POSITIVE DISPLACEMENT PUMPS—PERFORMANCE AND APPLICATION

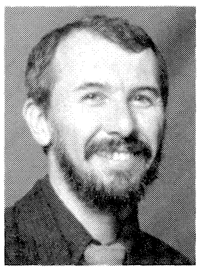
by

David B. Parker

Manager, R&D Testing

Warren Pumps Incorporated Division of IMO Industries

Warren, Massachusetts



David B. Parker is Manager of Research and Development Testing for Warren Pumps Incorporated, Division of IMO Industries. He received his B.S. from the Universtiy of New Hampshire (1979) and is currently enrolled in Western New England College.

Mr. Parker was the Senior Chemist at Luvak Laboratory for eight years before joining Warren Pumps in 1987. At Warren, he was a field service engineer for two years. He became the Application Engineer in 1989 and Manager of Research and Development in 1992. Mr. Parker's responsibilities include pump specification and system design and integration for Warren's line of positive displacement and centrifugal pumps. His primary focus is on screw pumps and coating technology to expand the application range of that product. His experience in industrial applications includes the chemical process industry, the pulp and paper industry, petrochemical, power generation, marine, and military.

Mr. Parker is a member of ASM International.

ABSTRACT

The operating principles of positive displacement (PD) pumps differ from centrifugal pumps. This basic difference is evident in the pump's response to a system's head/flow curve. Several pump applications are presented to illustrate the selection process needed to insure pump reliability. The performance overlap region, where both pump types should be considered, is presented with guidelines to evaluate proper selection decisions.

The data that must be supplied in PD pump specifications are detailed both in definition of terms and their significance. Many engineering courses devote considerable emphasis to centrifugal pumps and system response but omit positive displacement discussion. Specifying a positive displacement pump without prior training is a difficult task. Technical requirements, performance limitations and terminology are presented to assist the person specifying a PD pump.

The PD pump range of operating conditions is presented in several examples to illustrate problems that can be overcome with a properly specified pump. Fluids with large gas fractions or high viscosities can not be moved with standard centrifugal designs. PD pumps allow a wider range of liquids, slurries and foams to be transported without product degradation. Understanding where PD pumps can be used may lead to opportunities to improve processes.

INTRODUCTION

Positive displacement (PD) pumps are not well understood by most users and specifiers. Properly applied, PD pumps offer significant opportunities to improve processes, improve efficiencies, and reduce costs.

PD pumps come in many designs and operating ranges, but they all work on the same principle. An increasing volume is opened to suction, filled, closed, moved to discharge, and displaced. The delivered capacity is nearly constant throughout the discharge pressure range. This constant capacity will intersect a system curve at a defined point, allowing a high degree of system control.

POSITIVE DISPLACEMENT PUMP TYPES

The Hydraulic Institute Standards book differentiates PD pumps into rotary and reciprocating pumps. Rotary pumps are defined as being: vane, piston, flexible member, lobe, gear circumferential piston, or screw pumps. In all of the rotary designs, the chamber is created progressively through rotation of the drive shaft. There may be one or more chambers opened per revolution depending on the design. The chambers are sealed off from suction by close clearance between the rotor and the housing, or by close clearance between intermeshing rotors. Rotation of the shaft moves the chamber along the bore or housing towards discharge. The chamber is displaced to discharge by rotation. The release to discharge progresses with rotation as the volume is expelled so that the flow is typically pulsation free.

Reciprocating pumps are defined as being: steam, power, or controlled volume pumps. In all reciprocating pumps, there are check valves on the suction and discharge. Fluid flows through the suction valve and into the chamber as the plunger, piston, or diaphragm recedes. At the end of the stroke, the chamber is at its maximum size. The suction valve closes, the plunger moves forward into the chamber, forcing the fluid out the discharge valve. The flow from each chamber is a pulse flow. If the pump has several chambers, they are timed to have sequential pulses to minimize the overall pulsation.

SYSTEM RESPONSE

PD pumps create flow, centrifugal pumps create pressure. In a PD pump, flow is created by enclosing a volume at suction, moving it to discharge, and releasing it. Pressure is created by the system's response to flow. If there was no connection at the discharge flange, the flow would exit the pump at atmospheric pressure. Centrifugal pumps create pressure by first imparting velocity to the fluid with the impeller, then converting the velocity to pressure with the volute. If there was no discharge flange connection, the flow would exit the pump with that developed pressure.

The system requirements will determine the type of pump required in most, but not all, cases. If a system calls for a pressurized network of piping with a constant pressure at various flow rates, a centrifugal pump is the best option. An example of this type of system is municipal water. In this system, a PD pump would be less efficient.

Oil pipelines normally require a constant flow at various pressures. At a constant flow rate, pipeline pressure will vary with changes in viscosity. Pipelines transport different products with different viscosities and pressures. Product cooling will increase viscosity and pressure. This is of concern if a pipeline is temporarily shut down then restarted. A centrifugal pump may not be able to produce a high enough pressure to clear the line. A PD pump will overcome the pressure and restart flow.

Fuel delivery systems require a constant fuel flow to control turbines or boilers. Pressure may vary as nozzles become clogged or erode open, but flow requirement remains constant. PD pumps supply a steady source of power. Centrifugal pumps would require recirculation to meet requirements.

Process systems frequently involve batch operations where products are circulated through reactors as the viscosity changes. Pressure and flow requirements are flexible. At the end of the batch, the vessels are pumped out. The pump must be able to handle the full range of viscosities as well as stripping and dry running.

Shear sensitive fluids may require PD pumps to avoid the high shearing action of centrifugal impellers. Most PD pumps operate with laminar internal flow regimes.

SPECIFICATION

The quality and quantity of information on suction conditions will determine the ultimate success or failure of any pump installation. The majority of pump problems, both centrifugal and PD, start at the suction. There must be a minimum amount of absolute pressure available to supply fluid to the pump suction. PD pumps generally require less absolute pressure than centrifugal pumps.

Net Positive Inlet Pressure Required (NPIPR), at the pump suction flange, is the rating of total inlet losses within that pump at rated conditions. Units are pressure terms; PSI, Kg/cm^2, Bar, KPa. These losses include the fluid friction loss along the internal suction path, the change in elevation from the suction flange to the enclosed volume, the fluid friction loss of entering the enclosed volume, and the acceleration to the velocity of the enclosed volume. For any given size, NPIPR will increase with increased viscosity or flow (increased flow = increased speed).

Net Positive Inlet Pressure Available (NPIPA) is calculated the same as NPSHA. It is the total static pressure available at the pump suction centerline, including atmospheric pressure if applicable, less all pipe friction losses at rated flow, less fluid vapor pressure. Vapor pressure does not contribute to available suction pressure, because when the fluid reaches vapor pressure, the fluid starts to boil and the pump enclosures fill with vapor, not fluid.

Viscosity of a fluid is the ratio of shear stress to the rate of shear strain. It is a measure of its resistance to flow. High viscosity fluids, like rubber, adhesives, or molasses, are very resistant to forces applied to move them. Low viscosity fluids, like kerosene or water, have very little resistance to force. Viscosity is reduced as temperature is increased; hot fluids flow more readily than cold fluids. Viscosity should always be given at a specified temperature. Typical units for viscosity are centipoise, centistokes, and SSU. Some examples are listed below:

FLUID	CP @ 40C	SSU @ 100F
Water	1.0	32
#2 Fuel Oil	3.0	38
Vegetable Oil	30	150
SAE 40 Oil	160	800
Molasses	1700	8000
Silicone	1,000,000	4,500,000

Centrifugal pumps are usually not applied above viscosities of 4000 SSU, due to the rapid loss of efficiency as viscosity increases. PD pumps maintain high efficiencies throughout the viscosity range.

Entrained gasses can be handled in large quantities by most PD pump designs, however care must be taken in specifying quantity of gas entrained and flow required. Volumes of gas are usually specified relative to standard temperature and pressure (STP) of 68°F and atmospheric pressure; 14.7 psia; 20°C, 1.034 Kg/cm^2 absolute. By specifying the standard volume of gas and specifying the suction pressure and temperature, the volume of gas present at the pump suction can be calculated. This capacity must be added to the liquid capacity in order to size the pump for the required liquid flowrate. If suction pressure is below atmospheric pressure, even small amounts of entrained gas will expand in volume requiring a larger pump.

Capacity should be defined for the rated condition. If there is an acceptable range of capacities, the minimum and maximum acceptable should be stated. This allows pump suppliers to offer standard products without having to modify for specific capacity requirements.

RATED CONDITIONS

Most applications have one rated condition of service. If there are several operating points, a full set of rated conditions should be specified *per point*. Supplying a range for capacity, pressure, and viscosity without detailing specific points requires pump vendors to offer units capable of operating under any combination of ranges. This can add considerable cost to a design.

Each rated condition requires a value for: capacity, suction pressure, discharge pressure, NPIPA, temperature, and viscosity. The description of the fluid should include the type or specification of the fluid, density, abrasive or corrosive characteristics, gas content, and solids content. If there are solids present, the amount, size, and hardness should be specified.

Most fluids, including water and oil, are Newtonian fluids. The viscosity changes with temperature, but does not change with shear rate. Some fluids exhibit a change in viscosity, increasing or decreasing, with increasing shear rate. Slurries typically thin when stirred, inks and starches thicken when stirred. If the fluid is non-Newtonian, curves of apparent viscosity versus shear rate should be supplied. Hydraulic Institute Standards contain a description of the various types of non-Newtonian fluids.

MECHANICAL REQUIREMENTS

The material of construction should be specified. If cast iron is acceptable, it is usually the least expensive material. If stainless steel or more exotic materials are required, the grade should be specified.

Shaft sealing requirements should be specified. Mechanical seals are available in numerous designs and materials. If there are known designs and materials that work well under similar circumstances, they should be specified. If there is no operating history for a difficult service, the pump vendor will have the seal manufacturer quote the service. If a double mechanical seal is required, a suitable barrier fluid should be specified. The barrier fluid should be compatible with the pumped fluid, capable of absorbing and removing heat, and have sufficient lubrication to protect the seal faces. Double seals require the barrier fluid to be supplied at 15 psi to 25 psi above pump suction pressure. If water is the barrier fluid, piping and drains may be all that is required. Other fluids will require circulating systems capable of supplying the necessary pressure, flow and cooling, or heating.

Drivers for pumps are usually fixed speed AC electric motors. For pumps with one rated condition, this is the least expensive option. Systems with several required conditions may require speed control. Variable frequency controllers for AC motors allow for speed ranges of 25 to 110 percent of synchronous speed. Hydraulic motors also have wide speed control ranges and have the advantage of being explosion proof rated. Turbines and diesels have limited speed ranges. Pumps driven by diesel engines are subjected to the diesel's torsional vibration and require couplings capable of dampening the rotational accelerations.

Relief valves are required in systems with PD pumps. A centrifugal pump can operate briefly without damage against a closed discharge valve and only generate a pressure equal to its shutoff head. Positive displacement pumps can not operate against a closed discharge valve or plugged line. PD pumps create flow and if that flow is blocked, pressure in the system downstream of the pump builds rapidly. If there is no relief valve, the peak pressure generated will be a function of driver horsepower. Pressures several times the designed operating limit can be attained in seconds.

Relief valves need to be sized for the full flow of the pump. Relief valves for centrifugal pumps need only be sized for partial flow; as pressure increases, flow decreases so at elevated pressure, there is less flow to relieve. PD pumps have a constant flow so relief valves must be able to pass the rated flow without raising the pressure above a set design point. The bypass flow from the relief valve should be piped back to the suction source, rather than the pump suction. Returning the flow to the pump suction creates a short loop for the recirculating fluid allowing temperature to rise too quickly. Rupture disc type relief valves work well for rotary PD pumps, but may fatigue due to flow pulsations from reciprocating PD pumps. Spring actuated relief valves have adjustable set points, but can become clogged if the fluid has a high viscosity.

EXAMPLES OF INSTALLATIONS

System Response

The point at which the system curve and the pump performance curve intersect is the condition of operation. Typically, a system curve will require higher pressures for higher flow rates. Centrifugal pump performance has reduced flow with increased pressure. The slopes are of the two curves are opposite. If the slopes are both gradual, the angle of intersection will be small. Minor variations of resistance to flow (partially clogged strainer, valves, etc.) will shift the point of intersection over a range of operation (Figure 1).

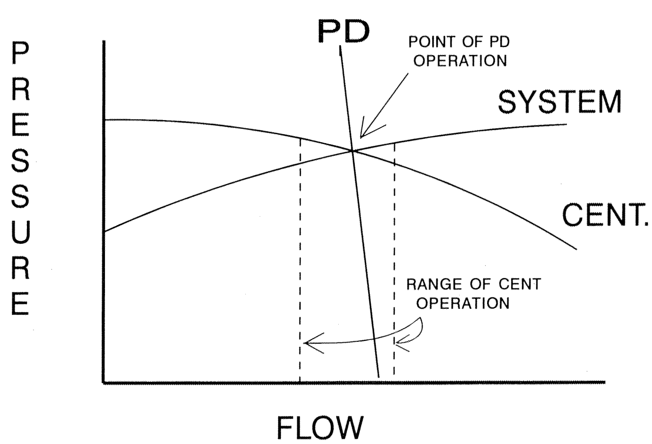


Figure 1. Comparison of System Responses.

PD pumps have a nearly vertical performance curve and, therefore, always intersect the system curve at one point. Minor variations in system resistance do not alter the flow.

Viscosity Range

The chemical process industry has several services beyond the capabilities of centrifugal pumps. Reactor circulator pumps are one example. A typical process involves a reactor and a heat exchanger. The ingredients are loaded into the reactor and the chemical reaction is initiated. The circulating pump takes suction from the bottom of the reactor and pumps the fluid through the heat exchanger and back into the top of the reactor. During the batch, the viscosity changes from one centipoise to over 100,000 centipoise. As the viscosity rises, NPIPA is reduced due to increased friction of the fluid to the reactor vessel walls. Throughout the viscosity rise, heat must be removed at a constant rate requiring a constant flow through the heat exchanger. At the end of the reaction, the product is pumped out of the reactor. The pump strips the reactor and runs dry. After stripping, the reactor is cleaned with solvents and the pump must be able to circulate the low viscosity solvents.

Constant Flow

Paper mills use a white liquor solution to dissolve the lignin form wood fibers. The lignin rich spent liquor, called black liquor, is used as a fuel for the boilers. In combustion, the chemical salts are reduced and the ash is made into fresh white liquor.

The black liquor is evaporated to 75 to 80 percent dissolved solids concentration to increase combustion efficiency. At this concentration, the viscosity at firing temperature of 235°F is 2000-50,000 SSU. Typical nozzle pressures are 125 psig at 600 gpm. PD pumps are used to maintain the constant flowrate as nozzle pressures change due to clogging and eroding. Precise control of fuel addition rates increases the operators control over combustion conditions. This in turn leads to reduced air emissions, a very critical concern in a highly regulated industry.

Gas Content

Fluids that contain large amounts of gas can not be pumped with centrifugal pumps. The gas fills the impeller eye and can not exit the tip of the impeller against the discharge pressure. The pump becomes vapor-bound and stops pumping. PD pumps enclose the gas fraction at suction pressure and can handle up to 95 percent gas in some designs. Most PD pumps are capable of handling in excess of 50 percent gas without modification.

The petroleum industry is using this feature to reduce the cost of offshore oil production and to reduce the chances of oil spills at sea. Traditional production requires large offshore platforms where production from several wells is prerefined; the oil, gas, sand, and water are separated. The oil is pumped ashore in one pipeline and the gas is compressed and pipe ashore in another line. Multiphase PD pumps can pump the unseparated flow from the wellhead to one pipeline ashore. The platform can be unmanned and small with minimal piping and connections, reducing the chance of spills or leaks.

Power Savings

Large centrifugal pump applications, with horsepowers over 100 HP and viscosity over 50 SSU, should be compared to PD pumps for the same service. PD pumps operate at high mechanical efficiencies over a wide range of viscosities. In the overlap region, where both centrifugals and PDs can operate, mechanical efficiency may be the deciding factor (Figures 2 and 3).

Three examples are presented. The first case is for 1000 gpm at 200 psi, using 1.0 specific gravity. The second is for 1000 gpm at 600 psi and the third case is for 2500 gpm at 500 psi. The centrifugal selections are at 3550 rpm with one, three, and two stages, respectively. Impeller specific speeds are between 1000 and 1200. PD pumps are screw pumps with rotor diameters of 6.25 in, 8.75 in and 10 in; speeds are 1750, 1150, and 1150 rpm, respectively. The initial purchase price for the centrifugal pumps may be less than the price of the PD pumps, but the power savings may pay the difference back quickly. If the pumps run continuously and an average cost of electricity of $0.05/KW Hour is applied, each horsepower difference costs $327 per year. For Case 1, at 2000 SSU, that amounts to $29,750. Case 2, at 2000 SSU, is a

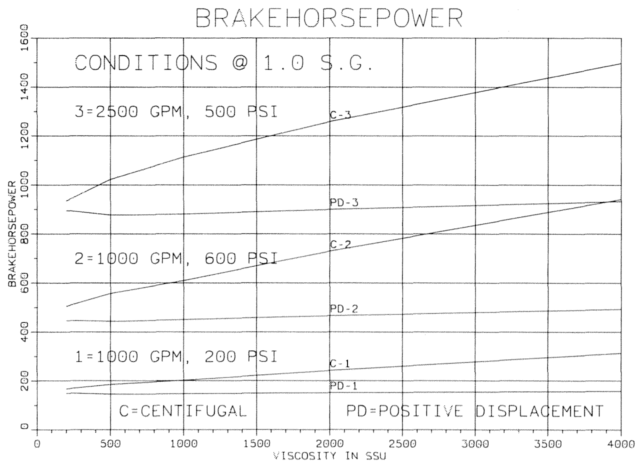


Figure 2. Comparison of Power Requirements.

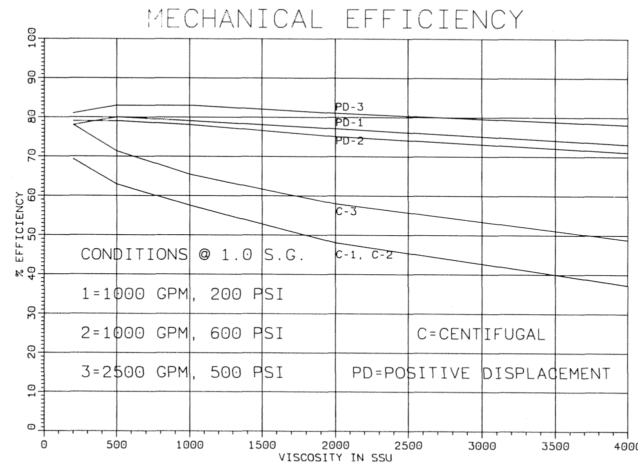


Figure 3. Comparison of Overall Efficiencies.

difference of $85,650 and Case 3 at 2000 SSU, is $117,100 per year. Even at 200 SSU, Case 3 has a difference of $12,750 per year.

CONCLUSION

Positive displacement pumps are capable of moving a wide range of fluids. Entrained gasses, solids, low viscosity to high viscosity, and low NPIPA can all be designed for. The flow is nearly constant, without pulsation (rotary design), and does not impart high shear to the fluid. The high mechanical efficiency offers energy savings.

The proper specification of a PD pump will stabilize operating systems. Supplying the complete suction condition for each design point will insure the success of the installation. In complex services, PD pump manufacturers will assist in the specification process to ensure that the project operates reliably.