Celal Bayar University Journal of Science

Comparison of Sucker Rod Pump and Progressive Cavity Pump Performances in Batı Raman Heavy Oil Field of Turkey

Sukru Merey*

Batman University, Department of Petroleum and Natural Gas Engineering, Batı Raman Campus, 72100 Batman, TURKEY
*sukru.merey@batman.edu.tr
*Orcid: 0000-0003-2354-2905

Received: 14 November 2019
Accepted: 15 June 2020
DOI: 10.18466/cbayarfbe.646805

Abstract

Batı Raman Heavy Oil Field is the largest oil field in Turkey in terms of oil reserve potential. Since 1961, oil production continues in this field. Although mostly sucker rod pumps (SRP) are used in this field to produce oil, the number of progressive cavity pumps (PCP) increases day by day. Hence, in this study, it is aimed to design SRP system and PCP system in the conditions of Batı Raman Heavy Oil Field. According to daily oil well production data of this field, these designs were completed for three cases: Case 1 (60 bbl/day), Case 2 (5 bbl/day) and Case 3 (150 bbl/day). The output results of this study indicates that less power requirement of PCP system (54.5 %, 46.9 % and 49.1 % of the power requirements of SRP systems for Case 1, Case 2 and Case 3, respectively) and its flexibility in viscous-heavy oil including solid particles make PCP system more advantageous.

Keywords: Heavy oil, inflow performance, PCP, SRP, outflow performance.

1. Introduction

Depending on reservoir pressure and wellbore flowing pressure, oil wells can be either on natural flow or on artificial lift by the help of oil pumps [1]. The number of oil wells in the world was estimated approximately 2 million. Artificial lift is essential for more than 1 million of these wells (Lea, 2007). The percentages of different artificial lift systems in oil wells in all around the world were summarized as: 41% naturally flowing, 26% plunger lift, 21% sucker rod pump (SRP), 4% gas lift, 1% progressive cavity pump (PCP), 1% electrical submersible pump (ESP) and 6% other types (Takacs, 2015). The selection of oil well pumps depends on many well/reservoir parameters and criteria. Table 1 [2, 3] compares the artificial lift selection criteria for SRP, PCP, gas lift, plunger lift, and ESP.

In this study, it is aimed to design and compare the performance of SRP and PCP in the conditions of Batı Raman Heavy Oil Field of Turkey, which is under production since 1961. In Table 2 [4-10], the reservoir properties of this oil field were summarized. When Table 1 and Table 2 are analyzed together, it is obviously seen that SRP and PCP are appropriate pumps for Batı Raman Heavy Oil Field. Before designing SRP and PCP systems for the wells of Batı Raman Heavy Oil Field, it is important to discuss this reservoir because reservoir properties are determining factors in oil well pump designs. Batı Raman Heavy Oil Field is in the South Eastern of Turkey and it is the biggest oil field in Turkey (1.85 MMMSTB) in terms of reserve potential. This oil field was found in 1961.

With the increase of production wells, oil production from Batı Raman Oil Field increased up to 9000 bbl/day in 1969 as seen in Figure 1. However, with the decline of reservoir pressure from 1800 psia to ~400 psia, oil production decreased sharply as seen in Figure 1 [4-7].

Oil is produced from Garzan limestone in Batı Raman Oil Field as seen in Figure 2. Basically, it is a long, partly asymmetric anticline oriented in the east-west direction (17 km length-4 km width). Garzan limestone is heterogeneous. Moreover, in the central and western part of Batı Raman Oil Field, the reservoir is a fractured

Celal Bayar University Journal of Science
Volume 16, Issue 2, 2020, p 191-199
Doi: 10.18466/cbayarfbe.646805

vuggy limestone. On the other hand, the reservoir is chalky and tighter in the east part [4,11]. Due to heavy oil with high viscosity, low reservoir pressure and weak reservoir drive mechanisms (only expansion of reservoir rock and fluid; very weak water drive influence at the central north flank wells), the primary oil recovery of Bati Raman Oil Field was only 1.5-1.7% [7,9,11].

Table 1. Artificial Lift Selection Criteria for Different Oil Well Pumps [2, 3].

Criteria	SRP	PCP	Gas Lift	Plunger Lift	ESP
Operating Depth, m	30-3050	610-1829	1524-4572	2438-	305-4572
Operating Volume, bbl/day	5-5000	5-4500	200-30000	1-5	200-30000
Operating Temperature, °C	38-288	24-121	38-204	260	38-204
Corrosion Handling	Good to Excellent	Fair	Good to Excellent	Excellent	Good
Gas Handling	Fair to Good	Good	Excellent	Excellent	Poor to Fair
Solids Handling	Fair to Good	Excellent	Good	Fair	Poor to Fair
Fluid Gravity, API°	>8	<35	>15	Gas-Liquid Ratio: 300 scf/bbl	>10
Prime Mover	Gas or Electric	Gas or Electric	Compressor	Well's Natural Energy	Electric Motor
Offshore Application	Limited	Good	Excellent	N/A	Excellent
Overall System Efficiency, %	45-60	50-75	5-30	N/A	35-60

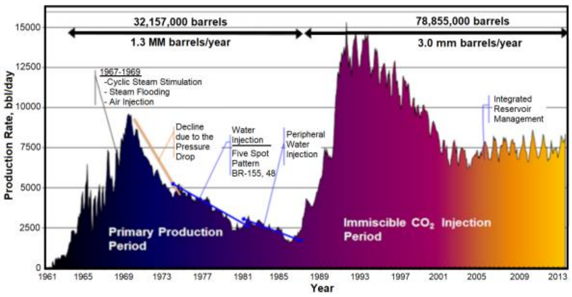

Figure 1. Batı Raman Oil Field Production History [10].

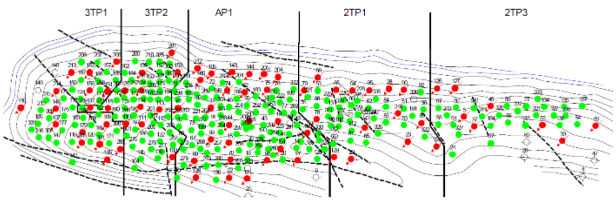

Figure 2. Garzan Structure Map of Batı Raman Oil Field (Green circles: production wells; Red circles: injection wells) [7].

Table 2. Reservoir Properties of Batı Raman Oil Field [4-10].

Estimated Oil Reserve, MMMSTB	1.85
API° Gravity	12 (9-15.1)
Well Depth, m	1310
Gross Reservoir Thickness, m	64 (60-80
Net Reservoir Thickness, m	50
Reservoir Lithology	Garzan Limestone
Reservoir Structure	A long, partly asymmetric anticline oriented in the east-west direction (17 km length-4 km width)
Oil-Reservoir Drive Mechanism	Rock and Fluid Expansion, Insignificant Water Drive
Solution Gas-Oil Ratio (GOR), scf/bbl	18 (10-46)
Bubble Point Pressure, psia	160
Original Reservoir Pressure, psia	1800
Average Reservoir Porosity, %	18 (10-25)
Connate Water Saturation, %	21
Average Matrix Permeability, md	16 (10-100)
Effective Permeability (Well Test Data), md	200-500
Oil Viscosity Range in Reservoir, cp	592 (450-1000)
Reservoir Temperature, °C	59-65.5
Formation Water Salinity, ppm	40,000 to 160,000
Total Compressibility, 1/psia	8.61×10^{-6}
Oil Production Rate Per Well, bbl/day	<100

Enhanced oil recovery techniques (EOR) were essential in Batı Raman Oil Field because of its low primary recovery and huge reserve amount. Many EOR techniques (Waterflooding, steam injection, microwave heating, CO_2 injection, water alternating gas injection) were tested in this field to raise oil recovery of this field [8,9,12,13]. Among them, CO_2 injection (transported with pipelines from natural CO_2 field of Dodan, 89 km away from Batı Raman Oil Field) increased oil production enormously as seen in Figure 1 [4,6,12]. Basically, injected CO_2 was immiscible to heavy oil at the reservoir conditions of Batı Raman Oil Field, but it swelled heavy oil in the porous media and made it more mobile. Moreover, CO_2 injection increased the reservoir pressure. This project was implemented to the whole reservoir between 1988 and 1993 [6,9]. To illustrate, the peak oil production from Batı Raman Oil Field was 13000 bbl/day in 1993 after the implementation of immiscible CO_2 injection project [7]. From 1986 to 2014, the recover factor reached to approximately 6 % with the help of CO_2 injection project [14]. Currently, CO_2 from Dodan Field is being still injected to Batı Raman Oil Field. It is expected that the oil recovery from Batı Raman Oil Field is likely to reach up to 10-10.5 % by taking the advantage of immiscible CO_2 EOR technique [9,15].

Overall, the reservoir properties and well properties of Batı Raman Heavy Oil Field of Turkey are appropriate for the installation of both SRP and PCP. After the discovery of this field, SRP was chosen in the wells as in the other part of the world. However, recently the number of PCP in both Batı Raman Oil Field and the world increase. Both pumps have certain advantages and disadvantages. Table 3 lists the comparison of advantages and disadvantages of SRP and PCP. As listed in Table 3, PCP is advantageous due to its applicability to high viscous fluids, large concentration solids and its tolerance to free gas. Injected CO_2 is also being produced from the production wells together with heavy oil in Batı Raman Oil Field nowadays due to the implementation of immiscible CO_2 EOR technique since 1986 [14]. Although the number of PCP in Batı Raman Oil Field is increasing, SRP is still the dominant artificial lift method. For this reason, SRP and PCP designs were made for this field and their performances were compared in this study.

Table 3. Comparison of advantages and disadvantages of SRP and PCP [3,16].

Sucker Rod Pump (SRP)		**Progressive Cavity Pump (PCP)**	
Advantage	*Disadvantage*	*Advantage*	*Disadvantage*
Simple design	Deviated Wells	Low Cost	Deviated Wells
Easy installation	High Solid Content	High Viscous Fluids	Sensitivity to Fluid Environment
Low Pressure Wells	Limited Production Rate	Large Concentration of Solids	Limited Production Rate
High Temperature and High Viscous Oil	Gassy Wells	Toleration to Free Gas	Limited Temperature
Widely Availability in Different Sizes	Depth Limitation	No Valve Problems	Depth Limitation
Flexible	Paraffin Problems	High Efficiency	Corrosion Handling

SRP is one of the most used artificial lift methods in the world [17]. Moreover, it is a symbol of oil industry. Oil wells (especially heavy and viscous oil) have harsh conditions, which causes many failures in pumps. For instance, subsurface pump failure (i.e. valve failures), tubing failures, rod failure and polished rod failure are commonly seen problems in SRP [3]. All of these failures cause oil production loss and additional high workover/rodpull costs. Therefore, it is crucial to design an artificial lift system appropriately for each well. For heavy oils in sandy and viscous environment, SRP do not have a good performance and often failures occur. However, PCP has good performances for heavy oils in sandy and viscous environment as listed in Table 1 and Table 3. After 1970s-1980s, the number of PCPs in the world started to increase especially for heavy viscous oils and high solid content [18]. For instance, SRP artificial systems in Teca and Nare Oil Fields in Colombia (12 API^o, 12000 cp, 20-150 bbl/day) were shifted to PCP artificial systems because well downtimes due to sand sticking and rod failures were occasionally seen in SRP systems of these fields. By shifting SRPs to PCPs in Teca and Nare Oil Fields, significant savings in well downtime and energy consumption were obtained. PCP systems were quite appropriate for these fields so well service cost in PCPs was reduced to almost half of the well service cost in SRP systems. Furthermore, 78-88 % of energy savings in PCP systems was obtained compared to SRP systems [19]. Similarly, the number of PCPs was increased owing to its better performances in the oil fields (mature, sub-hydrostatic, viscous, and sandy oil) of Oman [20]. SRP systems include subsurface pump with valves and these valves has gas pounding problems if produced oil includes free gas as well. In the harsh conditions of the heavy oil fields (heavy, viscous and gassy-1600-2300 scf/stb) of Venezuela, PCP systems indicated a better performance compared to SRP systems [21]. In the heavy oil field of Argentina with high gas-oil ratio (600 m^3/m^3) including CO_2 presence, good performances were obtained in PCP systems [22] In the world, the number of PCP systems ranges from 70000 to 80000. Moreover, in Turkey, more than 250 PCP systems are used according to 2015 data of Dunn [23].

PCP artificial systems are in a trend of shifting SRP artificial systems. However, in literature, there is almost no design study of SRP and PCP systems for Batı Raman Oil Field, which is the largest oil field of Turkey in terms of reserves. For this reason, in this study, it is aimed to design SRP and PCP systems in the conditions of Batı Raman Oil Field and to compare their performances.

2. Materials and Methods

Figure 3 shows complete SRP system and PCP system. As shown in Figure 3-a, SRP system mainly includes prime mover, surface pumping equipment, sucker rod string and subsurface pump [1,16]. Basically, walking beam is moved with prime mover. Then, this movement is transferred to subsurface pump via rods inside tubings. In down stroke, travelling valve is opened and standing valve is closed. In this way, reservoir fluid (oil, water, gas and other solid contents) between travelling valve and standing valve is taken inside tubing. Then, with up stroke, travelling valve is closed and standing valve is opened to take new fluid inside pump barrel. In the design of SRP, the following calculation should be made by depending on target production rate: sucker rod string design, polished rod load calculation, counterweight calculation, stroke calculation, and power requirement calculation [16,24].

PCP system is quite different than SRP system as seen in Figure 3. The main parts of PCP system are electric motor (prime mover), drive systems, rods, stator and rotor [25]. Like SRP system, rods are also a part of PCP system. It is a positive displacement pump by eccentrically rotating single-helical rotor inside a stator However, instead of up and down movement in SRP, rods are rotated via drive system in Figure 3-b. This rotation is transferred to rotor inside stator elastomer and stator housing via rods, therefore the spinning of "helical" steel rotor creates pumping action to produce reservoir fluid to surface [1]. In the design of PCP, the following calculations should be made by depending on target production rate: rod string design, polished rod load calculation, volumetric displacement calculation, torque requirement and power requirement calculation [1,24].

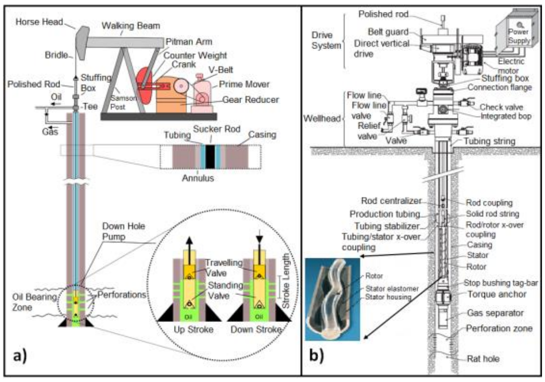

Figure 3. a. Sucker Rod Pump (SRP) System (SRP, 2008) **b.** Progressive Cavity Pump (PCP) System [1,25].

Artificial lift system is important to transfer reservoir fluid from perforations to surface as wellbore flowing pressure is less than hydrostatic pressure of fluid column inside wellbore. Production rates from oil wells are adjusted by depending on bottom-hole pressure (wellbore flowing pressure). At a certain bottom-hole pressure, the production rate from oil wells that can be achievable from reservoir is defined as "reservoir deliverability". Many parameters (i.e. reservoir pressure, reservoir thickness, reservoir fluid properties, etc.) affect reservoir deliverability. There is a relation between bottom-hole pressure and production rate, which is called "Inflow Performance Relationship-IPR". The following IPR equations are used for a vertical well in an undersaturated oil reservoir using the generalized Vogel equation [24]:

As reservoir pressure is greater than bubble point pressure:

$$q = J(P_e - P_{wf}) \quad \textbf{(2.1)}$$

$$J = \frac{kh}{141.2 B_o \mu \left[ln\left(\frac{r_e}{r_w}\right) - \frac{3}{4} + S\right]} \quad \textbf{(2.2)}$$

q: production rate, bbl/day; J: productivity index, bbl/day/psia; P_e: reservoir pressure, psia; P_{wf}: bottom-hole pressure or wellbore flowing pressure, psia; k: reservoir permeability, md; h: reservoir net thickness, ft; r_e: drainage radius, ft; r_w: wellbore radius, ft; S: skin factor; P_b: bubble point pressure, psia

As reservoir pressure is lower than bubble point pressure (Vogel's Equation):

$$q = J(P_e - P_b) + \frac{JP_b}{1.8}\left[1 - 0.2\left(\frac{P_{wf}}{P_b}\right) - 0.8\left(\frac{P_{wf}}{P_b}\right)^2\right] \quad \textbf{(2.3)}$$

By using Equation 2.1, Equation 2.2 and Equation 2.3, it is possible draw IPR curve, which is basically P_{wf} versus q. In this study, IPR curves at different cases were constructed mainly by using Equation 2.1, Equation 2.2 and Equation 2.3.

As well as reservoir deliverability, well deliverability is also important for production. Wellbore deliverability is basically defined as the combination of well inflow performance (IPR) and wellbore flow performance. Different than IPR, wellbore flow performance describes the resistance to flow of production string. Mainly, tubing diameter, casing diameter and surface production facilities affect wellbore flow performance [24]. Tubing performance relationship (TPR) is used to understand wellbore flow performance. In this study, the method of Hagedorn and Brown [26] was used to construct TPR curve. The following equation of Hagedorn and Brown [26] was solved iteratively in this study:

$$144\frac{dP}{dz} = \bar{\rho} + \frac{f_F M_t^2}{7.413\times10^{10} D^5 \bar{\rho}} + \bar{\rho}\frac{\Delta(u_m^2)}{2g_c \Delta z} \quad \textbf{(2.4)}$$

Where M_t: total mass flow rate, lbm/day; ρ: in-situ average density, lbm/ft^3; f_F: Fanning friction factor; u_m: mixture velocity, P: pressure, psia; z: distance, ft; f_F: friction factor; D: conduit inner diameter, ft

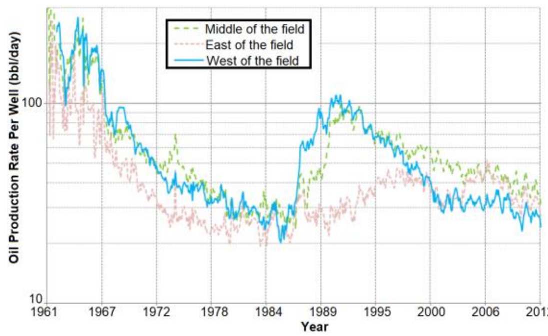

Figure 4. Regional average oil production rates per well in Batı Raman Oil Field [9].

In this study, SRP and PCP designs were made in the conditions of Batı Raman Field. By using the equations in Table 4 and Table 5 mainly, a set of python codes was written for SRP and PCP designs in this study. Figure 4 shows the average production rates in the east, middle and west part of Batı Raman Heavy Oil Field with time. From this figure, it is possible to observe the peak in the production after 1986 with the application of immiscible CO_2 EOR method in this field. Recently, the average production rate per well in this field ranges from 25 to 40 bbl/day [9]. Minimum and maximum production rates among the dozens of production wells in Batı Raman Oil Field are 5 bbl/day and 150 bbl/day, respectively. In this study, the cases in Table 6 were selected for designing a SRP system and PCP system. Moreover, some of the reservoir parameters were obtained from Table 2.

Table 4. The equations used for the design of SRP [24].

Parameter	Equation *	Equation
Polished rod stroke length (S)	$S = 2c\frac{d_2}{d_1}$	**(2.5)**
Maximum allowable pumping speed (N)	$N = \sqrt{\frac{70471.2L}{s\left(1-\frac{c}{h}\right)}}$	**(2.6)**
Gross plunger cross-sectional area (A_p)	$A_p = \frac{\pi d_p^2}{4}$	**(2.7)**
Rucker rod cross-sectional area (A_r)	$A_r = \frac{\pi d_r^2}{4}$	**(2.8)**
Fluid Load (W_f)	$W_f = 62.4S_f\frac{DA_p}{144}$	**(2.9)**
Rod Load (W_r)	$W_r = \frac{\gamma_s DA_r}{144}$	**(2.10)**
Maximum polished rod (PRL_{max})	$PRL_{max} = W_f - 62.4S_f\frac{W_r}{\gamma_s} + W_r + W_r\left(\frac{SN^2(1 \pm c/h)}{70471.2}\right)$	**(2.11)**
Minimum polished rod (PRL_{min})	$PRL_{min} = -62.4S_f\frac{W_r}{\gamma_s} + W_r - W_r\left(\frac{SN^2(1 \pm c/h)}{70471.2}\right)$	**(2.12)**
Peak Torque (T)	$T = \frac{1}{4}S\left(W_f + \frac{2SN^2W_r}{707471.2}\right)$	**(2.13)**
Counterweight (C)	$C = \frac{1}{2}(\mathrm{PRL}_{max} + \mathrm{PRL}_{min})$	**(2.14)**
Maximum stress on polished rod (σ_{max})	$\sigma_{max} = \frac{PRL_{max}}{A_r}$	**(2.15)**
Tubing cross-sectional area (A_t)	$A_t = \frac{\pi d_t^2}{4}$	**(2.16)**
Machinery Factor (M)	$M = 1 \pm \frac{c}{h}$	**(2.17)**
Plunger Stroke (S_p)	$S_p = S - \frac{12D}{E}\left[W_f\left(\frac{1}{A_r} + \frac{1}{A_t}\right) - \frac{SN^2M}{70471.2}\frac{W_r}{A_r}\right]$	**(2.18)**
Liquid flow rate delivered by plunger pump (q)	$q = 0.1484\frac{A_pNS_pE_v}{B_o}$	**(2.19)**
Net lift (L_N)	$L_N = H + \frac{P_{tf}}{0.433\gamma_l}$	**(2.20)**
Hydraulic Power (P_h)	$P_h = 7.36 \times 10^{-6}q\gamma_l L_N$	**(2.21)**
Power required to overcome friction losses (P_f)	$P_f = 6.31 \times 10^{-7}W_rSN$	**(2.22)**
Required prime mover power (P_{pm})	$P_{pm} = F_s(P_h + P_f)$	**(2.23)**

* S: polished rod stroke length, in; c: crank length, in; d_1: beam dimension 1, in; d_2: beam dimension 2; N: maximum allowable pumping speed, stroke per minute (spm); h: crank to pitman ratio; L: maximum allowable acceleration factor; A_p: gross plunger cross-sectional area, in^2; A_r: sucker rod cross-sectional area, in^2; d_r: rod diameter, in; d_p: plunger diameter, in; W_f: fluid load, lb; D: pump setting depth, ft; S_f: specific gravity of fluid; γ_s: specific weight of steel (490 lb/ft^3); PRL_{max}: Maximum polished rod, lb; PRL_{min}: Minimum polished rod, lb; T: peak torque, lb-in; C: counterweight, lb; A_t: tubing cross-sectional area, in^2; d_t: tubing diameter, in; M: machinery factor; q: liquid flow rate delivered by plunger pump, stb/day; L_N: net lift, ft; H: depth to the average fluid level in the annulus, ft; P_{tf}: flowing tubing head pressure, psig; γ_l: liquid specific gravity; P_h: hydraulic power (power required lifting fluid), hp; P_f: power required to overcome friction losses, hp; P_{pm}: required prime mover power, hp; F_s: safety factor (1.25-1.50); σ_{max}: Maximum stress on polished rod, psia

Table 5. The equations used for the design of PCP [1,25].

Parameter	Equation *	Equation
Minimum required pump displacement (S_{min})	$S_{min} = \frac{q_a}{wE}$	**(2.24)**
Pump intake pressure (P_i)	$P_i = P_{ch} + P_g + P_L - P_{tail}$	**(2.25)**
Pump discharge pressure (P_d)	$P_d = P_{th} + P_L + P_{loses}$	**(2.26)**
Net lift (P_{lift})	$P_{lift} = P_d - P_i$	**(2.27)**
Hydraulic torque (T_h)	$T_h = 8.97 \times 10^{-2}sP_{lift}$	**(2.28)**
Total pump torque (T_t)	$T_t = T_h + T_f + T_v$	**(2.29)**
Pump pressure load (F_p)	$F_p = 0.79[0.6(P_d - P_i)(2d^2 + 13ed + 16e^2) - P_d d_r^2]$	**(2.30)**
Rod-string axial load (F_r)	$F_r = F_p + \sum F_w - \sum F_u$	**(2.31)**
Total stress of the rods (σ_e)	$\sigma_e = \sqrt{\frac{1.6 \times 10^{-5}F_r^2}{\pi^2 d_r^4} + \frac{0.1106T_r^2}{\pi^2 d_r^6}}$	**(2.32)**
Required prime-mover power output (P_{pmo})	$P_{pmo} = \frac{1.904 \times 10^{-2}T_{pr}w}{E_{pt}}$	**(2.33)**

*S_{min}: minimum required pump displacement, bbl/day/rpm; q_a: required fluid rate, bbl/day; w: pump rotational speed, rpm; E: volumetric pumping efficiency in service; P_{lift}: net lift, psia; P_d: pump discharge pressure, psia; P_i: pump intake pressure, psia; P_{ch}: casing-head pressure, psia; P_g: annular gas-column pressure, psia; P_L: annular liquid-column pressure, psia; P_{tail}: pressure loss associated with auxiliary components, psia; P_{th}: tubing-head pressure, psia; P_{losses}: tubing flow losses, psia; T_h: hydraulic torque, the component used to overcome differential pressure, ft.lbf; T_f: pump friction torque, ft.lbf; T_v: viscous pump torque, ft.lbf; F_p: pump

Celal Bayar University Journal of Science
Volume 16, Issue 2, 2020, p 191-199
Doi: 10.18466/cbayarfbe.646805

pressure load, lbf; d: nominal rotor diameter, in; e: pump eccentricity, in; d_r: rod string diameter, in; F_r: rod-string axial load, lbf; ΣF_w: sum of rod string weight below location, lbf; ΣF_u: sum of uplift forces below location, lbf; P_{pmo}: required prime-mover power output, hp; T_{pr}: polished rod torque, ft.lbf; w: polished-rod rotational speed, rpm; E_{pt}: power transmission system efficiency, %

Table 6. Design parameters for different cases in the conditions of Batı Raman Oil Field (chosen by using the data of Kaplan and Duygu [14], Sahin et al. [7, 9] and Table 2).

Parameter	Case 1	Case 2	Case 3
Depth of Perforation, ft	4380	4380	4380
Pump Setting Depth, ft	4511	4511	4511
Static Fluid Level, ft	*1563*	*2305*	*926*
API of Oil	13	13	13
Productivity Index, J, bbl/day/psia	1	1	1
Bubble Point Pressure, psia	158	158	158
Reservoir Temperature, ^oC	65	65	65
Wellhead Temperature, ^oC	25	25	25
Wellhead Pressure, psia	250	250	250
Flow Rate, stb/day	*60*	*5*	*150*
Reservoir pressure, psia	*1190*	*877*	*1465*
Tubing Size, in (”)	2.875 x 2.441	2.875 x 2.441	2.875 x 2.441
Casing Diameter, in	7	7	7

3. Results and Discussion

In this study, IPR (Inflow Performance Relationship)-TPR (Tubing Performance Relationship) curves were constructed for the cases in Table 6. Then, SRP (Sucker Rod Pump) system and PCP (Progressive Cavity Pump) system were designed in the conditions of Batı Raman Oil Field for different cases in Table 6. Figure 5 indicates IPR and TPR curves of Case 1. For a tubing with 2.875” outer diameter (OD) and 2.441” inner diameter (ID), TPR curve in the conditions of Case 1 in Table 6 was generated by applying the method of Hagedorn and Brown [26]. As seen in TPR curve and IPR curve of Case 1 intersects when wellbore flowing pressure (P_{wf}) and expected flow rate (q) are 595 psia and 60 bbl/day, respectively.

Initially, SRP system was designed for Case 1 in Table 6. According to the plunger sizes recommendation table of Brown [26], the suggested plunger sizes in the conditions of Case 1 (flow rate: 60 bbl/day, net lift: 2153 ft) are $1^{1/2}$” and $1^{1/4}$”. In this study, $1^{1/2}$” plunger was selected. For the rod selection criteria of Brown [16], 7/8” and 3/4” rods are suggested for $1^{1/2}$” plunger. Hence, 7/8” rods (Rod No: 76, D Class) were selected in this study for SRP design because of higher stress requirements in heavy oils. Then, SRP design for Case 1 was made by solving the equations in Table 4. The outputs of SRP design for Case 1 are listed in Table 7. Basically, 4 stroke per minute (spm) and 4 hp power are needed to obtain 60 bbl/day production from the well in the conditions of Case 1. The minimum yield strength of D class rods is approximately 85000 psia [1]. As seen in Table 7, the maximum stress on the rods in Case 1 is 14894 psia.

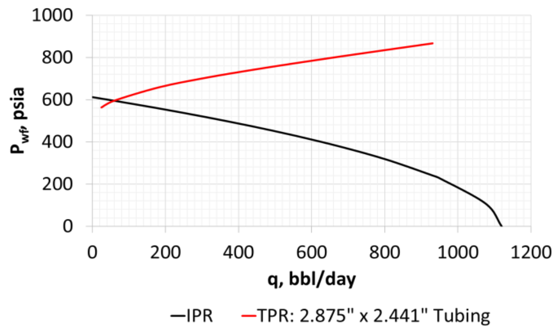

Figure 5. IPR-TPR curves constructed for Case 1 in this study.

Table 7. SRP Design Parameters for Case 1.

Parameter	Value
Sucker rod pump unit type	Conventional
Plunger size, in	$1^{1/2}$
Rod size, in	7/8 (Rod No: 76, D Class)
Polished rod stroke length, in	85.52
Pumping speed, spm	4
Maximum polished rod load, lb	11698
Maximum stress on polished rod, psia	14894
Net lift, ft	2153
Flow rate, bbl/day	60
Required prime mover power, hp	4.0

PCP design was also completed in the conditions of Case 1 in Batı Raman Heavy Oil Field. There are many manufacturers of SRP and PCP systems so the sizes and properties of these pump systems might vary with manufacturers. In this study, it is aimed to estimate the pump requirements and, it is possible to choose appropriate pumps from catalogs in this way. According to minimum PCP requirement for Case 1 (0.202 bbl/day/rpm), a PCP system from the catalog of Flexon [27] in Table 8 was selected. In PCP system, 7/8” was (Rod No: 76, D Class) was selected. The results of this design are listed in Table 8. Mainly, a PCP system with 0.315 bbl/day/rpm displacement, 1450 psia pressure rating, and sizes listed in Table 8 was chosen. With this system, it is possible to produce 60 bbl/day from the well in the conditions of Case 1 in Table 6 as round per minute, total stress on rod and require power are 190.5 rpm, 20977 psia and 2.18 hp, respectively.

Table 8. PCP Design Parameters for Case 1.

PCP Parameters	Values
Displacement, bbl/day/rpm	0.315
Pressure rating, psia	1450
Major diameter, in	1.638
Minor diameter, in	1.386
OD, in	2.993
Length, ft	12.80
Rod size, in	7/8 (Rod No: 76, D Class)
Design Parameters	
Minimum required pump displacement, bbl/day/rpm	0.202
Round per minute	190.5
Flow rate, bbl/day	60
Net lift in terms of pressure, psia	1157
Rod-string axial load, lb	11242
Total pump torque, lb.ft	60.2
Total stress of the rods, psia	20977
Required prime-mover power output, hp	2.18

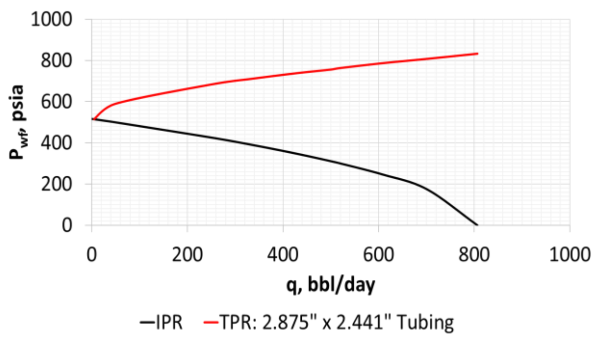

Figure 6. IPR-TPR curves constructed for Case 2 in this study.

Table 9. SRP Design Parameters for Case 2.

Parameter	Value
Sucker rod pump unit type	Conventional
Plunger size, in	$1^{1/4}$
Rod size, in	7/8 (Rod No: 76, D Class)
Polished rod stroke length, in	85.52
Pumping speed, spm	0.5
Maximum polished rod load, lb	10432
Maximum stress on polished rod, psia	13283
Net lift, ft	2895
Flow rate, bbl/day	5
Required prime mover power, hp	0.49

In Batı Raman Oil Field, there are also wells producing nearly 5 bbl/day. Hence, it is important to design SRP system and PCP system for this case, which is Case 2 in Table 6. In Figure 6, IPR-TPR curves of Case 2 were constructed in this study. TPR and IPR coincide at 5 bbl/day (q) and 514 psia (P_{wf}). SRP design in the conditions of Case 2 was completed and the output results are listed in Table 9. The plunger diameter was chosen as $1^{1/4}$" because of very low production rate in Case 2. As listed in Table 9, 0.5 spm and 0.49 hp are required to produce 5 bbl/day from the well in Case 2. Expectedly, less spm and power requirement are essential for Case 1 compared to Case 2. In PCP design of Case 2, 0.101 bbl/day/rpm displacement, 1740 psia pressure rating, and sizes listed in Table 10 were selected. 50 rpm and 0.23 hp are necessary to produce 5 bbl/day. Like Case 1, power requirement in PCP is quite lower compared to SRP system.

Table 10. PCP Design Parameters for Case 2.

PCP Parameters	Values
Displacement, bbl/day/rpm	0.101
Pressure rating, psia	1740
Major diameter, in	1.26
Minor diameter, in	1.10
OD, in	2.60
Length, ft	8.86
Rod size, in	7/8 (Rod No: 76, D Class)
Design Parameters	
Minimum required pump displacement, bbl/day/rpm	0.0168
Round per minute	50
Flow rate, bbl/day	5
Net lift in terms of pressure, psia	1473
Rod-string axial load, lb	10312
Total pump torque, lb.ft	24.6
Total stress of the rods, psia	17586
Required prime-mover power output, hp	0.23

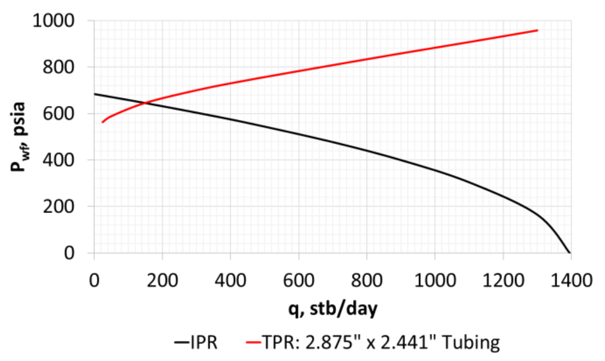

Figure 7. IPR-TPR curves constructed for Case 3 in this study.

Celal Bayar University Journal of Science
Volume 16, Issue 2, 2020, p 191-199
Doi: 10.18466/cbayarfbe.646805

Finally, IPR-TPR curves of the well in the conditions of Case 3 in Table 6 were prepared in this study by using mainly Equation 2.1, Equation 2.2 and Equation 2.3. As illustrated in Figure 7, IPR curve and TPR curve intersect at 150 bbl/day (q) and 646 psia (P_{wf}). 150 bbl/day is the highest flow rate observed in Batı Raman Oil Field and in this study, SRP system and PCP system were also designed for this case (Case 3). The selected plunger diameter is $1^{1/2}$" according to the pump plunger size recommendations of Brown [16] in the conditions of Case 3. In order to produce 150 bbl/day in this condition with SRP system, nearly 9.3 spm and 8.7 hp are required. The other requirements are shown in Table 11.

Table 11. SRP Design Parameters for Case 3.

Parameter	Value
Sucker rod pump unit type	Conventional
Plunger size, in	$1^{1/2}$
Rod size, in	7/8 (Rod No: 76, D Class)
Polished rod stroke length, in	85.52
Pumping speed, spm	9.6
Maximum polished rod load, lb	12830
Maximum stress on polished rod, psia	16335
Net lift, ft	1516
Flow rate, bbl/day	150
Required prime mover power, hp	8.7

Table 12. PCP Design Parameters for Case 3.

PCP Parameters	Values
Displacement, bbl/d/rpm	0.629
Pressure rating, psia	1740
Major diameter, in	1.732
Minor diameter, in	1.378
OD, in	2.992
Length, ft	16.732
Rod size, in	7/8 (Rod No: 76, D Class)
Design Parameters	
Minimum required pump displacement, bbl/day/rpm	0.504
Round per minute	238
Flow rate, bbl/day	150
Net lift in terms of pressure, psia	885
Rod-string axial load, lb	10880
Total pump torque, lb.ft	94.1
Total stress of the rods, psia	23424
Required prime-mover power output, hp	4.27

For Case 3 in Table 6, PCP system was also designed in this study and the results are shown in Table 12. For 150 bbl/day production, 0.629 bbl/day/rpm is appropriate from the catalog of Flexon [27]. The size information of stator and rotor is also given in Table 12. 238 rpm and 4.27 hp are essential to produced 150 bbl/day from the well in the conditions of Case 3.

In the world, PCP systems have advantageous while producing heavy oil, sands and gases compared to SRP systems. Moreover, they need less power requirements. This also was shown in this study. In Figure 8, power requirements in SRP and PCP systems for Case 1, Case 2 and Case 3 were compared. In all cases, PCP systems require less power. The power requirements of PCP systems are 54.5 %, 46.9 % and 49.1 % of the power requirements of SRP systems for Case 1 (60 bbl/day flow rate), Case 2 (5 bbl/day flow rate) and Case 3 (150 bbl/day flow rate), respectively.

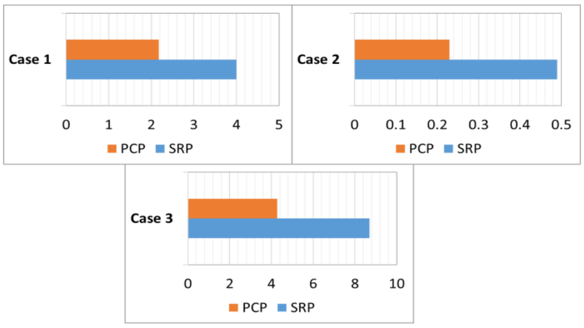

Figure 8. Comparison of power requirements in SRP and PCP systems for Case 1 (60 bbl/day), Case 2 (5 bbl/day) and Case 3 (150 bbl/day).

4. Conclusion

In study, the designs of SRP and PCP systems were made for current production rates (from 5 bbl/day to 150 bbl/day) of Batı Raman Heavy Oil Field. According to these designs, the following conclusion remarks were obtained:

- PCP system consumes less energy than SRP system in the conditions of Batı Raman Oil Field. Hence, in the long-term operations, cost-savings will occur if PCP system is used.
- PCP system is appropriate for oil and reservoir properties of Batı Raman Heavy Oil Field. However, real field well data collected from the wells with PCP and SRP system should be compared to prove this.
- Theoretically, 7/8" rods are appropriate for both SRP and PCP systems in the conditions of Batı Raman Heavy Oil Field. However, in real field practices, 1" rods might also be used for safer operations.

Author's Contributions

Sukru Merey: Drafted and wrote the manuscript, performed the estimations and result analysis.

Ethics

There are no ethical issues after the publication of this manuscript.

References

[1]. Clegg, J.D. Volume IV: Production Operations Engineering; Society of Petroleum: Texas, USA, 2007.

[2]. Berry, M.R. Rational Lift Selection, SIPES Continuing Education Seminar, Houston, USA, 2015.

[3]. Takacs, G. Sucker-Rod Pumping Handbook; Gulf Professional Publishing: Houston, USA, 2015.

[4]. Kantar, K., Karaoguz, D., Isever, K., Varana, L. 1985. Design Concepts of a Heavy-Oil Recovery Process by an Immiscible CO_2 Application. *Journal of Petroleum Technology*; 37 (02): 275-283.

[5]. Spivak, A., Karaoguz, D., lssever, K., Nolen, J.S. Simulation of Immiscible CO2 Injection in a Fractured Carbonate Reservoir, Batı Raman Field, Turkey, the SPE California Regional Meeting, Bakersfield, USA, 1989, SPE-18765.

[6]. Issever, K., Pamir, N.A., Tirek, A. 1993. Performance of a Heavy-Oil Field Under CO2 Injection, Batı Raman, Turkey. *SPE Reservoir Engineering*; 8(4): 256-260.

[7]. Sahin, S., Kalfa, U., Celebioglu, D. Bati Raman Field Immiscible CO_2 Application: Status Quo and Future Plans, SPE Latin American and Caribbean Petroleum Engineering Conference, Buenos Aires, Argentina, 2007, SPE-106575-MS.

[8]. Babadagli, T., Sahin, S., Kalfa, U., Celebioglu, D., Karabakal, U., Topguder, N.N. Development of Heavy Oil Fractured Carbonate Bati Raman Field: Evaluation of Steam Injection Potential and Improving Ongoing CO2 Injection, SPE Annual Technical Conference and Exhibition, Denver, USA, 2007, SPE-115400-MS.

[9]. Sahin, S., Kalfa, U., Celebioglu, D., Duygu, E., Lahna, H. A Quarter Century of Progress in the Application of CO_2 Immiscible EOR Project in Bati Raman Heavy Oil Field in Turkey, SPE Heavy Oil Conference, Calgary, Canada, 2012, SPE-157865-MS.

[10]. Sahin, S., Kalfa, U., Uysal, S., Kilic, H., Lahna, H. Design, Implementation and Early Operating Results of Steam InjectionPilot in already CO_2 Flooded Deep-Heavy Oil Fractured Carbonate Reservoir of Bati Raman Field, Turkey, SPE Improved Oil Recovery Symposium, Tulsa, USA, 2014, SPE-169035-MS.

[11]. Arslan, I., Akın, S., Karakece, Y., Korucu, O. Is Bati Raman Heavy Oil Field a Triple Porosity System?, 2007 SPE/EAGE Reservoir Characterization and Simulation Conference, Abu Dhabi, U.A.E., 2007, SPE 111146.

[12]. Sahin, S., Kalfa, U., Celebioglu, D. Unique CO2-Injection Experience in the Bati Raman Field May Lead to a Proposal of EOR/Sequestration CO2 Network in the Middle East, SPE International Conference on CO2 Capture, Storage, and Utilization, New Orleans, USA, 2010, SPE-139616-MS.

[13]. Ozgur, E. Enhanced Oil Recovery Methods and Suggestions for Turkey (In Turkish); Chamber of Petroleum Engineers: Ankara, Turkey, 2017.

[14]. Kaplan, V., Duygu, E. Selection and Optimization of Artificial Lift System in Heavy Oil Fields, SPE Latin American and Caribbean Petroleum Engineering Conference, Maracaibo, Venezuela, 2014, SPE-169288-MS.

[15]. Ozgur, E. 2019. The role of enhanced oil recovery in the upstream petroleum sector, a case study from Turkey. B*ulletin of the Mineral Research and Exploration*, 158: 291-297.

[16]. Brown, K.E. The Technology of Artificial Lift Methods, Volume 2a; PennWell Books: Tulsa, USA, 1980.

[17]. Moreno, G.A., Garriz, A.E. 2020. Sucker rod string dynamics in deviated wells. *Journal of Petroleum Science and Engineering*; 184: 106534.

[18]. Lehman, M. 2004. Progressing cavity pumps in oil and gas production. *World Pumps*; 457: 20-22.

[19]. Ramirez, J., Abril, W., Vargas, L., Trivino, C. Saving Energy in Heavy-Oil Fields in Colombia with Progressive Cavity Pump, 2007 SPE Latin American and Caribbean Petroleum Engineering Conference, Buenos Aires, Argentina, 2007, SPE-108083-MS.

[20]. Al Shukri, M.S., Abou-ElKhair, A. Innovative Progressive Cavity Pump Design for Brown Fields in South of Oman, 2009 SPE Saudi Arabia Section Technical Symposium and Exhibition, AlKhobar, Saudi Arabia, 2009, SPE-126049-MS.

[21]. Seince, L., Caballero, D., Chacin, N. Multiphase Progressing Cavity Pumps Operated in Harsh Conditions, SPE Progressing Cavity Pumps, Edmonton, Alberta, Canada, 2010, SPE-137168-MS.

[22]. Zimmer, L., Young, E., Bertomeu, F. Successful deployment of a new generation of progressive cavity pump in a high GOR Argentinian Heavy Oil Field, SPE Latin American and Caribbean Petroleum Engineering Conference, Mexico City, 2012, SPE-152228-MS.

[23]. Dunn, L. Progressing Cavity Pumping Systems Overview with a Focus on Coal Seam Gas Applications. https://www.spe-qld.org/useruploads/files/pcpspeaustraliafinalv1.pdf (accessed at 29.10.2019).

[24]. Guo, B., Lyons, W.C., Ghalambor, A. Petroleum Production Engineering: A Computer-Assisted Approach; Elsevier Science & Technology Books: Amsterdam, Netherland, 2007.

[25]. Wittrisch, C., Cholet, H. Progressing Cavity Pumps Oil Well Production Artificial Lift; Editions Technip: Paris, France, 2013.

[26]. Hagedorn, A.R., Brown, K.E. 1965. Experimental study of pressure gradients occurring during continuous two-phase flow in small-diameter conduits. *Journal of Petroleum Technology*; 475.

[27]. Flexon. Progressive Cavity Pumps. http://petrosmartsolutions.com/ownedFiles/PCP_Flexon_Cat.pdf (accessed at 29.10.2019).