# Application of Motor-Driven 11,000 RPM Centrifugal Pump to Hydrofrac Development

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## ABSTRACT

*Development of wells by the hydraulic fracturing method occasionally requires extended periods of pumping at pressures in excess of those normally available in the brine field. To accomplish this, it is customary to rent an engine-driven piston type pump because of its mobility, high pressure capability and flexibility as to pressure and capacity. Disadvantages lie in high cost due to overdesign for mud-handling, operating labor and fuel, and allowance for maintenance of engines and fluid parts; in a company-owned unit, the intermittent use and high cost of mud pumps along with the storage problem of engine-driven units make these pumps expensive for well development.*

*When operated at speeds of 8,000-30,000 RPM, a single stage centrifugal pump can develop the head and capacity required for this work. By series and parallel connection of two units, the wide range of pressure requirements for well development can be met while optimizing flow. Electric motor drive permits unattended operation with suitable controls.*

*The unit discussed employs two pumps mounted on a skid with primary power integrated into the unit. Swivel mount of the in-line pumps permits parallel or series connection and easy conversion from one mode to the other in the field.*

## INTRODUCTION

Applying large amounts of hydraulic horsepower for well development at field locations on a short-term basis offers an interesting problem in selection and application of pumps to field situations. This paper discusses use of motor-driven single stage centrifugal pumps in development of salt wells. It is recognized that indefinite terms like high or low when used in reference to quantities are factors which are characteristic of the specific locality in which the reader is interested; however, it is thought that enough latitude is available in the ranges discussed to cover most common brine field conditions. With modification only in scale, the concepts of this work can be applied anywhere.

## THE PROBLEM

Development of an usable connection between two wells in a salt bed by the hydrofrac method requires reduction of the circulation pressure across the fracture connection from that approximately equal to the hydrostatic load of the overburden to the pressure of the available service water. In an oversimplification it is thought that the mechanism consists of pumping against the overburden pressure until sufficient salt has been dissolved to increase the area of the conduit to permit the desired fluid to pass with little or no friction loss. This pumping time, once circulation is established, varies from well to well and locality to locality. The range is from a low of several hours where the connection is in a pure salt bed, to several months; sometimes when the connection is in a bed of low solubility, or has swelling or plugging characteristics, pumping is abandoned when results are not obtained.

The cost of readily-available rental equipment is high, because the daily rate must include allowances for moving, depreciation, repairs, labor, and fuel on a mobile, self-powered machine capable of delivering practical flow rates at elevated pressures. An extended period of pumping will run up a rental charge which can approach the cost of the well, and since decline of pressure is frequently not directly related to pumping time or fluid quantity, the decision to extend pumping time is difficult. An electric motor-driven centrifugal pump was applied to this service because its simplicity of operation and low cost would permit extended periods of development pumping essentially for the cost of the electric power.

## HYDRAULIC CONDITIONS

In its basic concept, development of a fracture connection in salt presents a decreasing head requirement as solution increases the cross-sectional area of the connection between the well being developed and its outlet. Since decrease in pumping load is frequently sudden and unpredicted, the pumping machine must be capable of making this change without damage in absorbing the differential. Protection of the equipment from runout or overload requires the continuous attention of a competent operator or use of protective devices.

An engine-driven mud pump from the well drilling rig is commonly retained for well development after completion of drilling. Since the engines and fluid end of these units represent considerable investment, a contractor furnishing this type of pump usually requires an operator on a continuous basis.

As solution progresses, the cross-sectional area of the connection between the wells is increased, flow through the conduit changes from turbulent to laminar, and head requirement to maintain flow through the system falls. Since it is the objective of this work to develop the new well and put it in active service in a minimum of time, the pump should have capacity to maintain flow rates of the upper laminar to turbulent type during the high-head requirement interval, and be capable of high flow rates when head requirement falls off. Equipment is selected which will attain the maximum pressure anticipated and operate across the range from maximum to the pressure of available brine field service water; service water pressure determines the lower limit of pressure requirement. Flow, the other variable in the development system, is held at as high a level as possible, since it is generally held that time and flow rates are somewhat inversely related.

Typical system curves after a connection is initiated are illustrated in Fig. 1; slope and units vary from locality to locality. Curves are shown where pressure rises with time and flow, in the case of a swelling formation or plugging situation; where the curve stays flat, in the case of a connection in insoluble material; and falling curves, slope varying with percentage of soluble material, time and flow.

## ENGINE-DRIVEN PISTON PUMP

An engine-driven piston pump of the type used as the mud pump for rotary drilling has the mobility and pressure-flow capability suitable for this work. By varying liner and piston size and engine speed over tolerable limits, this type of pump can be made to conform to the system curve in a series of steps as is shown in Fig. 2. Care must be taken to provide relief back to suction to prevent bursting or overstressing the system in the low-flow periods. Liner and plunger sets are heavy and quite expensive. A change requires two men several hours, so changes are major undertakings, not without considerable cost.

An engine-driven mud pump with one or two engines and accessories, capable of pressures of several thousand psi and flow rates in excess of 50 gpm at high pressures to 500 gpm at low pressure, costs \$30,000-50,000. Protracted pumping at elevated pressure puts high strain on all moving parts in this type of reciprocating machine; repairs on the engines and fluid end, while infrequent, are quite expensive. Because of the intensity of utilization and the dynamic character of the load against which it is applied, the contractor furnishing a mud pump usually insists on

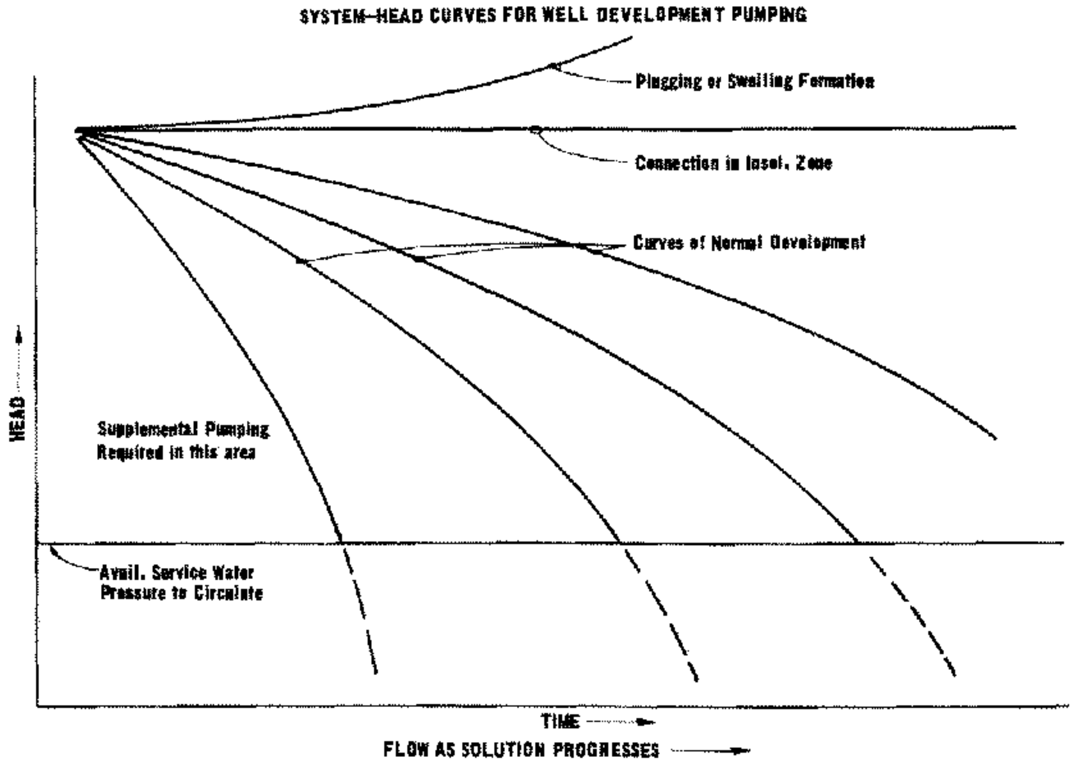



Figure 1. Curves showing change in head required to maintain flow across a fracture connection. The curves also indicate increase in flow at a given pressure as time (solution) enlarges the connection. Development is complete at service water pressure.

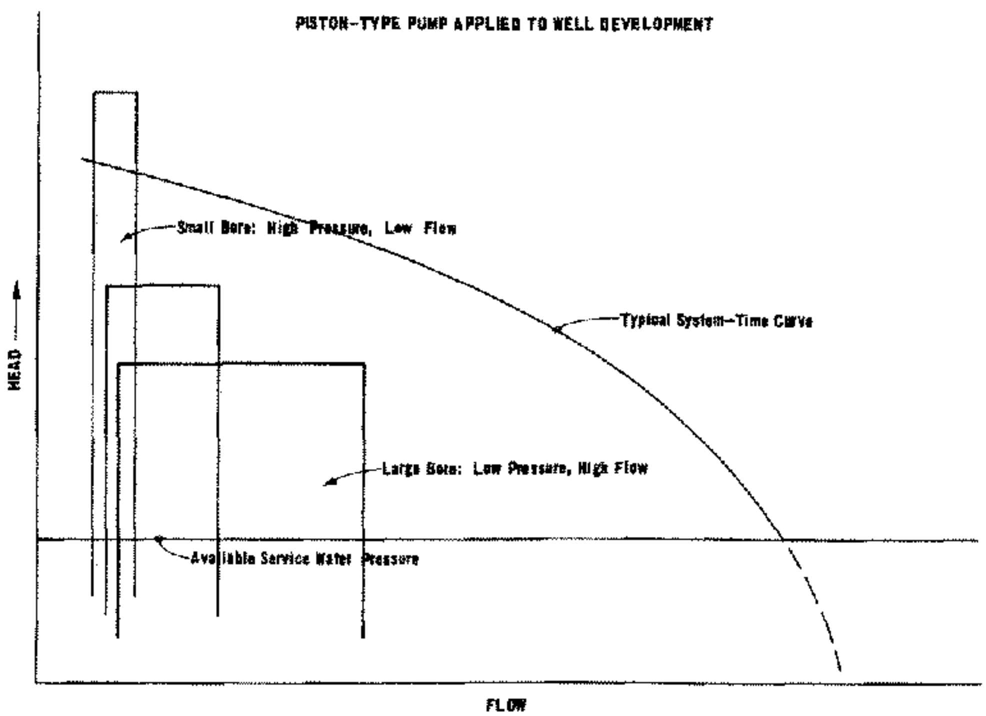



Figure 2. Pressure-Flow envelopes for various liner bore -- RPM combinations. Upper limit is pressure capability of engines. Left-hand limit is minimum torque and RPM capability of engines.

supplying qualified operators on a continuous basis, not only to see that the machine performs satisfactorily, but also to stand by to shut it down in case of a malfunction, before extensive damage takes place. Fuel cost for one or two 300 hp engines runs on the order of $50.00 per day.

It can be seen that furnishing a mud pump on a short term, indefinite pumping job with moving, labor, repairs, fuel and depreciation can justify a charge ranging from $300 to $500 per day with a significant stand-by charge during downtime.

Because well development is done infrequently, say once every few years, and because it is impossible to predict the pumping period, optimistically a matter of a few hours or days, it is difficult to justify investment in a mud pump and accessories, especially in view of its high moving cost, fuel cost, potential repair expense, and particularly the difficulty of finding competent labor on an as-needed basis to conscientiously look after this complex machine under brine field operating conditions. It is recognized that internal combustion engines deteriorate if allowed to stand idle for protracted periods between jobs. Thus, it appears that the mud pump, while convenient for experimental work on a rental basis, is not the optimum type of pump to incorporate into the Brine Department for well development.

## CENTRIFUGAL PUMP

A high head motor-driven centrifugal pump packaged on a suitable skid offers a solution to many aspects of the problem. The head curve of a centrifugal pump conforms somewhat to the head requirements of the system in that it adjusts itself to decrease in pressure requirement by increasing capacity over a wide range while maintaining motor load within tolerable limits, see Fig. 3. The motor-pump combination can be protected by rather simple safety devices. Anyone who has approached a piston-type mud pump under full load will appreciate the radical difference in noise level.

During the initial phase of well development, pressure requirement is highest and flow in the turbulent range is of secondary importance; a centrifugal pump can operate at or near its shut-off point, developing maximum pressure while automatically optimizing flow by moving out its capacity

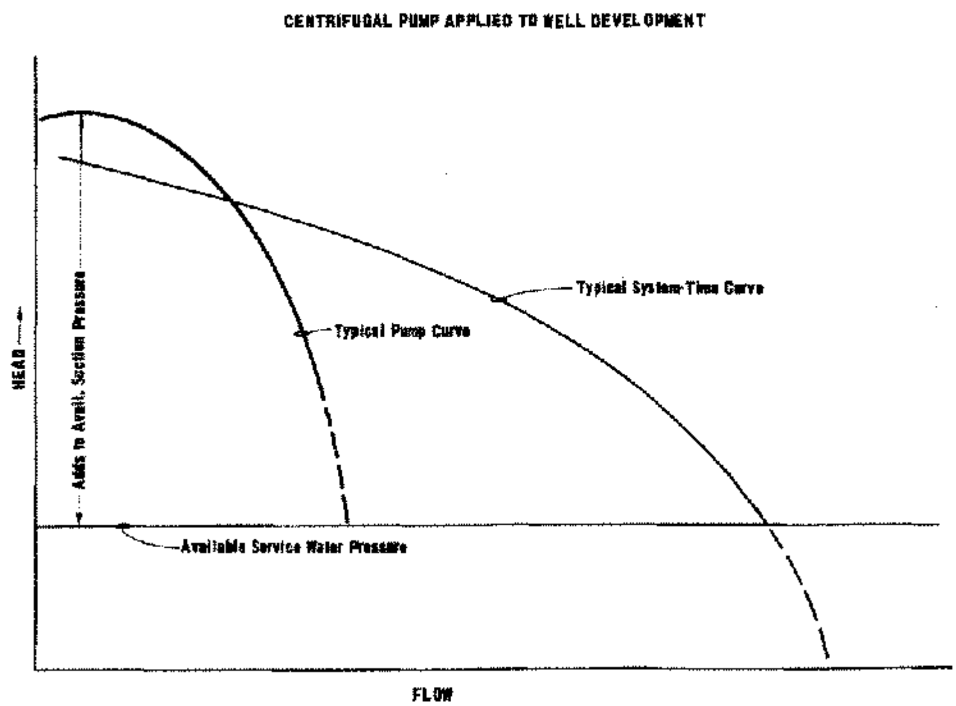



Figure 3. Curve of centrifugal pump conforms to well curve by automatically increasing flow as pressure requirement decreases. Pump adds head to available service water pressure, and operates safely at low flow during initial period.

curve as head requirement falls off. A sudden change even so gross as a broken line cannot destroy the unit as a similar "runout" would on a mud pump if the operator was not on hand, since simple over and undercurrent relays can be set to cut the power off.

Those familiar with high-head centrifugal pumps will recognize that a moderate size unit capable of developing heads of several thousand feet at nominal flows will not deliver high capacity at lower heads. The solution used was to apply two pumps with a simple conversion from series to parallel connection which could be made in the field.

Considering again the generalized system-head curve requirement for well development, the series parallel match can be seen, Fig. 4. Mobility requirements precluded application of a multiple-stage centrifugal pump of the boiler feed type because of shaft alignment and vibration limitations which would necessitate a massive base.

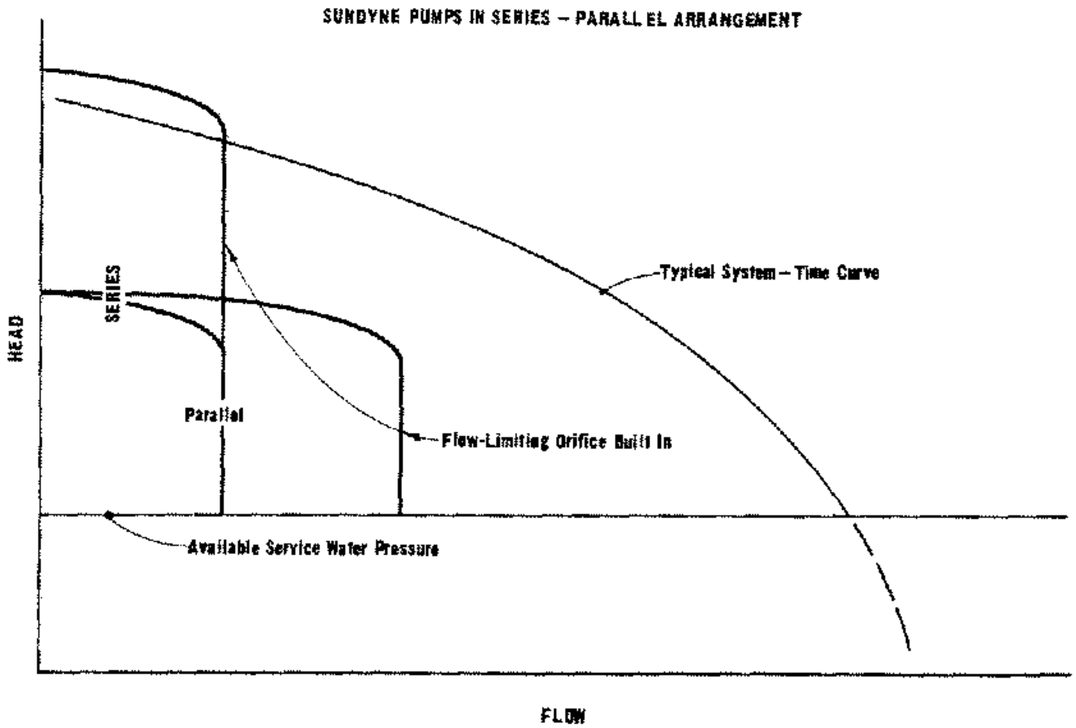



Figure 4. Pumps add head to available service water pressure. Orifice limits flow to prevent runout and motor overloading. Pumps can run at low flow rates during initial period without damage.

## HIGH SPEED ONE-STAGE PUMP

The pump selected for this work is a one-stage, in-line type which operates through a gear case at speeds above 3,600 rpm, ranging through steps to an upper limit of 30-40,000 rpm, manufactured by the Sundstrand-Denver Company, Denver, Colorado. The pump, marketed under the name "Sundyne" has the following general outline, Fig. 5. The motor is a conventional vertical type. The gear case is flanged directly to the motor, eliminating alignment and couplings. Gear ratios develop the desired output speed. The gear case is pressure lubricated and gear speeds and bearing loads are well within acceptable engineering standards. A mechanical seal is provided, designed for the material being pumped. The impeller is a simple, straight-vane type. The pump case carries the inlet and outlet flanged connections and encloses the diffuser casting or pump bowl. Other than the seal, fluid end parts consist of the impeller and diffuser, both of which are small, simple castings; their cost, in terms of extraordinary materials for corrosion or wear resistance, is small in relation to the total machine.

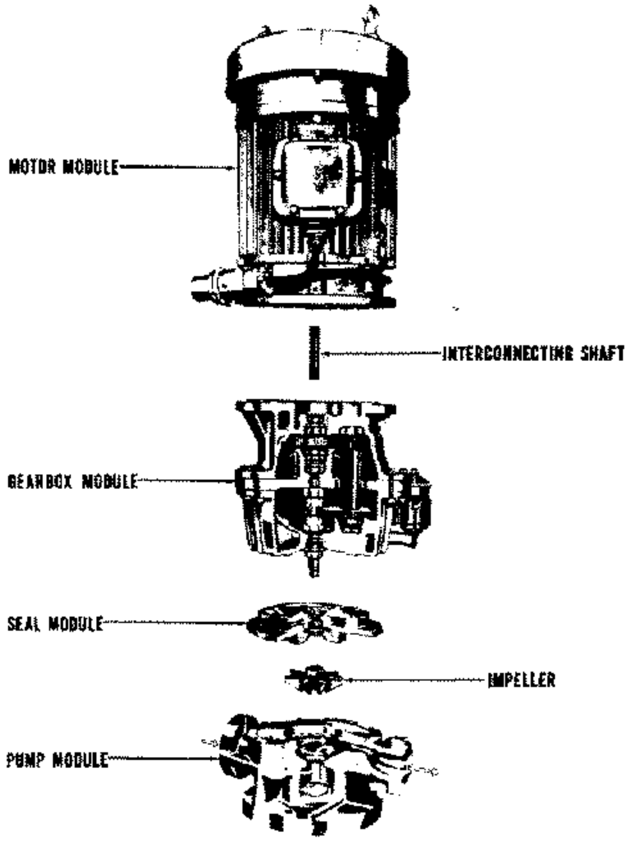



Figure 5

## WYANDOTTE APPLICATION OF THE SUNDYNE PUMP

The well development pump system designed for use at WYANDOTTE has the following features; see Fig. 6.

Two 60 hp, 11,000 rpm, one-stage vertical in-line pumps;
Motor starters -- weatherproof with indicating ammeters and outlet for plug-in power to motor;
Transformer 2,300-440 V; and
Sled type base for above, welded steel construction.

Power is furnished from the brine field well pump electric mains at 2,300 volts by means of surface cables and junction boxes. Service water at the well site is available from the brine field manifold system at 250 psi, which furnishes more than adequate NPSH. Connections are made by flanged hose and flexible-joint temporary piping sections.

A mount for each pump was designed consisting of a cylindrical pedestal attached to the pump base and a matching socket fastened to the sled. Actual load was carried on Teflon rings which cover the surface between the top of the socket and pump base, serving as a low friction bearing. This base construction permits the pumps to work straight through for series operation or to swivel 45 degrees for parallel connection with a suitable manifold. The base arrangement allows the pump to be lifted out of its socket and to be transported, complete, on a suitable cradle. The Teflon rings allow the entire pump to be rotated about a vertical axis with little effort when making the change from series to parallel connection, Fig. 7. When the unit is to be moved, the pumps are lifted out of their sockets by an A-frame truck and transported laying down in their cradles. The sled with electrical rack, transformer and starters is lifted at the transformer end by a winch truck and dragged or suspended from the back of the truck bed. When set in position on the well location, the pumps are dropped into their sockets, electrical cables plugged into receptacles on

END VIEW OF PUMPS ON MOBILE BASE SHOWING PARALLEL CONNECTION

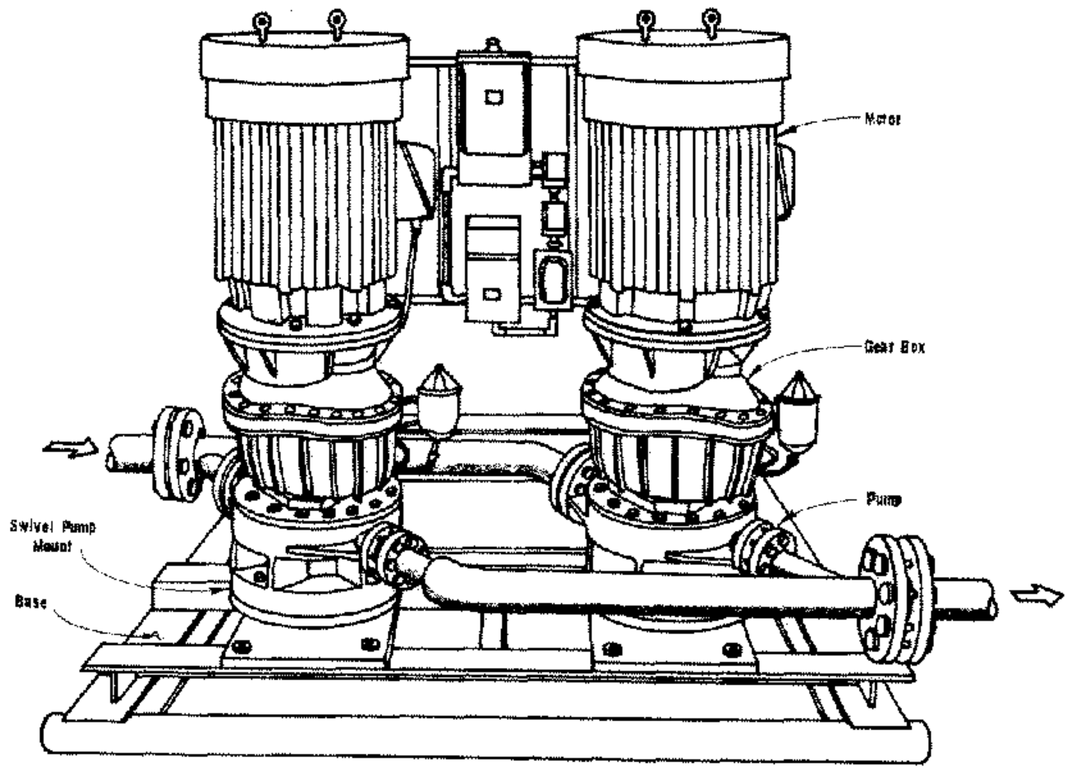



Figure 6

the starters, and suction hose and discharge pipe connected. All this work is done by the Brine Department crew. Meanwhile, plant electricians spool and relay the 2,300 volt electric cable from the nearest junction box to the pump and reconnect at the fuse disconnects. Cable lengths of several thousand feet from the nearest 2,300 volt source are made up in 500 foot units connected at junction boxes.

## OPERATION AND CONTROLS

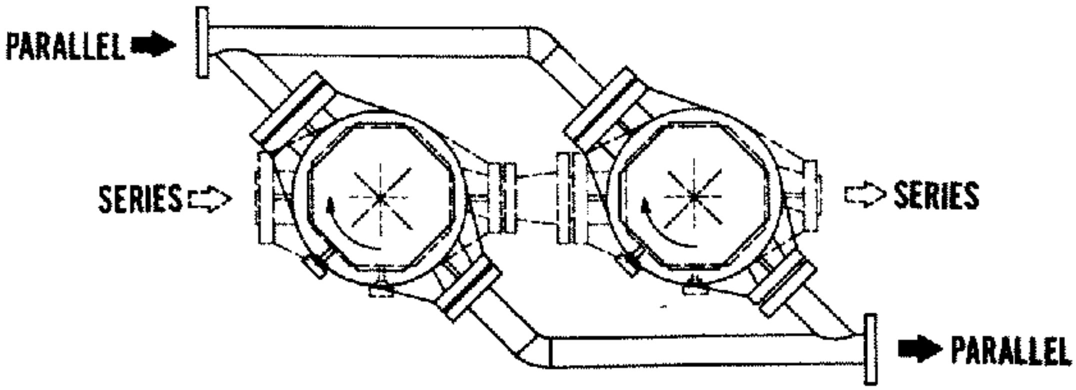
Water is metered on the suction side by a propeller type flowmeter. Flow to the well is regulated by a valve on the well head to keep motor load within design limits by observing indicating ammeters on the face of the starters. Suction, interunit and discharge gages are provided to indicate performance of each element. A recording pressure gage gives a record of well history.

The starters are provided with high and low current cutouts and interconnected to stop both units in the event one goes down. Phase reversal relays prevent backward rotation in the event random reconnection of the three phase power produces an arrangement which will cause rotation other than the right direction.

## COST

The sled type base was fabricated in a shop from drawings furnished -- cost $350; the bushing post swivel mounts cost $300 each, total for steel base and pump mounts: $1,000. Pumps, 400 psi, 140 gpm each for series or parallel from 200 psi inlet, including 60 hp TEFC motor, 11,000 rpm gear box and pump, complete unit: $3,900 each.

Two 75 hp well pump transformers were utilized because they were available on a no-cost basis from surplus and because two units would spread the load profile and keep the center of gravity down, a factor of consideration during moving. A single 150 KVA transformer could be




TOP VIEW SHOWING METHOD OF CONVERSION FROM PARALLEL TO SERIES CONNECTION BY ROTATING PUMPS ON SWIVEL MOUNTS AND INSTALLING SPOOL PIECE.

Figure 7

used, cost -- $1, 200. Starters cost $600 each. Estimated total cost about $12, 000 including assembly labor, fabricated spools for series and parallel connection, small parts and painting.

Direct operating cost is power requirement for two 60 hp motors; somewhat less than $20 per day. Labor charged to well development consists of the time of the Brine Department shift man who changes charts, regulates flow and power load once or twice a day during a protracted pumping job. In freezing weather, a Plant Protection man observes the pump on his periodic rounds and notifies the Brine Department if the system is out of order.

The unit is still in its first year of operation and as such has yet to incur repairs or maintenance. The Sundstrand Company is ready to ship a gear case on an exchange basis, which can be changed in the field. If desired, the gear case or seal can be changed in the shop by lifting the entire unit out of its socket with an A-frame truck and transporting it to an inside work area. The gear case can be changed in one or two hours by one man with hand tools and a hoist. Other wearing parts are the mechanical seal, impeller and diffuser: these can be changed with hand tools by one man; there are no close tolerances to be adjusted or other alignments to be made in the field.

## CONCLUSIONS

The first project to which the pump was applied was a well which had connected but had not pumped down. The pump was connected and after approximately ten weeks the well would take water at service water pressure. It is doubtful if we would have continued pumping with a rented engine-driven pump at $500 per day -- it would be hard to abandon a well at the part-way point if pumping failed to reduce the system pressure below that of available service water. It could be said that this pumping unit paid for itself on its first job.

## ACKNOWLEDGMENTS

This application of the high-speed pump concept to the complex problems of a brine field required liberal thinking on the part of those involved in the project to develop the flexibility necessary to meet the wide range of head requirements while optimizing flow, to build simplicity and mobility into a unit which could be picked up, moved and set down at a new location and be in business in short order, and to make over a hundred horsepower available on a plug-in basis. Special mention should be made of the enthusiasm with which the engineers and field personnel of the Sundstrand-Denver Corporation attacked the problem of applying their pump to a system-head curve with a reverse slope and dynamic operating point. Through their efforts this project achieved its present degree of success.