SELECTING A PROGRESSIVE CAVITY PUMPING SYSTEM

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Introduction

The Progressive Cavity (PC) Pump is being used in various types of applications world wide, particularly because of its simplicity of operation and increased mechanical efficiency over other methods of artificial lift. As with all fluid lift methods, the proper selection of the pumping system's size and materials of construction is most important to ensure increased operating life and overall efficiency. The selection process for a pc pump system is relatively easy due its simple design. The down hole pump consists of only two parts: the single helix rotor and the double helix stator. See figure 1. The rotor is normally alloy steel machined to an exact tolerance and chrome plated. The stator consists of a steel tube into which an elastomer is injected and chemically bonded. The selection process involves selecting the rotor base metal with the type of plating or coating and the stator elastomer type. Included in the following text is a step-by step procedure for sizing a PC pump system including selecting: a pump model based on production rates, pressure and fluid characteristics; the rod string size and grade based on proven combined stress calculations and well conditions; the surface drive system based on the pump and rod size; and specific ancillary equipment.

Down-hole Pump Materials of Construction

Rotor

The rotating gear of the pump, the rotor, is normally fabricated from alloy steel equivalent to 4140 or 4150 carbon steel, a Brinell Hardness of 200-240 , with a heavy layer of chrome plate.
Alternate coatings for corrosion and heavy concentrations of abrasives have been applied with some degree of success. Some of the more popular coatings tried include tungsten carbide, boron, nickel and ceramic. 300 and 400 series stainless steel as well as 17-4 pH stainless have been applied in very corrosive environments.

Stator

The stationary gear, the stator, is molded from an elastomer. Many different elastomers have been tried and field tested. Most of them are nitrile based compounds formulated using various acrylonitrile (ACN) concentrations as well as various additives and cures that alter the elastomers basic performance characteristics. The basic compounds on the market today consist of low or medium high acrylontriles or Buna N, high nitriles (increased ACN content), highly saturated hydrogenated nitriles (HSN) and a few different flourel formulations (vitons). These elastomers are limited by the oil gravity (<40 API), temperature (< 350 F), CO_2 concentration (<2% in-solution), H_2S concentration (< 15% in-solution) as well as the compatibility with treating chemicals and some chemicals used in EOR operations.

Analysis of the fluid and pre-installation immersion testing should be done to determine which elastomer is best for the application.

Surface Drive System Designs and Configurations

The surface drive system supports the weight of the rod string and fluid as well as supplies the necessary power to the pump through the rod string. The configuration of the system is determined by the type of prime mover desired or required. The bearing housing of the gear head supports the weight of the rods and the hydraulic load via a bearing supported drive shaft or polished rod depending on the design of the head. The drive shaft can be turned using belts and sheaves or directly by connecting the prime mover to the drive shaft. The prime mover can be an electric motor (see figure 2.), hydraulic motor, gas, gasoline or diesel engine. The gear head can be either solid or hollow shaft. Both designs are popular and have relatively the same features but the hollow shaft offers the added advantage of lifting the rotor out of the stator without having to remove the gear head form the wellhead. Selecting the proper size drive system is dependent on the pump size selected and the associated required rod size.

Determining the Required PC Pump Materials of Construction

Rotor

To select the best materials of construction for the rotor consideration must be given to the pH and/or corrosive nature and abrasive characteristics of the well fluid. If the pH is between 5 and 8 chrome plate can be used. If the pH is below 5, then stainless steel should be selected. Most stainless steels are soft compared to 4140 alloy steel, therefore, the percent of solids and the abrasive nature of the solid particles must be considered before specifying the type of stainless steel. 316 stainless is most common, but it is the softest of the other materials such as 416 or 17-4 pH. Other more exotic materials such as a boronized rotor, for example, is both corrosion and abrasion resistant and can yield run lives of 3 to 5 times that of chrome in the same application. However, chrome plate is comparatively less costly and offers very good wear resistance. The rotors can be easily and inexpensively replated if the base metal is not damaged. Rotors are available with varying thickness' of chrome plate and experience indicates that increased chrome thickness allows for longer life in abrasive/corrosive environments. As the chrome is worn the pump begins to loose volumetric efficiency and upon removal from the well the rotor still has chrome on the surface and the base metal is not damaged. With only .010" of chrome per side the base metal is damaged before the drop in efficiency is noticeable, therefore, the rotor may not be replated. A plating thickness of .016-.020" per side has proven to be most effective in facilitating rechroming and also offers extended service life in most applications.

Stator

The best elastomer for the application is dependent on the oil gravity, percent water, the water conditions, concentrations of both H2S and CO2 in-solution with the well fluid, and the nature of the treating chemicals that may be used. Each manufacturer offers different elastomers that may react differently in the same environments, therefore, it is recommended to contact the appropriate manufacturing representative for compatibility details. Most of the manufacturers use nitrile based compounds as a standard, and as mentioned earlier,the main difference is in the ACN content.

Buna N or Low to Medium Acrylonitrile (ACN) Nitriles-

For typical oils of less than 25 API the standard Buna N or low to medium high acrylonitrile can be applied. This elastomer also performs well in high water cut applications as well as applications where CO_2 is present in the fluid. The temperature limitation of this type of elastomer is around 200 F under static conditions and is normally not used in wells exceeding 180 F. Buna has very low tolerance for H_2S in any concentration.

High (ACN) Nitriles-

This type of elastomer can be used in the same applications as that of buna and will yield similar performance. The higher ACN content gives these elastomers increased aromatic swell resistance which yields better performance in typical oils with API gravities above 25 and have been successfully used up to 38 API.. Depending on the ACN content, this elastomer can have varying degrees of swell in oil, therefore, the manufacturing representative should be consulted for a well fluid compatibility analysis. This elastomer has some resistance to H_2S hardening, but is not recommended for H_2S service. The temperature limitation is slightly higher than that of buna at 200 F operating.

Highly Saturated, Hydrogenated Nitriles (HSN)-

This elastomer is mostly used in H_2S and higher temperature environments. The H_2S resistance varies with the compounds. To date the highest concentration into which this type of elastomer has been successfully applied is 15% in-solution. The temperature limitation ranges from 250 F to 300 F, again depending on the formulation of the compound. This elastomer type normally does not have the aromatic resistance of the High Nitirile, but can be utilized in most of the same applications if proper pump selection procedures are used.

Factors Effecting the Selection and Operation of the PC Pump

Solids

Solids present in formation fluids can reduce the operating life of the pump by wearing both the rotor and stator. It is very difficult to categorize the abrasive nature of solids in oil and water. How abrasive a solid particle can be is dependent on its size, shape, hardness, the percent or concentration and the nature of the medium carrying the solids.

PC pumps have been applied at speeds in excess of 600 rpm but the normal operating range is 50-500 rpm. To reduce the effects of abrasion the pump selected should operate as slow as possible and its pressure capability should be sufficient to yield a relatively high volumetric efficiency reducing the amount of slip. Slip is the measured decrease in flow as the differential pressure across the pump increases. See figure 3. The fluid is forced back between the elements across the seal lines and when the fluid is carrying solids the potential for wear increases. Slip can be reduced by derating the pressure per stage which is achieved through increasing the number of stages required or the compression fit between the rotor and stator. Selecting the higher pressure pump, when possible, is the most desirable approach.

The amount of wear generated in an abrasive application is more proportional to the square of the speed than to a linear relationship. Research has found that by cutting the speed in half the life of the pump can be increased up to four times. This is a significant factor in the pump selection process.

Viscosity

In a pc pump, as the rotor begins a revolution the cavity opens and the fluid enters the cavity. Then as the rotor finishes the same revolution the cavity is closed again pushing the fluid to the next cavity. The amount of fluid that can enter the cavity is certainly dependent on the fluid viscosity, the size and shape of the opening and the differential across the opening. The more viscous the oil the higher the entrance losses into the first cavity requiring more time for compete cavity fill. If the rotor is turning too fast, the cavity will only be partially filled resulting cavitation and a decreased pump volumetric efficiency. There is a critical speed associated with the fluid viscosity at which 100% volumetric efficiency is not achievable. Above this critical speed the cavity is not completely filled, so in order to achieve a desired flow rate the pump speed must be increased. Increasing the speed magnifies the cavitation problem further reducing the volumetric efficiency. Therefore, it is a better practice to select a pump that will run well below critical speed for the viscosity of the fluid maintaining 100% cavity fill. See figure 4.

Potentially offsetting the drop in volumetric efficiency is the reduction in slip in the pump due to the viscous fluids resistance to flow back between the elements. Pumping a viscous fluid increases the pressure capability of the pump at slow speeds. The pump could pump higher than its 100 psi/stage rating, but the life of the pump would be sacrificed. The line losses that occur in the tubing string above the pump, due to the high fluid viscosity, add pressure to the pump discharge increasing pressure per stage and the potential for slip. The best approach to take in pump selection for heavy viscous oils is to choose the higher pressure rated model that has high enough displacement to operate at a speed below the critical speed for the viscosity.

Gas

The pc pump will pump limited quantities of gas if liquid is present to carry away heat of friction developed between the rotor and stator. Lack of an adequate amount of liquid would result in a "run dry" condition, which is a scorching of the elastomer surface. To prevent this type of failure the pump should be set below the gas producing zone so that the gas will not readily displace the fluid from the pump intake. If there is sufficient fluid available to lubricate the elastomer, then the pump will produce the gas without causing any damage. Since this pump will not gas lock, the gas will have an effect on the amount of liquid that is produced at the surface. The gas takes up volume in the cavities which results in a decreased volumetric efficiency. To check the performance of the pump simply adjust the fluid production at the surface for the conditions at the pump intake. Avoid the mistake of increasing the pump speed to compensate for the lower volumetric efficiency. This may result in pumping the well off and damaging the stator.

Sizing The Down Hole Pump

1. The two basic conditions required to size the down hole pump are total dynamic head and desired flow rate. The total dynamic head (TDH) or the differential pressure across the pump is determined by calculating the discharge pressure and subtracting the pump intake pressure. The discharge pressure in the tubing string is the sum of the pressure due to the fluid column, associated line losses (pressure drop) and surface line/facility pressures. The pump intake pressure is the sum of the fluid column pressure in the casing annulus, gas pressure above the fluid level and associated surface line/facility pressures. For most applications with water or light oil (higher than 20 API and/or less than 1000 cp.) the TDH is the producing fluid level (ft) plus the flow line pressure converted to feet. If the oil gravity is lower than 20 API and/or the viscosity is higher than 1000 cp., then the line losses in both the tubing string and flow line should be calculated. The calculation requires the flow rate (bpd), tubing and rod size, down hole viscosity, surface viscosity, and flow line size.

2. Determine the abrasive characteristics of the fluid. Special considerations should be taken for the percentage of solids in-solution at the pump intake and the abrasive nature of the solid particles. There are speed limitations for the pump based upon the abrasiveness of the fluid. The the solids concentration is considered heavy, avoid running the pump in the upper half of the pump speed range. The maximum pressure capability of the pump should be derated to compensate for the solids concentration. Making these speed and pressure adjustments results in sizing a larger pump for the application which extends the operating life of the elements.

3. Choose a pump model that fits the requirements for pressure/stage, speed/abrasion and desired flow rate. Determine the compression fit or the volumetric efficiency desired. This is dependent on the anticipated increase in compression that will result form elastomer expansion due to temperature and swell due to aromatic content of the oil.

4. Check to see that the selected pump will fit in the casing.

5. Examine the performance curve for a pump of the required fit to determine the horsepower and speed required for the application. Use the starting torque to determine prime mover size required. If variable speed is utilized the prime mover can be selected using the running torque. If a fixed speed system is used the prime mover should be sized using the starting torque.

6. Determine the rod string size by using published data or calculate the maximum shear stress of the rod due to combined axial and torsional loads using the equation below:

$$Ss= [(16 \times 63025 \times Hp/3.14d^3 \times N)^2 + (.5(.88WrL+Ap(.433DG+Ps)/Ar)^2]^{.5}$$

where:

Hp= running horsepower	Wr = weight of rod (lb/ft)	G= sp gr	Ar = rod area (sq in)
d= rod diameter (in.)	L = length of rod string (ft)	Ap= effective rotor area (sq in)	
N= rpm	D= fluid level (ft)	Ps=surface pressure (psi)	

The effective area of the rotor is the crest-to-crest diameter area minus the cross sectional diameter area. This is the area of the rotor where all of the hydraulic load is applied.

Through much field testing and a study of the successful application of sucker rods, it has been proven that for design purposes the maximum shear of the rod should not exceed 30,000 psi for a grade "D" rod or an equivalent. This limitation is proportional to the yield strength of the rod, so compare the yield of the rod you intend to use and increase or decrease the maximum shear limitation proportionately. When sizing the rod string calculate the maximum shear, if it exceeds 30,000 psi choose the next largest rod diameter or use a grade with a higher yield.

7. Select a drive system and gear head. Select a gear head that has the thrust capacity that fits the application and will yield sufficient bearing life. Calculate the L10 life of the bearing to determine if the expected life is sufficient. Use the following equations to calculate the expected L10 life in hours:

Calculate the axial load (Fa) that the bearing will need to support:

$$Fa\ (lbs) = [Wr\ (1-.128G)L] + [Ar\ (D/2.31)] + [Ps(Ar)]$$

then;

Calculate the L10 life if the bearing in hours under these conditions:

$$\text{Expected life (hrs)} = (L10/Fa)^{3.3} \times 3000 \times 500/N$$

where:

L10= axial bearing load rating (lbs)

N= rpm

8. Select the drive system configuration. As mention earlier, this can be any type of prime mover. Be sure that the power source is sized correctly to start the unit.

9. Determine what ancillary equipment will be necessary to enhance the operation of the system by protecting the pump, tubing, rods and maintenance personnel. The following section discusses pump-off controls, rod guides, special rod couplings and different anchors used in the system.

Ancillary Equipment to Enhance the Operation of the System

Flow detection devices

Flow detection devices should be considered if the desired fluid level is expected to be near the intake of the pump or when the inflow of the well is not known, as in a new well. The following is a brief description of a few of the most used devices:

Flow meters- Meters are used to measure the liquid production at the surface. Monitoring the fluid production allows a decrease in the flow rate to be measured so that the unit can be shut down with a predetermined decrease in the flow rate.

Differential pressure switches- This is an arrangement in the flow line where fluid flow is directed through an orifice. A given flow rate will result in a specific pressure drop across the orifice. This pressure drop or differential can be monitored through a pressure gauge that has a preset low and high pressure shut off. As the flow rate decreases the differential pressure across the orifice drops accordingly and once the low set point is met the unit is shut down.

Thermal dispersion devices- This is also a flow line mounted system. The sensor, which is consists of two probes, is mounted in the flow line where a full stream of fluid passes by the thermal probes. The temperature variance between the two probes is dependent of the nature of the fluid and the flow rate between the probes. The temperature correlates to a measured milli-amp signal that can be recorded. A low milli-amp signal indicates a decrease in flow or a change in the medium passing through i.e., a change from liquid to gas. When the preset low milli-amp signal is reached the unit can be shut down.

All of these devices can be instrumented with recorders and timers to control the pump operation. The systems can be designed for manual restart or set to automatically restart after the well is given time to recover.

Rod guides/centralizers

Rod guides are primarily used in deviated applications, although many producers routinely use them as a precaution against tubing wear. The most popular guide type is a molded synthetic material that is either field applied or molded to the body of the rod above and below the couplings and is some cases in the center of the rod length. The number and location of the guides is determined by the severity of the deviation.

A new design is receiving some attention in the field. This is a rod centralizer that fits snugly in the tubing and the rod spins inside the centralizer. This decreases the drag in the tubing and eliminates any problems of tubing/rod guide wear.

Coated rod couplings have been used and also are very popular. The coupling surfaces are either plastic, hard metal faced or rubber. Many times these are used in conjunction with the rod guides on the body of the rod for added protection. The amount of solids in the application should be considered before selecting the guide style and material.

Gas separators or anchors

Gas separators should be considered in any application where the gas may be produced through the pump as the gas will effect the volumetric efficiency of the pump. There are several gas separator designs each having advantages and disadvantages. The efficiency of the separator is the most important issue. The conventional "poor boy" style is not an efficient separator. The best style to use is the "cup type" which uses the "poor boy" design but with an additional separator at the entrance into the anchor which increases the efficiency. In applications with production rates in excess of 600 bpd conventional gas separator designs are generally not very efficient and should not be considered.

The best separation technique is to set the pump intake as far below perforations as possible. This allows for the gas to break out of solution in the casing annulus before reaching the pump intake. In most applications, setting below perforations and using a "cup type" anchor will yield sufficient gas separation.

Tubing anchors

Tubing anchors are used to ensure that the tubing will not come unscrewed during operation. Most applications do not require anchoring the tubing because it is unlikely that the prime mover has enough torque capability to unscrew the tubing, if the tubing threads are in good condition and tightened to at least API optimum specs. Variable speed drive systems do offer the advantage of very high torque at low speeds. When using variable speed drives tubing anchors may be necessary.

References:

1. Klein, S. T., "Effects of Viscosity, Sand and Gas on the Selection and Operation of Progressing Cavity Down Hole Pumps", Pacific Coast Oil Show, 1984.

2. " Operators Manual", BMW Pump, Inc., 1992

Author's Biography:

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Employed with BMW Pump Inc. since December 1993. Prior to BMW was with Robbins & Myers, Moyno Oilfield Products for 10 years with principle responsibilities of marketing and technical advancement of the progressive cavity pump in down hole oilfield applications.
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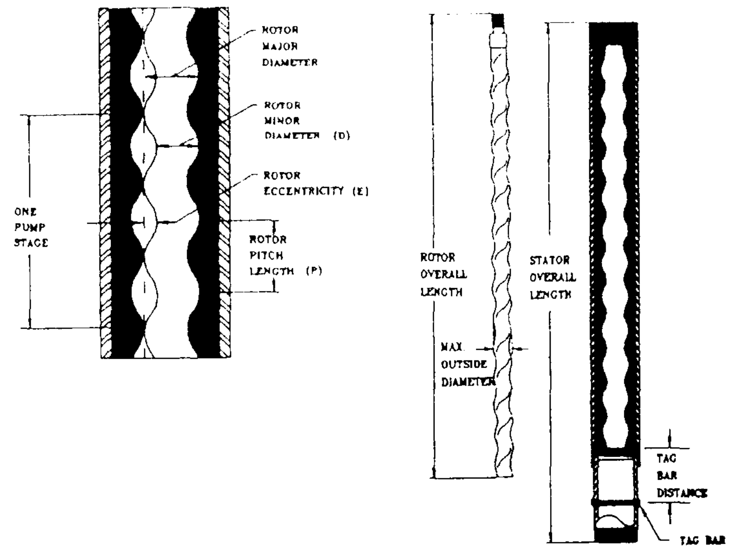

Figure 1 - PC pump cut away

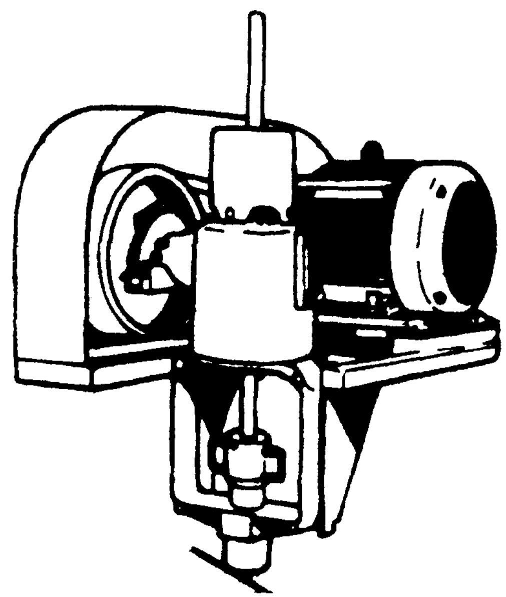

Figure 2 - Electric motor surface drive

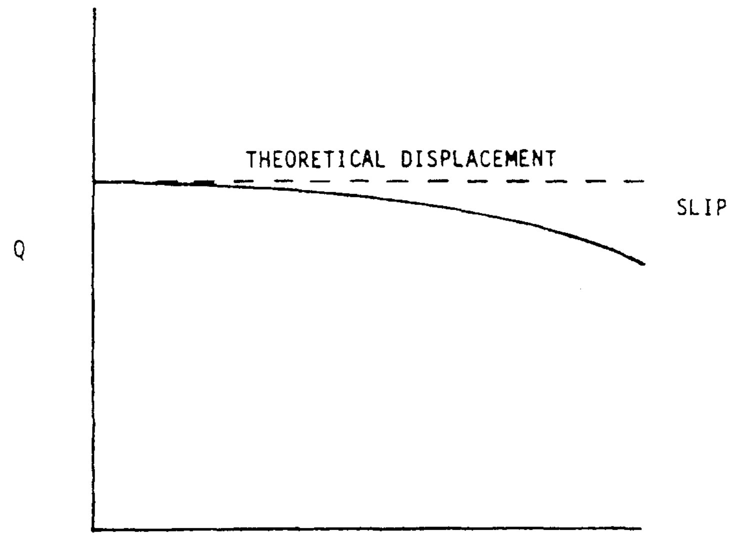

Figure 3 - Slip is directly proportional to pressure

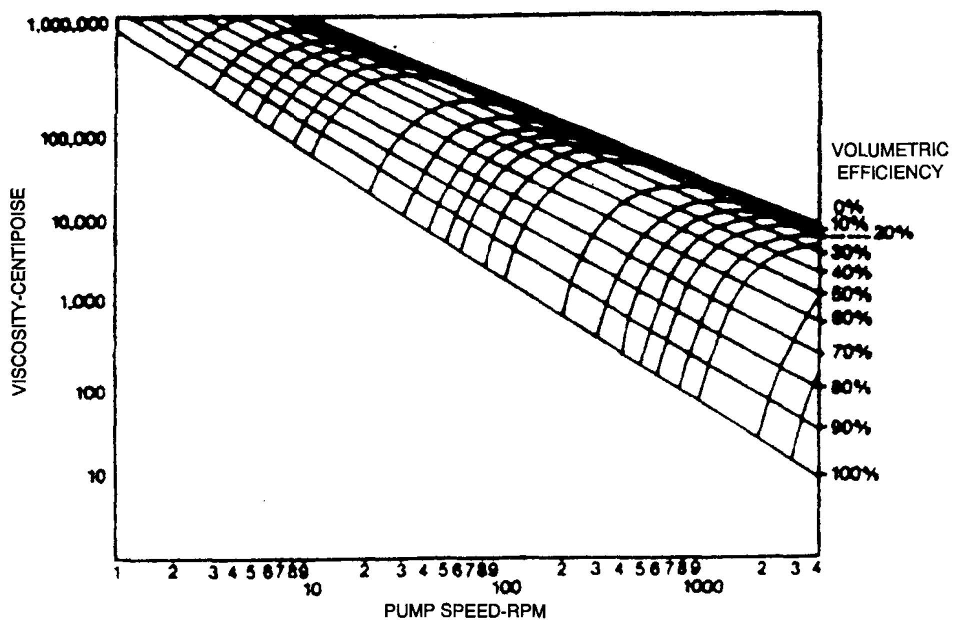

Figure 4 - Efficiency related viscosity and speed