumps without sufficient flexibility to meet changes in injection requirements.

The initial cost of a centrifugal pump installation is less than the initial cost for a plunger pump installation with the same output capacity within a certain range of difference in efficiencies. This will be discussed in more detail later in this paper. The price of a filtering system must be considered when centrifugal pumps are to handle fluid containing abrasive solids. Ordinarily, filters are not needed with plunger pumps. It has been previously mentioned that these pumps tolerate suspended solids in the injection stream much better than centrifugals. Normally, pulsation dampners should be installed downstream of plunger pumps to eliminate water hammer.

For protection against corrosive source water, corrosion resistant materials should be used with both types of pumps. Corrosion resistant alumi num bronze fluid ends and ceramic plungers are now standard equipment for plunger pumps. The use of corrosion trim alloys such as 316 stainless steel and Monel materials for horizontal centrifugal pumps increases the overall pump costs about 60 per cent.

Effect of Flood Performance

To reach reservoir fillup in a flood system, the injection volume must exceed the total fluid withdrawals. This is usually accomplished by injecting large volumes of fluid at low injection pressures. Dependent upon reservoir voidage this period may vary fom several months to several years.

After fillup phase has been reached, the injection rate may be decreased so as to meet current withdrawals. It is conceivable that this rate may be reduced to 30 to 40 per cent of maximum capacity. When this cutback occurs, surplus horsepower and capacity exist. If plunger pumps are used, the surplus pumps and prime movers may be readily salvaged. Thus the operator actually receives a return on his original investment through salvage. However, in many cases it is necessary to operate vertical turbine pumps in series to meet injection pressure requirements, and in these cases salvage of individual pumps is not possible as injection volumes decrease following fillup.

Horizontal centrifugal pumps may be manufactured with higher head ratings than the turbine pumps; however, series operation is often required as with the turbines thus eliminating the possibility of pump salvage. With the reduction in horsepower requirements, the large prime movers may be replaced with smaller ones. This change, however, represents little or no monetary gain to the operator as the new prime mover costs and the removal and installation costs are generally prohibitive. Also, disposal of a large used multicylinder engine at a price which will offset the cost of the new lower horsepower engine is often difficult.

Flexibility of Injection Facilities

Relatively early in the life of an injection project formation water production will increase. The problem of produced water disposal then confronts the operator. The logical answer is tc use this water in the present injection system.

Will this water be compatible with the source water enabling mixing of the two or will it be necessary to inject each separately? Compatibility tests must be performed to establish the feasibility of mixing the waters. If incompatibility exists, the two waters must be handled separately to prevent injection well and line plugging. Suspended solids may also be present in the formation water making is necessary to install filtering or settling systems upstream of the pumping station, particularly if centrifugal injection pumps are used.

Separate injection of these waters requires a degree of flexibility with an injection plant. At a plunger pump facility the produced water may be routed through one or more pumps without alteration of the system with the exception of minor piping changes. However, with high volume centrifugal pumps this problem becomes more serious. Small volumes of produced water will normally be handled in the early stages of a flood operation. These centrifugal pumps lack the flexibility to separately pump these produced water volumes, thereby necessitating the need for an additional pump.

The cost of injection lines is a major expense to waterflood projects. Frequently this cost may be reduced by installing several small or medium capacity plunger pump stations instead of one large volume centrifugal station. Smaller diameter and shorter injection lines may then be used. This reduction in line costs may offset the additional station costs and result in an initial investment savings. The validity of this application depends upon each project's individual requirements. Another consideration is in the increase in operating labor and maintenance involved with more than one station.

Operating Costs

Along with the immediate investment required for a project installation, future operating expenses must be considered. These operating costs may dictate what type pumps are to be bought. If an operator is inexperienced in the use of a specific pump, vendors and other companies in the same area should be consulted. Also pump serviceability is of primary importance. Are trained servicemen available in case of pump failure? If not are Company personnel capable of making necessary repairs? If the answer is no to both questions, excessive downtime may be the consequence.

Plunger pumps require more attendance than do centrifugal pumps. The reciprocating parts of a plunger pump demand a sizeable lubrication system, whereas a centrifugal pump needs little lubrication. These facts influence routine maintenance costs. Consideration of the above factors may result in a significant monetary savings to the operator.

Project Life

As mentioned earlier a sound economic injection pump selection must be based upon estimated conditions prevailing throughout the expected life of a flood system. Initial expenditures present only a portion of the picture. A combination of these expenses with operating costs projected over the project life yields a valid basis for pump selection.

FIELD APPLICATION

In the Landon (San Andres) and Slaughter Fields in West Texas, Pan American Petroleum Corporation has vertical triplex (plunger pumps), vertical centrifugal and, horizontal centrifugal waterflood installations currently in operation. Following the installing of these systems a study was conducted to determine the actual costs incurred with each. With each project, the complete station costs were tabulated. Equipment and piping prices, building, construction and installation costs at each station were studied.

These costs were then totaled for each type pump station and divided by the combined capacity of the stations in each category. The results are as follows:

TABLE I

(All plant rates at 3000 psi maximum design pressure)

Type Station	Average Plant BWPD Capacity	Cost/BWPD Capacity
Horizontal Centrifugal	22,000	$ 7.19
Vertical Centrifugal	12,000	$ 8.14
Vertical Triplex	7,000	$11.31

Injection station capacity obviously had an influence on the above cost figures since capacities of the plants in the three categories were not strictly comparable. However, costs per BWPD for the individual vertical triplex plants exhibited only a slight variation with extreme differences in plant capacity. It is therefore concluded that a substantial amount of the indicated higher cost of vertical triplex installations over the other two types would continue through larger plant sizes.

Natural gas prime movers are utilized at all stations. The costs for filters were included in the horizontal centifugal figure as one station is operating with a filter plant and a need for a filtering system is indicated at the second. Corrosion trim parts are not being used at the centrifugal stations. Ceramic plungers and aluminum bronze fluid ends are used on all triplex pumps; however, this fact doesn't affect the comparative costs appreciably as pump vendors pointed out that this equipment only increases the price of these particular triplexes about $300.

In conjunction with the above study, pump operating and maintenance costs at each station were computed. These costs were taken from approximate one year operating periods for all stations excluding the two horizontal centrifugal plants. At the time of this investigation these stations had been operating only five months. Operating costs of the vertical triplexes were only 0.5 mil/BW injected. A slightly higher cost of 1.0 mil/BW was experienced with the vertical centrifugal pumps. The horizontal centrifugal pumps produced an operating figure in excess of 4.0 mils/BW. This high cost for the horizontal centrifugal pumps is probably not representative since it is primarily the results of unexpected pump repairs, which will be discussed later in more detail. Information received from other operators in West Texas had led us to expect cheapest operation from these pumps.

Each pump presents a different variety of operating and maintenance problems. Without the use of pulsation dampners with plunger pumps, piping and fluid end failures may be prevalent. Pan American's main trouble with vertical triplex pumps in the Slaughter Area has been the cracking of steel valves in the pump fluid ends. This problem has been eliminated by the use of more resilient Delrin valves.

Improper suction and discharge conditions contribute to premature valve failure. The common use of lubricated plunger packing in lieu of dry packing material has greatly increased packing life, thereby decreasing maintenance time and leakage. Ceramic plungers have given excellent service.

Mechanical seal replacement at the vertical centrifugal plants has been the major maintenance expense. At one installation mechanical seal failures have necessitated replacement every 60 days at an approximate cost of $150 per pump. These frequent failures are thought to be caused by excessive horizontal movement of the vertical pump shaft. At one Station in the Slaughter Field, both vertical turbine pumps had to be replaced because of extreme corrosive damage caused by the source water. These pumps contained standard cast iron and carbon steel metallurgy. Following the replacement of these pumps less corrosive source water was used.

At another unit in the Slaughter Field, two horizontal centrifugal injection stations are in operation. Each station contains two pumps connected in series. Water is being injected at a rate of 29,000 BWPD. Injection commenced at this Unit during December, 1963. Since that time several major pump repairs have been necessary. Pump Number One at the North Station was inspected in April, 1964. When the pump case was opened, the center stage piece, one shaft sleeve and balance sleeve and several wear rings were found to be excessively worn. These parts were replaced. Three months later in July, 1964, this pump was again inspected and extreme wear was found on all eight stage wear rings. Evidence of graphitization was present on the pump case and wear rings. There was also evidence of mechanical abrasion; therefore filters were installed. In September, 1964, the second pump at the South Station was examined. When the pump case was opened several wear rings were found cracked and broken. Severe wear was evident on the rings and impellers. Graphitization and improper impeller installation by the manufacturer contributed to this pump's failure. These pumps consisted of steel cases, cast iron wear rings and 11/13 chrome steel impellers. By September, 1964, pump Number One at the North Station was returned to service. The worn cast iron wear rings had been replaced with 11/13 chrome steel rings. Three weeks later the first stage wear rings had seized. The cause of this seizure is undetermined. This malfunction has been corrected and the pump is now in operation.

SUMMARY

In summary, considerably more operating problems with resulting higher operating costs have been experienced with the horizontal centrifugal pumps than with either the plunger the vertical centrifugal pumps. It is entirely possible that these problems would have been greatly reduced had better metal combinations been specified for the horizontal centrifugal pumps.

The fundamental facts and considerations required for injection pump selection have been discussed. Obviously, all of the questions haven't been answered. However, the factors presented in this paper should be considered in each individual waterflood before determining which type pump is to be utilized. Thus with this basic information clearly in mind a sound economic decision may be made.

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ACKNOWLEDGMENTS

The author wishes to express his appreciation to Pan American Petroleum Corporation for permission to prepare and publish this paper. Special thanks are given to Mrs. Edna Shewmake for her assistance in preparing this paper.

Fig. 1
Typical Centrifugal Pump Installation with Two Pumps Operating in Series

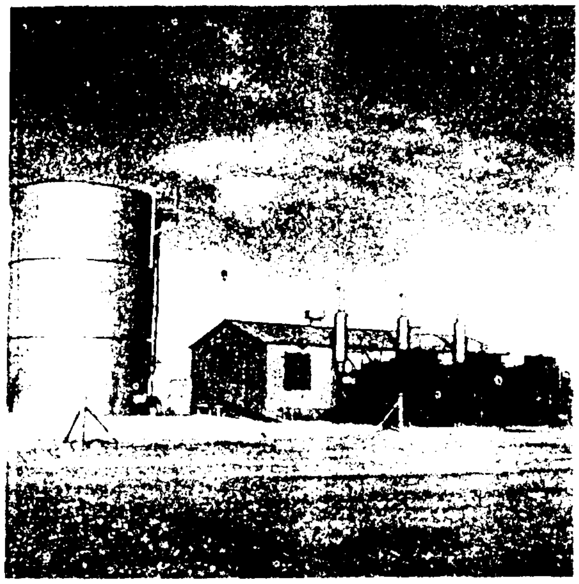

Fig. 2
Exterior View of Vertical Centrifugal Pump Installation Showing Multicylinder Engine Prime Movers

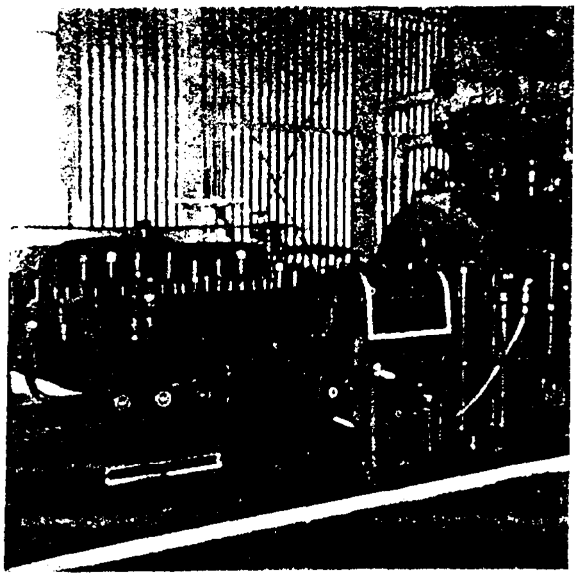

Fig. 3
Horizontal Split Case Centrifugal Pump with Speed Increaser Driven by Multicylinder Engine

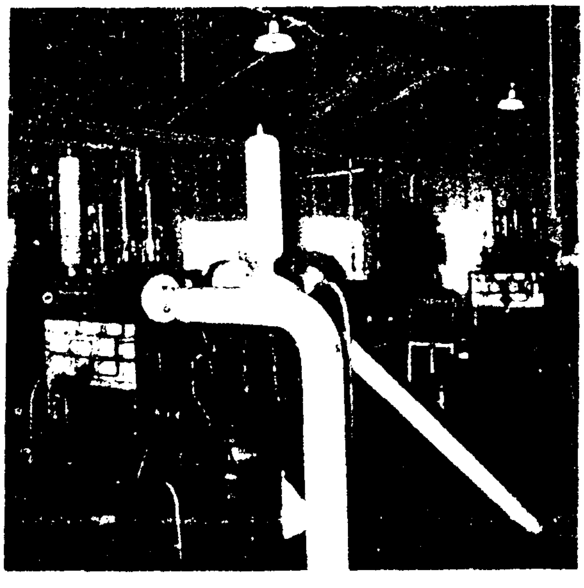

Fig. 4
Vertical Triplex Pump with Single Cylinder Engine as Prime Mover