Multistage Horizontal Centrifugal Pumping Systems Compared to Positive Displacement Pumps for Produced Water Injection

Robert Lannom, SPE,
& Garry Sutton
Electrical Submersible Pumps, Inc.
Oklahoma City, Oklahoma

This paper was presented at the 46th Annual Southwest Petroleum Short Course held at the Lubbock Memorial Civic Center, Lubbock, Texas, April 21 – 22, 1999.

Abstract

This paper will provide a comparison between multistage horizontal pumping systems and reciprocating positive displacement pumping systems. We will compare their applications, costs and advantages and disadvantages.

Introduction

Energy companies are very happy when they are producing and selling oil, but there is a down side. That is, produced water is a product that oil companies have had to deal with since the turn of the century. Historically the oil industry has used positive displacement pumps. They were well suited for water injection at high pressures required to pump water into the formation. The prime mover could be either natural gas engine or electric motor. Natural gas drivers were less favorable because of capital cost, physical size, high maintenance, and complicated mode of control. Typical horsepower range is 100 to 300, with larger sizes of 600 to 1000 hp. As water rates and higher discharge pressures increased some oil companies installed centrifugal split case pumps. They worked well but were very expensive and required a lot of site preparation. The electrical submersible pump has been used since the early 1970's in down hole applications. The next step in its evolution was to design a horizontal pumping system using the submersible pump, hence the HPS.

Initial equipment costs and the need to reduce repairs and maintenance have encouraged oil companies to consider alternate equipment for their pumping systems.

Water injection and water disposal is an inherent problem, both from operational, legal, and environmental points of view.

Introduction

From the earliest oil field discoveries energy producers used positive displacement reciprocating pumps for fluid pumping service. They primarily used this pump in the areas of salt water disposal, high pressure waterflooding and pipeline service. Electric motors or natural gas engines were typically used as the prime movers. These pumps can be large, but most of the units used in the oil field service are 150 to 200 horsepower with the larger sizes being 500 horsepower. They are frequently configured as triplex or quintiplex units.

Initial costs and need to reduce maintenance have encouraged considering a possible change from the positive displacement reciprocating pumps for fluid pumping service.

The oil industry has continued to push the envelope of operations and locations for finding and producing oil and natural gas. The industry is now embracing reasonable changes that a few years ago were not even considered. Not long ago, production in the Gulf of Mexico from oil platforms deeper than 400 feet of water depth were considered unrealistic. Some companies decided to sell out or phase out their operations in the Gulf of Mexico. When significant oil and natural gas reservoirs were found in deeper water, the oil industry was challenged to produce these reserves. One answer to the deeper water production is a floating production facility. Weight, maintenance and initial cost are very important design considerations for these facilities. These offshore structures are complex facilities. Today the deeper waters are not the limitation, but achieving favorable economics can be very challenging.

Fluid Pumping Service

For oil field operations the most commonly used high pressure fluid movement pump is a positive displacement reciprocating pump. With high rate and relatively higher pressure, pipeline companies may user a centrifugal split case pump.

The electric submersible pumping industry was developed to provide fluid pumping service for oil wells. Manufacturers have expanded these multistage centrifugal pumps for use in surface applications. These horizontal pumping systems are viable alternatives for replacement of the positive displacement reciprocating pumping system.

What has changed to make the horizontal multistage centrifugal pumping system a good solution for surface applications?

The solution to reliable surface applications came from many years of work to solve one of the hard pumping problems of producing abrasive fluids from oil wells. There have been many ideas conceived with varying degrees of success.

Eldon Drake was truly a great influence to the electrical submersible industry. In 1982, when Eldon was with Dresser Westech, he installed ceramic washers on the stages and diffusers because the material is harder than sand. This device operated in a well operated by Sun Oil Company in Louisiana, but the ceramics of the time were brittle and the pump was difficult to ship and install without breakage. Improved ceramics materials are now commercially available.

If vertical stability is solved with a hardened sleeve materials, the pump stages can still have a down thrust problem. One of the solutions is have a full fixed stage pump (compression pump) that has each stage fixed to the pump shaft and thus transfer the thrust of each stage to a thrust chamber.

With close attention to operating stage loading and hydraulic balancing, the major problems of surface installations have been solved. Equipment can now be designed for years of virtually maintenance free operations.

Multistage Centrifugal Pumping Systems are now available for fluid pumping service. Why are they not being considered by Consulting Engineering Companies?

Some design consultants are not familiar with horizontal pumping systems, as perhaps no customer has requested this type of system. Consultants can be creatures of habit and they are certainly not going to propose a system that does not have a proven operating history. Every oil company and consultant has stories of the snake oil salesman whose equipment has not lived up to expectations.

Many consulting engineering companies do not operate in an environment that is a cohesive solution solving environment. They function in selective disciplines working toward a solution. The mechanical process engineer will determine what is needed, and the structural engineer will design a foundation or structure for support of the facility. This is a typical working relationship. Unless the project is building a facility to supply electrical power for resale, electrical disciplines are usually placed on the project after many of the main items of a facility have already been considered. Very seldom is the electrical power consultant asked for input for a comprehensive cost effective solution on projects. The power electrical disciplines are asked for a workable solution, price, delivery, size and solutions to special problems.

The facility engineers are very attuned to efficiencies as part of their everyday activity. They work with centrifugal pumps to move fluid in many locations of a facility. If a multistage centrifugal pumping system is considered to replace a positive reciprocating plunger pump, the first items of concern are available pressure rating and operating efficiency.

A one stage centrifugal pump is limited by the available pressure. The facility engineer knows the typical efficiency of the positive reciprocating plunger pump approaches 90 percent. A centrifugal pump is 60 to 70 percent efficient.If the question of pump effects on the entire electrical system efficiency has not been evaluated, the result of this evaluation can be surprising to the facility engineer.

Which fluid pumping system has the best overall efficiency in a system that utilizes a stand-alone electric power generating system?

A standard reciprocating pump or series of pumps will need to provide 100 percent of the design rate with an additional unit to operate while maintenance is being performed. One typical installation will be to install three 50 percent design rated units. This provides for a full spare that can be operated at any time. There could also be four 33 ½ percent units again providing for one standby unit that is fully operational. Having many smaller positive displacement reciprocating pumps is not normally acceptable because maintenance costs on a large number of small units is usually very high. The positive displacement pumps can typically require the largest motor in the facility. This is true for oil or water pumping service. This large motor can determine the sizing of the generator required to start the largest motor with other needed loads operating.

If Variable Speed Drives are to be considered, special care must be used in the selection and economics of the system. These devices can become complex and encounter problems with electrical harmonics, phase balance, and power factor considerations.

If the fluid requirement or pressure is high enough, the motor size can be 400 or 500 horsepower. On a platform, this drives the electrical design to an intermediate voltage dependent on size. The starting of large motors should be reduced voltage, but they still require oversizing for generator spinning reserve to maintain a useable voltage during starting voltage collapse. With the same load, but in smaller design units, the generator will have a reduced size.

On paper, the difference in efficiency is about 35 percent between the two types of pumping systems. In practice, a positive displacement pump is a fixed rate pump. The speed can be changed by changing sheaves and belts to making the pump operate at different speed; however, this will not be done on a daily basis. A variable speed controller can be used to make the motor operate at different speeds. The electrical complexity, energy loss of the variable speed drive, and reduced reliability has made this technology seldom used on a large positive displacement pump.

To allow a positive displacement pump to operate on a pipeline application, bypass piping with a back pressure valve is installed. This will allow part of the pumped fluid to be bypassed back to the input of the pump for rate adjustment. This is a typical installation and when bypass piping is installed. The efficiency of the pump system is less dependent on the amount of fluid needing to be returned for pumping. Historically the oil industry is skilled in utilization of all available energy when it can be determined to be a reliable operating practice.

A direct comparison of three 50 percent size positive displacement pumps to six 20 percent multistage centrifugal designed pumps can favor either pumping system depending on the incremental fixed generator sizing available. If total system efficiency is equal or even close, the multistage centrifugal pumping system may be selected for the many advantages over the positive displacement pump.

Initial cost is always a consideration. The initial cost of equipment for comparable fluid pumped systems is higher for the positive displacement pumps. Larger motors increase the motor starter sizing if a required higher voltage is needed and the motor starter control room area and transformation takes up more space and weight. Larger motors can increase the need for larger generators. This increases the cost for the entire facility and if larger generators are required, the operating cost is increased for the electrical facility over the entire life of the system.

Which fluid pumping system requires the least maintenance?

These two pumping systems have vast differences of required maintenance. This is a very important difference between the two systems. Extensive maintenance is needed on the positive displacement reciprocating pump to keep the pump operating and the plungers from leaking fluid. Crankcase oil lubrication requires regular replacement from wear and contamination for longer life. This maintenance on a positive displacement reciprocating pump increases with increased pressure as the seals and valves leak with pressure.

The multistage centrifugal pump is not maintenance free, but the maintenance is only on the thrust chamber and low pressure rotating seal. The motor is a standard two pole motor requiring standard maintenance.

In a remote location like international or offshore, the major difference in maintenance can be a good reason for using a centrifugal pumping system. On offshore platforms, the very important operation of the oil pipeline pump needing repeated regular maintenance, will require additional mechanics to keep a facility operating. In the Gulf of Mexico, one position (two personnel with 7 days on and 7 days off) can cost annually over $220,000.

What are some of the other differences in the two fluid pumping systems?

Weight will be higher for the large reciprocating pumping systems. Increased weight will increase the structural cost of an offshore platform.

Mechanical vibration is high on large reciprocating pumping systems. They will vibrate the entire facility and piping on a platform. This continuous vibration and noise can become normal to the people living on the platform, but has long term detrimental results to the facility.

Fluid pulsations are high from the reciprocating pumping systems. One typical way to lessen the fluid pounding of the system is to install a pulsation dampener vessel on top of the pump. This equipment utilizes a gas that absorbs the pulsating energy. Maintenance is required to keep this device operational. A dampener is not needed on a centrifugal pumping system.

Pressure rating is a big advantage of the multistage centrifugal pumping system. The high pressure rating is limited to how large a pipe housing and discharge head manufactured from solid stock can be constructed. For more information see Reference 1. This type of construction is understood and can be tested to much higher than operating pressure. If a leak-proof higher rated pump is need, the pump head can be continuously seal welded for a much higher pressure rating. Pressure release may be regulatory required, but is not needed if the shut in pressure of the pump is less than the burst pressure of the system. The multistage centrifugal pumping system can be constructed to exceed the normal tubular design pressure rating with the installation of more stages.

Pressure release is required for positive displacement reciprocating pumps. The pressure on this type of system can increase until some item in the system relieves. In Russia, the positive displacement reciprocating pumping system is not acceptable for oil pipeline service because of problems with pipeline ruptures.

What are the special requirements of multistage centrifugal pumps used for oil pipeline service?

A bypass line is not required for oil pipeline service. Bypass lines are always designed by facility consultants and difficult to discourage. This is one item that a prudent operator will ***not*** want to have installed for oil pipeline operation. The location of the Lease Automatic Custody Transfer (LACT) unit is usually on the low pressure side of the pipeline pumps, thus recalculation is not acceptable to any location other than the input to the same pump. Do not install piping from output to input. This can allow an operator to burn up the pump with continued recirculation. Not requiring bypass is one of the advantages of the horizontal pump system, and a bypass line should not be installed.

A back pressure valve may be needed for horizontal pump operation. The pipeline company will provide information about the normal system pressure. A close evaluation of the actual pipeline pressure will indicate times of low pressure even on systems where the pipeline capacity is fully nominated. With limited oil tankage offshore and the need to sell all oil that is produced, the LACT is calibrated at higher than average production rates. This can result in times that production cannot supply sufficient oil volumes to keep the LACT operating in the proper ranges. These systems are batch operated with periods of no production into the pipeline. The pipeline companies have production limits through the LACT that meet calibration requirements.

The centrifugal pumping system cannot be allowed to vastly over produce due to lack of pressure on the system. These pumps can be operated at twice the desired rate with pressure significantly below design. They can operate fine, but if allowed to operate with no pressure, the hydraulic stage balance can cause the stage to go into upthrust. Each pump stage can be tested to determine where the high rate at reduced pressure occurs. This is an important design consideration that should not be overlooked by design consultants. The pressure can be set to maintain a fixed rate from the pumping system.

Unlike the oil well installation, the horizontal pumps can operate at an extended range from the normal pump sales catalog design rates.. The lower rate is limited by heat transfer in the pump, as the thrust chamber is fully rated for thrust from the pump. The pump is made from metals that do not deteriorate with normal heat. In pipeline service the LACT will not allow low flow rate because of calibrated measurement requirements. The typical motor is an air fan cooled induction machine that can have cooling problems when operated on a variable speed drive, but will not have cooling problems with lower rate and lower load.

A vibration control device is usually installed on the thrust chamber to turn off the unit if high vibration is detected.

Discharge pressure safety high/low controls are usual for detecting a blockage or leaking system. These devices for oil pipeline service are required and require regular testing. High and low pressure pump intake controls can be installed on the pump, but these do not have real value if the system is being supplied from a centrifugal prime pump with a fixed pressure for the LACT unit.

A discharge check valve is required with multistage centrifugal pumps to prevent one pump from circulating oil back through a pump which is not operating. Isolation valves are needed to take a pump out of the system. The isolation valves can be operated in such a way as to cause a problem if the check valve is leaking. If the input valve is closed first on an operating system and if the discharge isolation valve is still open with a leaking check valve the intake seal can be over-pressured. The discharge valve should be closed before the intake valves are closed.

Depending on the pump selected, a low motor current relay can provide an additional level of safety. Though not foolproof, the relay will aid an operator who may inadvertently try to operate a pump that does not have all the valves in the correct orientation. This can allow for manual operation if equipment like a programmable logic controller that monitors and automatically operates the pipeline pumping system is temporarily out of service. Automatic operation is easily achieved because these pumps can be started without operator intervention.

History of offshore oil pipeline platform service using centrifugal pumps

Some oil pipeline operations that had high rates and lower pressures used multistage centrifugal pumps installed in a large casing between levels of the platform. This is called a "can" pumping system. This was a typical pump that could have been installed in an oil well. These worked, but were expensive and the electrical systems were expensive with the typical submersible pump motor installations. The lack of flexibility and high cost with electrical failures made these installations unpopular.

Sun Oil Company (now Oryx Energy Company) installed eight cable suspends ESPs in the legs of the Gulf of Mexico, East High Island 327A platform in 1978 for oil transfer. Oryx Energy Company has never worked on 6 of these units which are still operating today. Eighteen years of operation is most likely one of the longest operating cable suspended ESPs in the world.

In November, 1994, Oryx Energy installed a multistage centrifugal oil pipeline pumping system on the East High Island 379B platform in the Gulf of Mexico. This is a 16,000 barrel of oil per day facility. Operation has been excellent with positive comments from the field personnel.

Oryx Energy Company has purchased a multistage centrifugal oil pipeline system for the world's first production Spar to be installed in September 1996 at Viosca Knoll 826. This is a floating facility in 1700 feet of water in the Gulf of Mexico with 25,000 barrel per day capacity that utilizes the economic advantages of the multistage centrifugal pumping system.

Conclusion

Multistage centrifugal pumping systems can provide significant advantages for fluid pumping service when compared with positive displacement reciprocating pumping systems. A complete analysis requires an evaluation of the effect of the pipeline pumping system on the design of the entire electrical power system. The use of Variable Speed Drives can enhance the performance and operating range of the system, but care must be taken in the initial design and economic evaluation.

Future floating production facilities, as well as remote installations with generator sets may find the use of multistage centrifugal pumping systems advantageous.

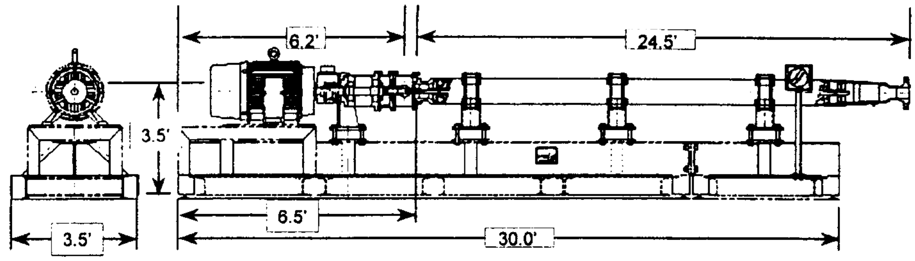
Future areas of study

A vertical pump design with the same characteristics of the horizontal pumping system will have space saving advantages for platform installations. Offshore platforms are unique with vertical space between decks being available for needed pump length. This can reduce the horizontal footprint of the equipment. Installation and maintenance is easy with a platform crane. Vertical motors and multistage centrifugal pumps are available, but current thrust chamber design is for horizontal operation only.

References :

1.) Packard, K; "Reduced Operating Harmonics on Variable Speed Drive Applications", April, 1995 SPE Gulf Coast Section ESP Roundtable.
2.) Bolin, W.D.; "Multistage Centrifugal Pumping System vs. Positive Displacement Pumps for Offshore Oil Pipeline Service", April, 1996 SPE Gulf Coast Section ESP Roundtable.
3.) O'Tool, W., and O'Brien, J.B.; "Testing New Submersible Pumps for Proper Sizing and Reduced Cost"; SPE # 15425, SPE Annual Technical Conference, October 1986.
4.) API RP 11-S-8; "Recommended Practice on ESP System Vibrations", 1992.

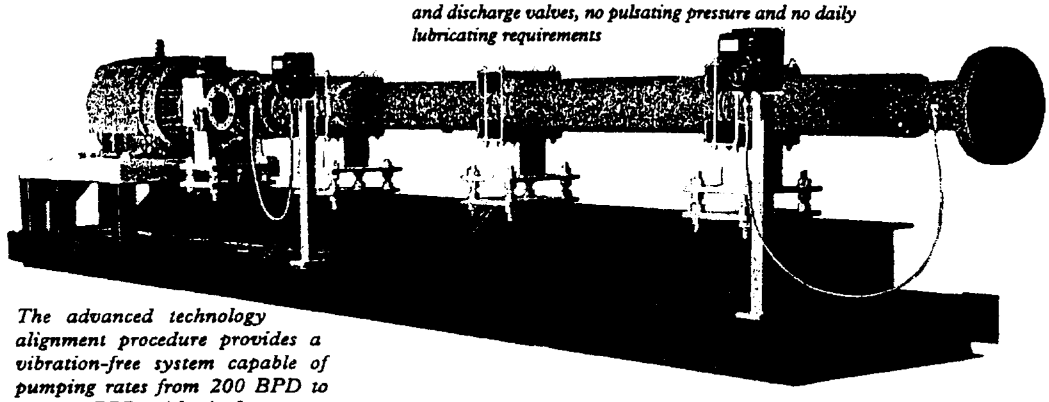
Acknowledgments: The authors would like to thank ESP, Inc. for permission to publish and present this paper.



Motor	Pump	Frame	Thrust Chamber	Options
350 hp , 380 volt, 2970 rpm @ 50 hertz S449SS Frame	Multi Stage Centrifugal TJ12000	30 ft.3900 lb base skid	High Capacity Bearinmg	GE Mag Break Starter, Soft Start, NEMA 3R & 4 Encl.
	48 Stage 12" 50#/ft. Center I Beam	L-10 life of over 70,000 hrs	Suction/Discharge safety switch	
Totally Enclosed Fan Cooled 1.15 Service Factor	Designed for 11000 bpd Discharge head of 1410 psi 4" ANSI class 100# Suction 4" ANSI class 1500# Discharge	8" 15#/ft. outriggers 6" 12#/ft. cros bracing 5-4" square tubing supports 3/4" steel plating	@ 3,000 lb of thrust 150 psi rated mechanical seal Rigidly supported	Vibration Saftey Switch Discharge & Suction Hose

Figure 1 - Typical Horizontal Pumping System
Designed for Water Injection Project

- ***System is skid mounted at the factory for easy set-up in the field***
- ***Minimum site preparation and lower initial cost for maximum production***
- ***Low maintenance by no packing, v-belts or gear reducers, no suction and discharge valves, no pulsating pressure and no daily lubricating requirements***



The advanced technology alignment procedure provides a vibration-free system capable of pumping rates from 200 BPD to 40,000 BPD with single pumps.

Figure 2 - Horizontal Pumping System

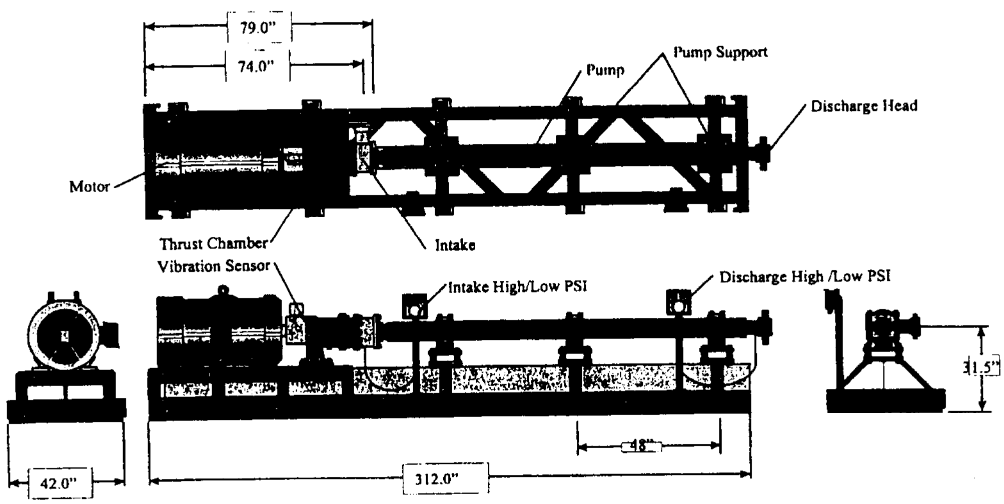
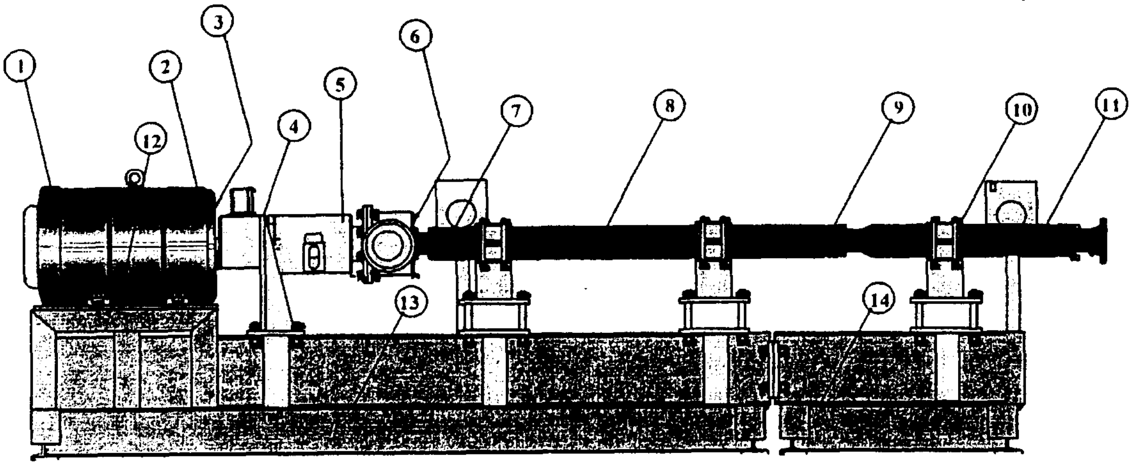


Figure 3 - Horizontal Pump Layout



MEASURE VIBRATION AT POINTS 1, 2, 4, 5, 7, 8, 9 10, 11 AND 12, 13 & 14 IN THE VERTICAL AND HORIZONTAL PLANES.
MEASURE VIBRATION AT POINTS 3 AND 6 IN THE AXIAL PLANE.
LIMITS ARE API RECOMMENDATIONS OF .156 IN/S @ 3600 CYCLES AND .100 IN/S @ OTHER CYCLES

Figure 4 - Horizontal Pump Vibration Analysis

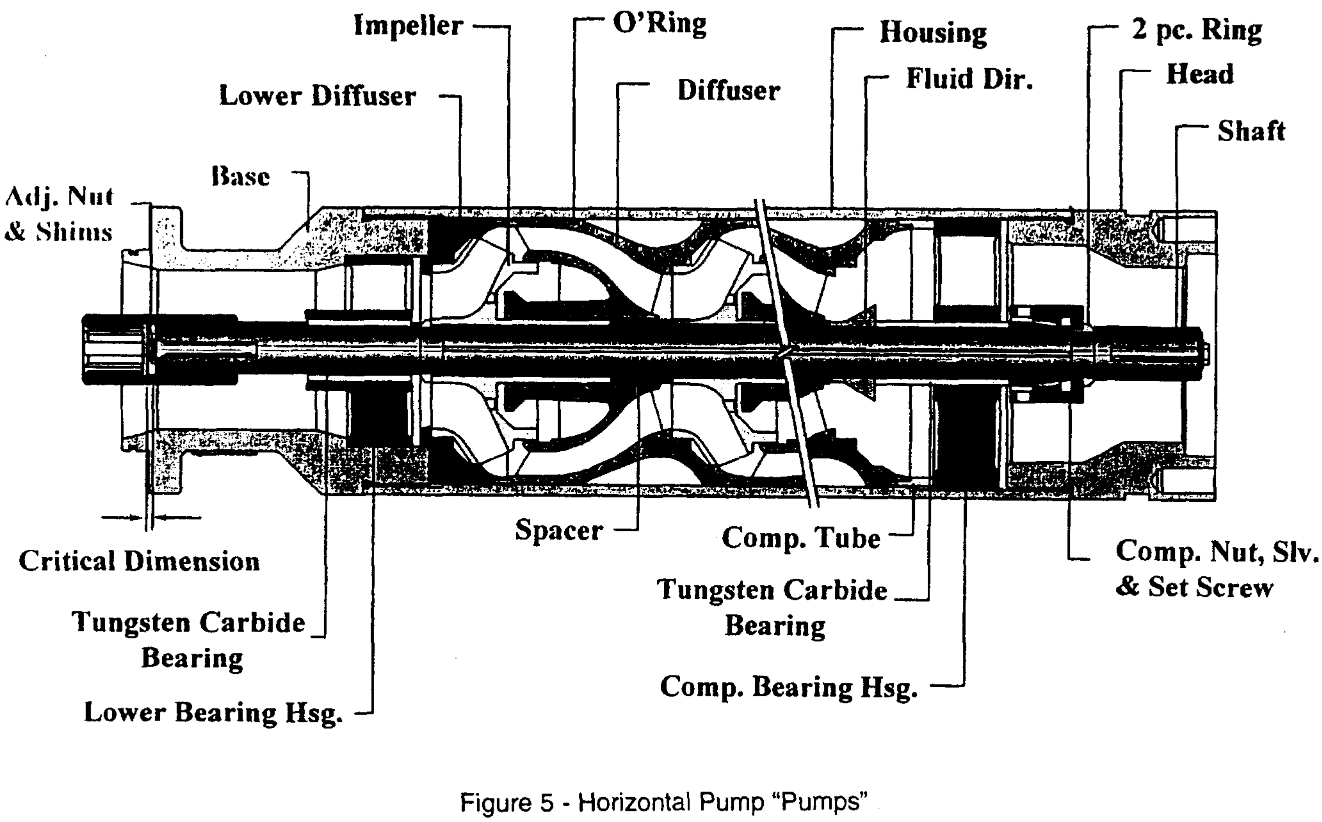


Figure 5 - Horizontal Pump "Pumps"