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Sudan University of Science and Technology
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Prediction Production Performance of Progressive Cavity Pump for High Viscous Oil

Case study: Alrawat

توقع أدائية انتاج مضخة التجويف التدريجي للزيت ذو اللزوجة العالية

تطبيق حقلي (الراوات)

A Study submitted for fulfilment of the requirements for the degree of B.sc in petroleum Engineering

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من كتاب الله الحكيم

﴿ آمَنَ الرَّسُولُ بِمَا أُنزِلَ إِلَيْهِ مِن رَّبِّهِ وَالْمُؤْمِنُونَ ۚ كُلٌّ آمَنَ بِاللَّهِ وَمَلَائِكَتِهِ وَ
كُتُبِهِ وَرُسُلِهِ لَا نُفَرِّقُ بَيْنَ أَحَدٍ مِّن رُّسُلِهِ ۚ وَقَالُوا سَمِعْنَا وَأَطَعْنَا ۖ غُفْرَانَكَ
رَبَّنَا وَإِلَيْكَ الْمَصِيرُ ﴿ 285 ﴾ لَا يُكَلِّفُ اللَّهُ نَفْسًا إِلَّا وُسْعَهَا ۚ لَهَا مَا كَ
سَبَتْ وَعَلَيْهَا مَا اكْتَسَبَتْ ۗ رَبَّنَا لَا تُؤَاخِذْنَا إِن نَّسِينَا أَوْ أَخْطَأْنَا ۚ رَبَّنَا وَلَا تَحْ
مِلْ عَلَيْنَا إِصْرًا كَمَا حَمَلْتَهُ عَلَى الَّذِينَ مِن قَبْلِنَا ۚ رَبَّنَا وَلَا تُحَمِّلْنَا مَا لَا طَاقَةَ لَنَا بِ
هِ ۖ وَاعْفُ عَنَّا وَاغْفِرْ لَنَا وَارْحَمْنَا ۚ أَنتَ مَوْلَانَا فَانصُرْنَا عَلَى الْقَوْمِ الْكَافِرِينَ
﴿ 286 ﴾ ﴿

سورة البقرة

Dedication

This study is dedicated to all our Fathers, Mothers, Brothers, Sisters, Friends, Teachers and Every person that ***support*** *us during our long journey in this* ***research*** *.*

May Allah (Subhanhu Wa Ta'ala) bless you and give you what you want .

Acknowledgments

After the Lord Allah (Subhanhu WaTa'ala), we would like to express our sincere gratitude to our Advisors Mr. Mohamed Meirghni (supervisor) and Mr. Mohanad Khiery (co-supervisor) for their continuous support during our research .

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Lastly but not the least , we would like to show our gratitude and love to all our families members for their everlasting support in our educational past period .

Abstract

The progressive cavity pump (PCP) is one of the best method of artificial lift which achieves the economic goals which achieve the country and company policies. Its component and function and the factor affecting it have been discussed in this research.

The aim of this study is prediction production performance of progressive cavity pump by using PIPESIM to estimate the oil flow rates for numbers of wells (four wells located in Alrawat field) have viscous crude oil, whereas Progressive Cavity Pump consider one of the best artificial methods that is Compatible with this crude .

Also Number of Parameters sensitivities, Nodal Analysis™ for tubing size by using PIPESIM have been done for the wells to show the effect of those parameter on their optimal design.

The study shows that Using PCP increases the overall oil flowrate from (322.845 bbl/day) to (4012.348 bbl/day) .

التجريد

تعتبر مضخة التجويف التدريجي واحدة من افضل طرق الرفع الصناعي التي تحقق الاهداف الاقتصادية التي تمكن من تحقيق سياسات كل من الشركة والدولة ، وتم توضيح اجزائها ووظيفتها والعوامل المؤثرة عليها في هذا البحث .

الغرض من هذا البحث هو توقع أدائية مضخة التجويف التدريجي باستخدام برنامج ال PIPESIM لتقدير كمية النفط التي يمكن انتاجها لعدد من الابار (في منطقة الراوات) حيث ان هذه الابار تتميز بأن النفط فيها ذو لزوجة عالية نسبيا وتعتبر من افضل المضخات التي تتعامل مع هذا النوع من الخام . وايضا تمت دراسة تأثير عدد من العوامل (Parameter Sensitivity) والتحليل العقدي (Nodal Analysis™) للTubing Size بإستخدام برنامج الPIPESIM لتوضيح أثر هذه العوامل على التصميم المثالي للآبار.

نتائج هذه الدراسة توضح ان استخدام مضخة التجويف التدريجي تزيد الانتاج الكلي للابار تحت الدراسة من 322.845 برميل/ اليوم الى 4012.348 برميل/ اليوم .

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Chapter 1

Introduction

1.1 Introduction

Petroleum production involves two distinct but intimately connected general system. The reservoir which is a porous medium with unique storage and flow characteristics; and the artificial structure which include the well, bottom hole, and well head assemblies .and surface gathering, separation and storage facilities. The goal in the development of production engineering might be said to be the attainment of maximum efficiency in the operation of those producing wells drilled into an oil –bearing reservoir; this implies the realization of the maximum profit from each and every such well. In order to achieve this end of the production engineer must not only know how to analyze and interpret well performance but also be able to maximize production or injection in cost effective manner (Michel, Adaniel,1994).

1.2 Artificial lift:

Artificial lift is a method used to lower the producing bottom hole pressure (BHP) on the formation to obtain higher production rate from the well this can be done by gas lift or positive displacement down hole pumps.

Artificial lift methods

1.2.1 Sucker Rod pump:

Sucker rod pumping system Consist of pumping unit at surface and plunger pump submerged in the produced liquid in the well. The sucker rod pump can pump-a well down to very low pressure to maximize oil production rate its applicable to slim holes, multiple completion and high-temperature and viscous oils. The main advantages of sucker rod pumping that its mechanically simple and units easily changed to other wells with minimum cost, also corrosion and scale treatments easy to perform and availability of different sizes and can apply varying degrees of automation the main disadvantages of rod pumping include excessive friction in crooked /deviated wells ,solid sensitive problems ,low efficiency in gassy wells ,downhole-pump design selection in small-diameter casing and special requirement needed to install in some irrigated fields (Larry,2006).

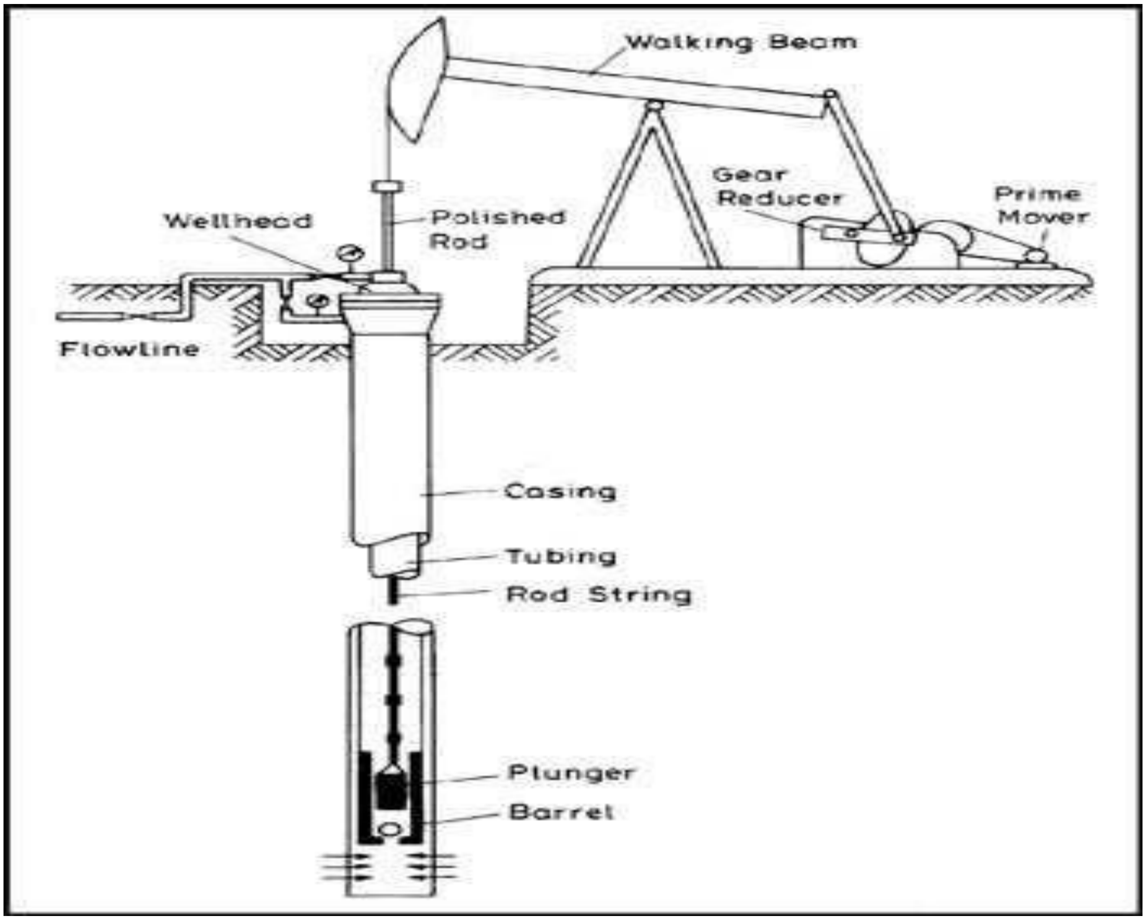


Figure (1. 1) schematic diagram of sucker rod pump(Larry,2006)

1.2.2 Gas lift:

Gas lift is method of artificial lift that uses an external source of high-pressure gas for supplementing formation gas to lift the well fluids. The primary consideration in the selection of a gas-lift system is the availability and cost of gas, gas lift s particularly applicable for lifting wells where high-pressure gas is available of highly deviated wells that produce sand and have high formation gas/liquid ratio are excellent candidates for gas lift when artificial lift is needed also its applicable in deviated or crooked wells. The main advantages of gas lift method includes ability of handling large volume of solids with minor problems ,easy to obtain downhole pressures and gradients , flexible system and a wide range of volumes and lift depth can be achieved with essentially the same well equipment ,but gas lift has limitation includes lift gas is not always available ,compressors are expensive , need for space and must properly maintained ,difficult to lift emulsions and viscous crudes and safety problems with high-pressure gas (Larry,2006)**.**

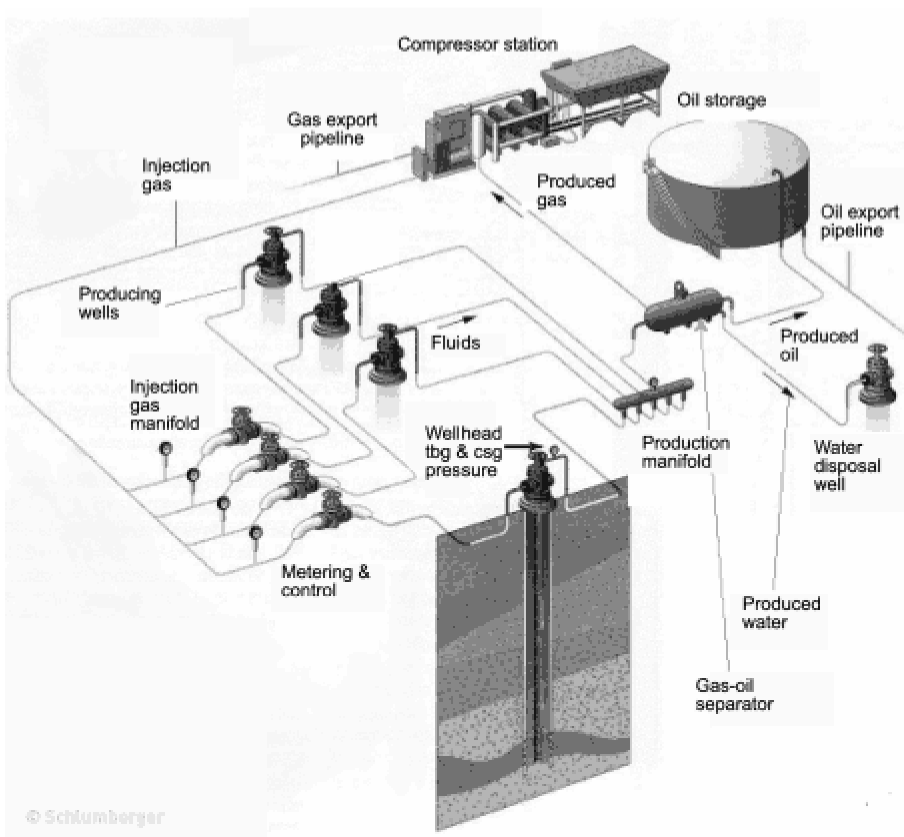


Figure (1. 2) schematic diagram of gas lift system (courtesy of schulmberger)

1.2.3 Electrical submersible pump (ESP):

ESP is multistage centrifugal pump for lifting moderate to high volumes of fluids from wellbore. Its effective in deeper wells and wells that produce large amount of water with oil. The pump is driven by an electric motor connected by cables to electrical power source at the surface. The main advantages of ESP that it's easy to install on operate, lifting cost for high volumes are generally very low, corrosion and scale treatment easy to perform and availability of different sizes. in other hand the dis advantages include limitations in high voltage, not applicable to multi completions, also not suitable to deep and high temperature oil reservoirs, gas and solid production is troublesome, casing sizing limitation, cable causes problems in handling tubulars and costly to install and repair (Larry,2006).

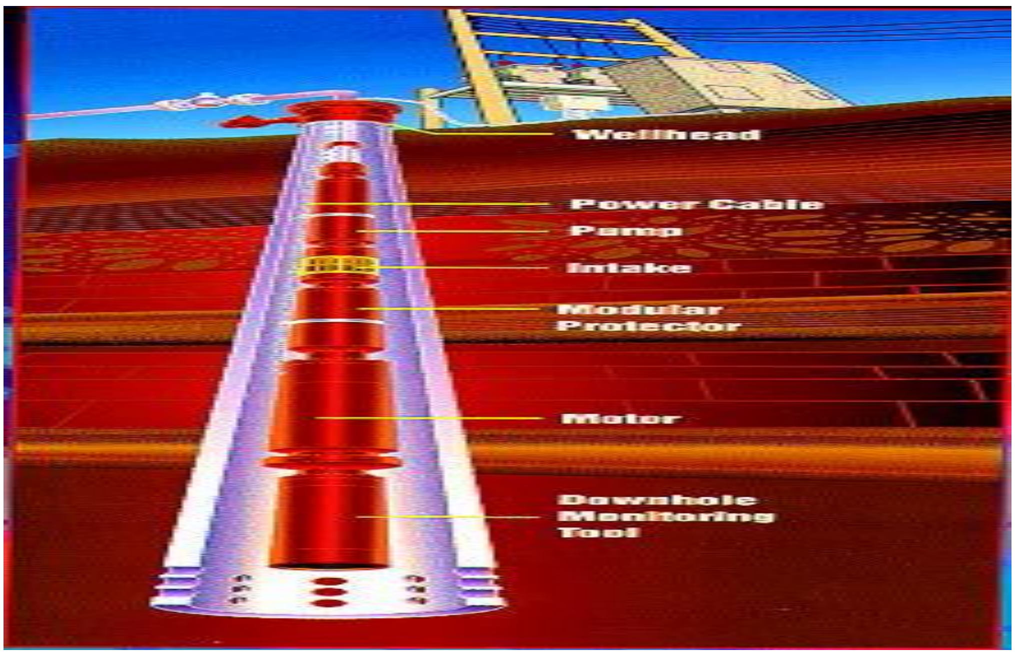


Figure (1. 3) Schematic Diagram of an ESP (courtesy of schulmberger)

1.2.4 Hydraulic Pumping

Generally, there are two primary kinds of hydraulic pumps:

Jet pumps:

For this kind high-pressure power fluid is directed down the tubing to the nozzle where the pressure energy is converted to velocity head (kinetic energy). The main advantages of jet pump that power fluid require less cleaning than piston pump, power source can be remotely located and can handle high volumes, on other hand it has complex design, sensitive to change in back pressure and power oil systems are suffering from fire hazardous (Larry,2006)

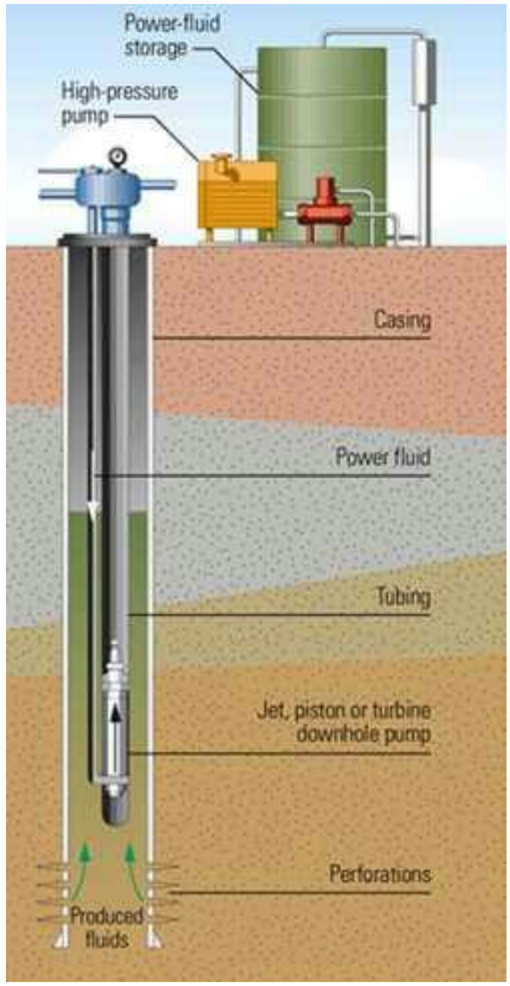


Figure (1. 4) schematic of jet pump system (courtesy of weatherford)

Reciprocating Positive displacement pump:

It consists of reciprocating hydraulic engine directly coupled to a pump piston or pump plunger in general either water or oil may be used as power fluid. Hydraulic pumping is applicable to wells that have great depth and large volume of liquid with low pressure, multiple completions and offshore operations, both electricity and natural gas can be used as power source (Larry,2006).

1.2.5 Progressive Cavity Pump (PCP):

The progressive cavity pump is a positive displacement pump using an eccentrically rotating single-helical rotor, turning inside a stator. The rotor is usually constructed of a high-strength steel rod, typically double-chrome plated. The stator is resilient elastomer in a double-helical configuration molded inside a steel casing, thus an interference fit can be obtained when the rotor is inserted in the stator, two chain lenticular, spiral cavities are formed. As the rotor turns within the stator, the sealed cavities spiral up the pump without changing size or shape and carry the pumped product, for oil production. Work of progressing cavity pumps is based on rotation of a rotor inside screw stator. The rotor of the pump sensitively is turned from the stainless steel or hardened steel, and the stator is formed from elastomer. The form and the sizes of these details are picked up in such manner that at enclosed rotor in stator the chain of water-proof cells (similarly to honey cells) is formed. At rotation of a rotor inside stator, these « honey cells » move on a spiral along an axis of the pump and thus without any changes under the form or the maintenance in liquid structure. This process moves working mass through the pump from an input to an output. PCP can be run into deviated and horizontal wells also can handle solids wells but the coating will erodes over time further than that the pump handles highly viscous in a production well .PCP is sometimes retrievable with rods ,moderate cost ,low profile , can use down hole electric motor that handles sand and viscous fluid and it has high electrical efficiency otherwise PCP lose efficiency with depth ,pumps shutdown control is difficult ,Elastomer in stator swell in some well fluids and rotating rods wear tubing (wind up and after spin of rods increase with depth)(Larry,2006).

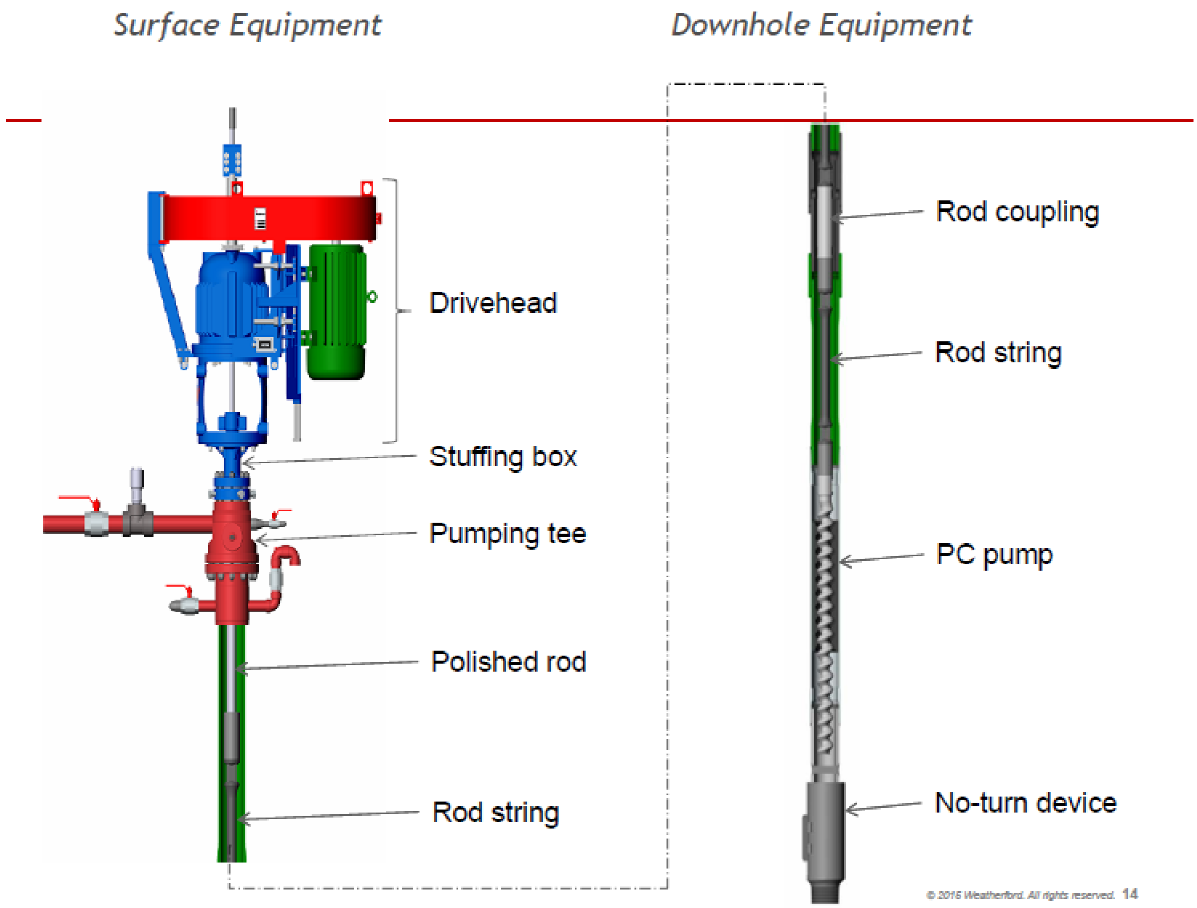


Figure (1. 5) schematic diagram of PC Pump (NETZSCH Oil Field Products)

Table (1. 1) capacity of various artificial lift methods (Larry,2006)

Method	Sucker Rod	Gas lift	ESP	Hydraulic pump	PC Pump
Capacity m^3/day	<100	800	>1000	800	600

Table (1. 2) Efficiency of various artificial lift methods (Larry,2006)

Method	Rod pump	Gas lift	ESP	Hydraulic pump	PCP
Efficiency %	30-40	25-32	50-60	30-40	60-80

Table (1. 3) working temperature of various artificial lift methods (Larry,2006)

Method	Rod pump	Gas lift	ESP	Hydraulic pump	PCP
Temperature (c°)	260	175	160	260	120

1.3 Problem statement:

Design a progressive cavity pump to estimate production of high viscous oil from wells located in alrawat field, and design network to calculate the overall flow rate for those wells by using PIPESIM software.

1.4 Research Objectives:

1. Calculate the natural oil flow rate of each well, and calculate oil flow rate after using progressive cavity pump.
2. Perform nodal analysis for each well to study the effect of the tubing on the production rate.
3. Study the effect of various sensitivity data such as (water cut, pump speed) on the production rate for each well.

4. Simulate the system in the PIPESIM software and show the results in tables and figures.
5. Design network to calculate the overall production.

1.5 Zone of study (Al-Rawat)

The block (25) located in the al-Rawat area in White Nile state, It's in the range block (7) within the scope of Maloot basin. Located between the White Nile and the South Kordofan and Blue Nile and Sinnar, it is about (40) km from the south of Kosti, about (132) Km south west of Kosti. Covers an area of about (26500) square kilometers, and is the northern part which was followed Petrodar.

This field has been discovered since the year "2000" and developed period (14) years, companies there are estate petroleum of Canada, and express the Nigerian and Sudapet National. The agreement was signed. On (26/3/2015) share Sudapet (70%), Express (15%) and estate (15%).

This block is at the frontier of the pipeline 0f Adarail, Bashair where the distance from the wells Explored less than (60) km and which is also close to the station treated the central city of the mountain of the White Nile that offer their services for the South petroleum.

1.6 Thesis outlines :

This thesis is divided into five chapters. In ***Chapter 1*** introduction of petroleum production and artificial lift methods and the objectives of the study were provided . ***Chapter 2*** is literature review contains progressive cavity pump system and progressive cavity pump studies over the world. ***Chapter 3*** explain the software (PIPESIM) used to design pump and network .The results are displayed in ***Chapter 4***. ***Chapter 5*** contains the study conclusion ,discussions, and recommendations.

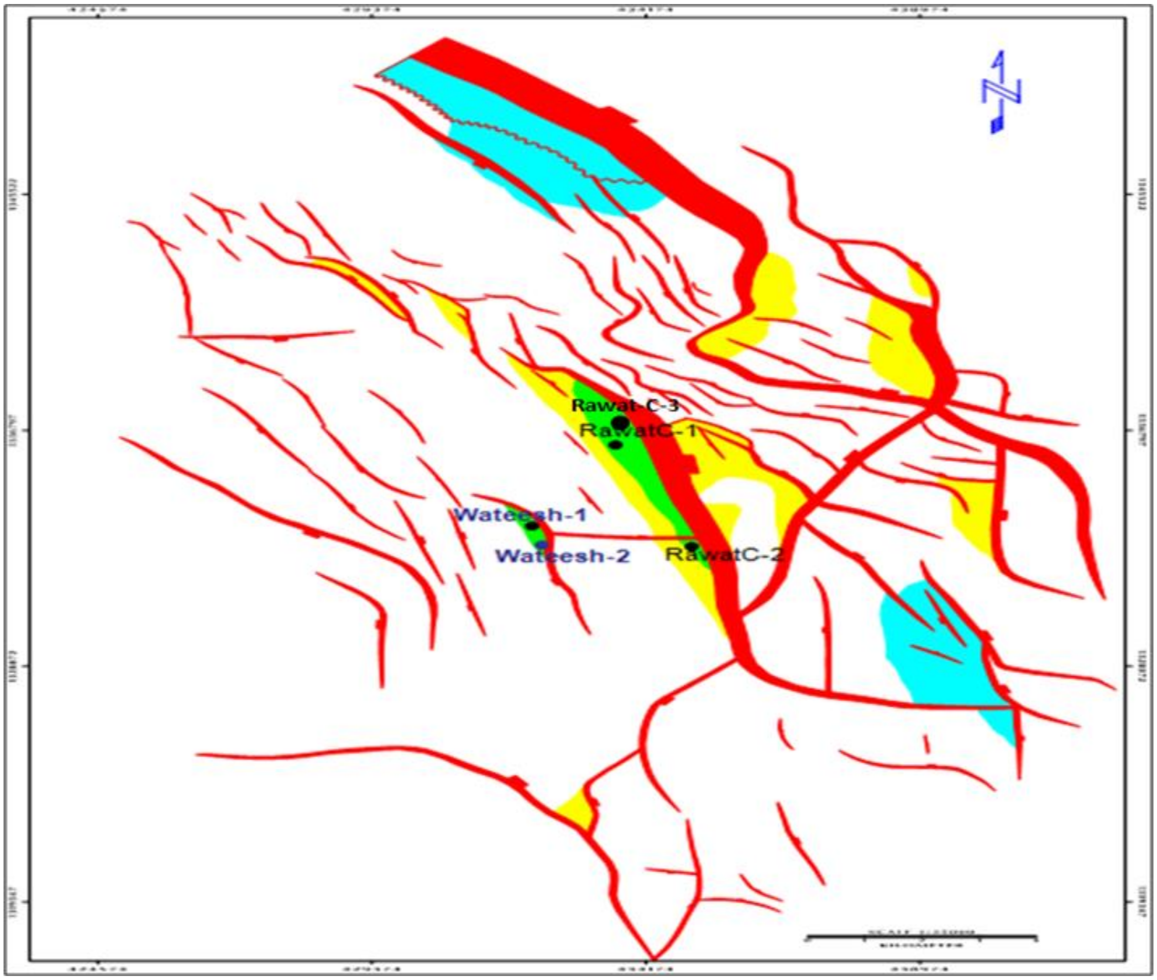


Figure (1. 6) REGIONAL STRUCTURE MAP OF AL-RAWAT

Chapter two

Chapter 2

Literature Review

2.1 Progressive Cavity Pump (PCP) Background:

Progressing cavity pump systems drive their name from the unique, positive displacement that evolved from the helical gear pump concept first developed by Rene Moineau in the late of 1920s, they also called screw pump, the PC pump initially were used extensively as fluid transfer pumps in wide range of industrial and manufacturing applications, with some attempt made to use them for the surface transfer of oil fields.

The two key features that differentiate PC pump system from other forms of artificial lift are the down hole pc pump and associated surface drive systems also other components such as the production tubing and sucker rod strings, are found in down hole lift system, the design and operational requirement typically differ for PCP applications also many additional equipment component, may be used in conjunction with PCP systems to contend with specific application condition.

The down hole PC pump is positive displacement pump that consists of two parts: a helical steel “rotor” and “stator” comprised of a steel tubular housing with a bonded elastomeric sleeve formed with a multiple internal helix matched suitably to the rotor configuration. The stator is typically run into well on the bottom of production tubing, while the rotor is connected to the bottom of the sucker rod string. Rotation of the rod string by means of surface drive system causes the rotor to spin within the fixed stator, creating the pumping action necessary to produce fluid to the surface (Michel, Adaniel,1994).

2.1.1 PC Pump system

The current line for artificial left applications and manufactured are progressing cavity pump and drives head, enabling to compound basically two different types of system:

1-conventional PCP system.

2-submersible PCP system.

These PC pumps system completion are shown in figure (2-1) even though the pumps basically the same, the systems are distinguished of each other depending upon the way the power is transmitted to the pump.

In conventional pc pump system, the power required to run the pump is transmitted to the rod string by the drive, located on surface. Typically, the conventional pc pump configuration involves:

- Drive head and prime mover.
- Sucker rod string.
- Down hole pc pump.
- Accessories (torque anchor, tubing anchor rod centralizers, BOP).

- Generally, the drive head is multifunction device on surface necessary to:

- Provide sealing from the well fluid on tubing head and polished rod.
- Provide the proper means to avoid pack spin of the rod string.
- Carry the weight of rod string and the load determined by the pumping action of a down hole pc pump.
- Transfer the power from the prime mover to the rods in order to run the pump.

The prime mover is the source of power supplier to the system, the amount of the power that the prime mover must deliver depend on the power demand at the polished rod and the efficiency of the power transmission system.

The Sucker Rod String acts as a driving shaft and is required to convey the power to the downhole pump. The rod on the bottom of string is directly coupled to the rotor while at the top of the rod column is coupled to a polished rod or axle that works on mechanical sealing through the drive head. Commonly, the sucker rods follow the API spec 11B, specification that originally covers Beam Pump applications, so that is only designed to axial loads. For this reason, the rods have been considered the weakest component of the system. Alternatively, though, some special rods exceeding API spec 11B requirements have been developed in order to accomplish with the tensile and torsion combined loads determined by the PC Pump when in operation. To date there are already enhanced rod types that make feasible the use of PC Pump Systems in adverse environments such deviated wells, for instance, with extended operating life.

In contrast to the cyclic rod stresses that occur in beam pumping, the rod stresses in PC Pump applications are relatively constant. As a result, effective rod stresses may approach the yield stress of the rod material without causing failures in PC Pump applications, although fatigue induced by bending can be an issue in directional and horizontal well applications. Deviated wells use rod centralizers to avoid premature failure of the rods and tubing string, consequently, to increase the life of the system. The centralizers are considered auxiliary devices and not properly another component of the system (larry,2006).

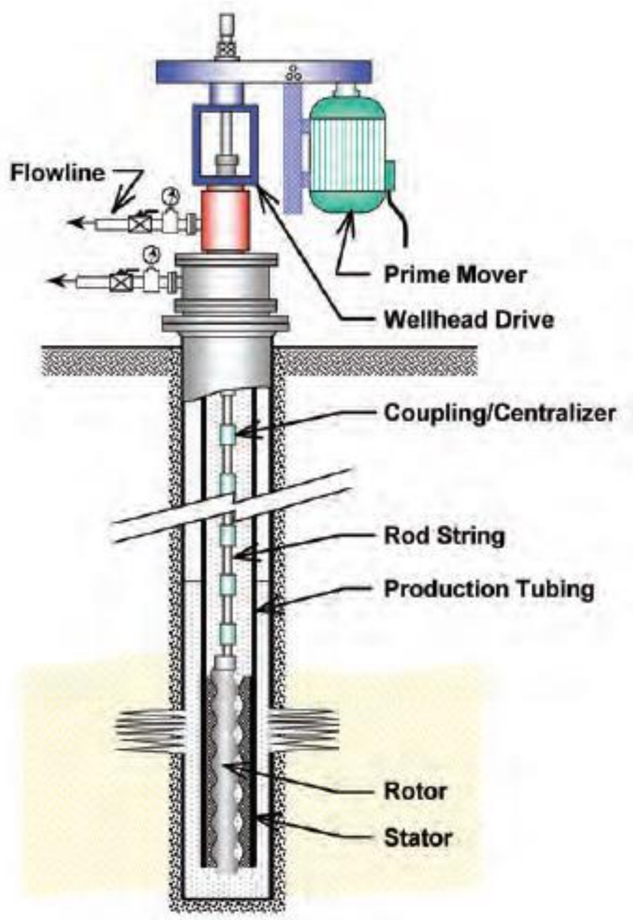


Figure (2. 1) Configuration of a typical progressing cavity pumping (PCP) system (larry,2006).

2.1.1.1 Down hole Equipment:

PC pump Down hole equipment include:

1. Polished Rod
2. Sucker rods
3. Sucker Rod Centralizers
4. Rotor & Stator
5. Pup joint
6. Stop bushing
7. Torque anchor

Polished rod:

The upper most joint in the string of sucker rod. Its enable an efficient hydraulic seal to be made around the reciprocating rod string.

Sucker rods:

Sucker rods function is to transmit the rotation from Top Drive to the rotor. The max stress is at the top of the rod string. (Sucker rod length 25 or 30 ft, Pony rods 1- 2- 4- 6- 8- 10- 12 ft.

Several different rod-string configurations are commonly used in PCP applications. These include continuous rods, standard rods with couplings (including hollow rods), standard rods with centralizers, and standard rods with bonded/molded rod guides.

Sucker Rods Grades:

There are three grades of sucker rods

- API grade C, made from carbon-manganese steel. For medium duty in noncorrosive fluid.

- API grade k, from nickel-molybdenum alloy steel. For medium duty in corrosive fluid (H_2s, Co_2).

- API grade D, from chrome-molybdenum alloy steel. For heavy duty in noncorrosive fluid.

Sucker Rods Torque and Load:

The forces exerted on rods are

- An axial load
- A torque which transmit the rotation.

The maximum stress in the rods is on the top of the rod string and The maximum allowable stress for the rod is depends on the rod grade, and it is increase with the rod outside diameter in the same grade.

Sucker Rods Centralizers:

To stabilize rod string, eliminate tubing wear and rod coupling wear.

Rotor:

Rotor is a single piece; total length of the rotor exceeds that of the stator by 0.45 to 0.50 m. There are different temperature codes and different outside diameters for each type of rotor, the higher the code the smaller outside diameter. To select the temperature code, we have to choose 2 scales over the actual downhole temperature. If downhole temperature is 90 C (code 10), we need to go to code 12 (temp. 125 C). Most pc pump manufacturers have stator products available with several different elastomer type. Because the formulation of these elastomer is considering proprietary, there is no standard naming convention. Certain generic names are common to the different manufacture but elastomer properties may very significant, the common types of elastomer are:

- Nitrile (NBR)
- Hydrogenated NBR (HNBR)
- Fluoroelastomer (FKMs)

Stator:

Stator is made from elastomer. The elastomer properties affected by the gas/liquid ratio and the temperature at the pump setting depth.

The common changes in elastomer mechanical properties are:

- Swelling which leads to excessive interference between rotor and stator.

- Hardening which leads to loss the elastomer resilience.

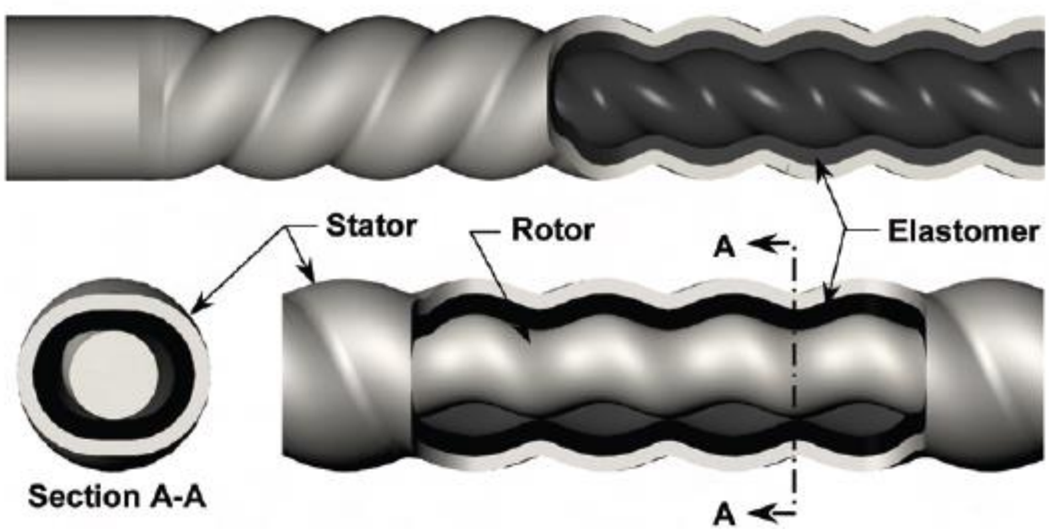


Figure (2. 2) PC pump design with uniform thickness elastomer (courtesy Weatherford).

Pup Joint:

The pup joint function is to allow for the movement of the rotor head and it is coupling, because the inside diameter of the tubing is small. The common length of this joint is 4 ft and the outside diameter is 4 inch.

Stop Bushing:

s connected to the bottom of the stator, it provides length of 0.30 m for possible elongation of the rod and serves as landing spot during spacing out.

Torque Anchor:

When the rotor rotates clockwise, it is friction against the stator tends to rotate the tubing clockwise and this creates a risk of tubing disconnected, the torque anchor eliminates this risk (Mohamed,2011).

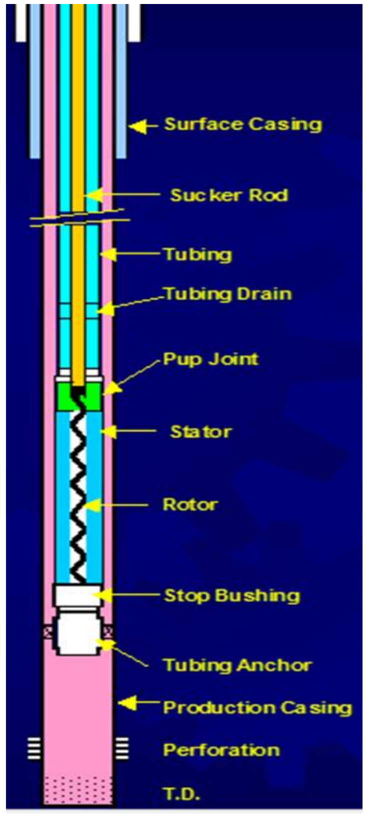


Figure (2. 3) schematic of PC pump downhole Equipment (Mohammed,2011)

2.1.1.2 Surface Drive System:

The surface equipment used in a conventional surface-driven PCP system must perform the following functions:

- Suspend the rod string and carry the axial loads
- Deliver the torque required at the polished rod
- Safely rotate the polished rod at the required speed
- Provide for safe release of the stored energy during shutdowns
- Prevent produced fluid from escaping the system.

To facilitate these requirements, all surface equipment systems include a wellhead drive unit (drive head), a stuffing box, power transmission equipment, and a prime mover, In addition, the surface equipment may also include safety shutdown devices, torque limiters, recoil control devices, and electronic speed control (ESC) and monitoring systems.(larry,2006)

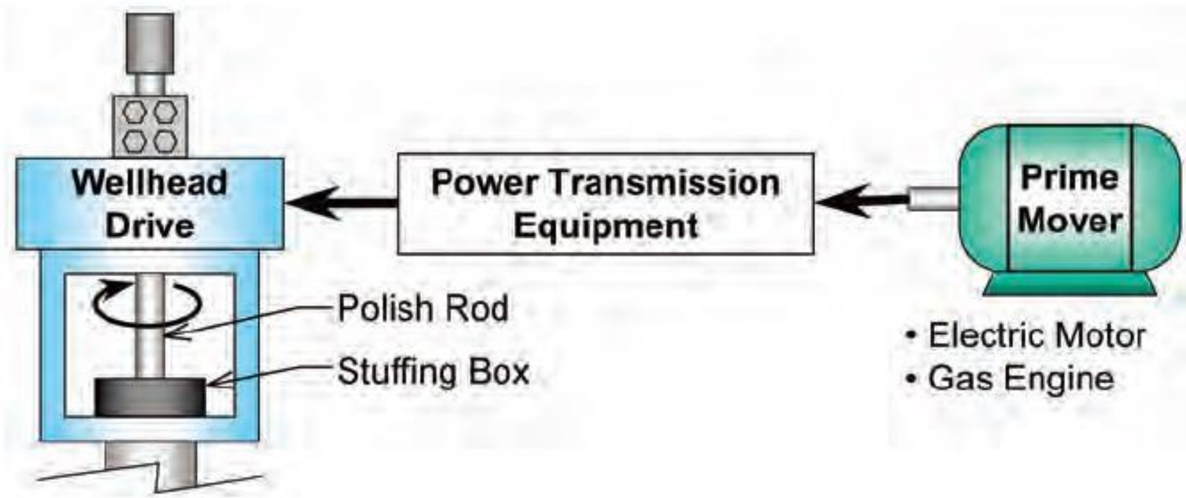


Figure (2. 4) Basic surface equipment for PC pumping systems (larry,2006)

2.1.1.2.1 Wellhead Drive Units

The wellhead drive unit consists of a wellhead frame, thrust bearing, a polished-rod braking system (in most cases), and sometimes a fixed gear or belt and sheave system. In many cases, the wellhead frame threads directly onto the tubing head. However, there is a growing trend toward the use of flanged connections, especially for applications involving drive systems that are 60 hp or larger (larry,2006)

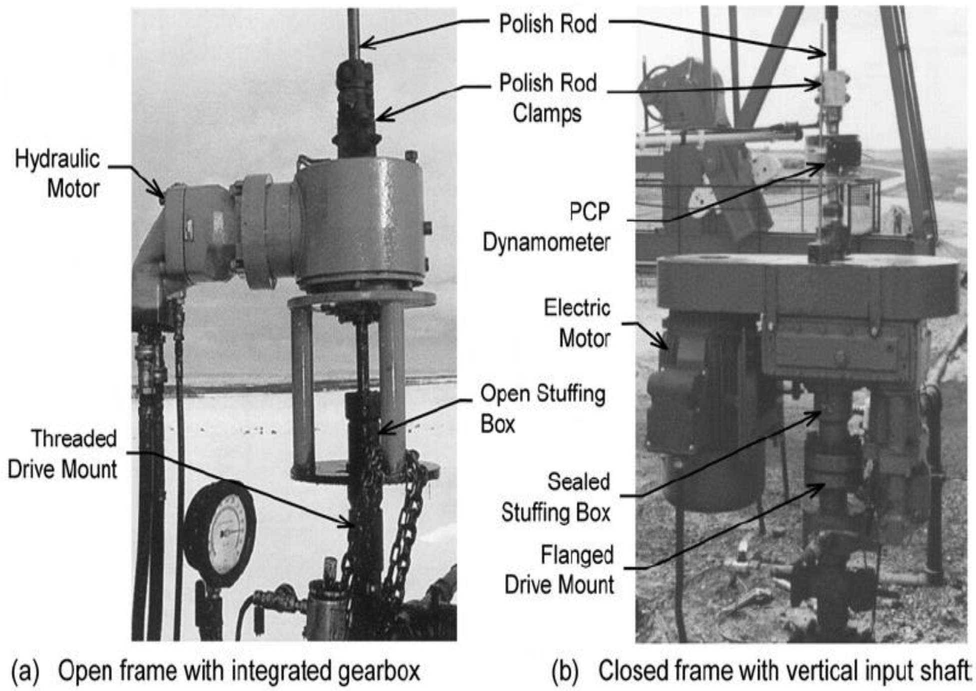


Figure (2. 5) Hollow shaft wellhead drive units. (larry,2006)

Normally, drive heads are connected to the power transmission equipment by a vertical shaft. However, horizontal connections can be facilitated by incorporating right-angle gearboxes directly into the drive head. These gearboxes typically enclose gears that provide a reduction ratio of up to 4:1 . To prevent gearbox failure, operators should adhere to manufacturer guidelines for maximum gearbox speed and torque (larry,2006).

2.1.1.2.2 Power Transmission Equipment

Power transmission equipment is used to transmit power (torque and speed) from the prime mover to the polished rod. This equipment almost always incorporates some type of speed reduction/torque transfer system that permits the prime mover to operate at a higher speed and lower torque than the polished rod. In some cases, power transmission components, such as gearboxes and fixed speed belts and sheaves, are integrated into the drive head. The various configurations can include almost any combination of hydraulic equipment, belts and sheaves, and gearboxes to provide the desired operating speed and torque characteristics. Note that power transmission equipment is usually `classified as either direct drive or hydraulic on the basis of whether or not it incorporates hydraulic system components.

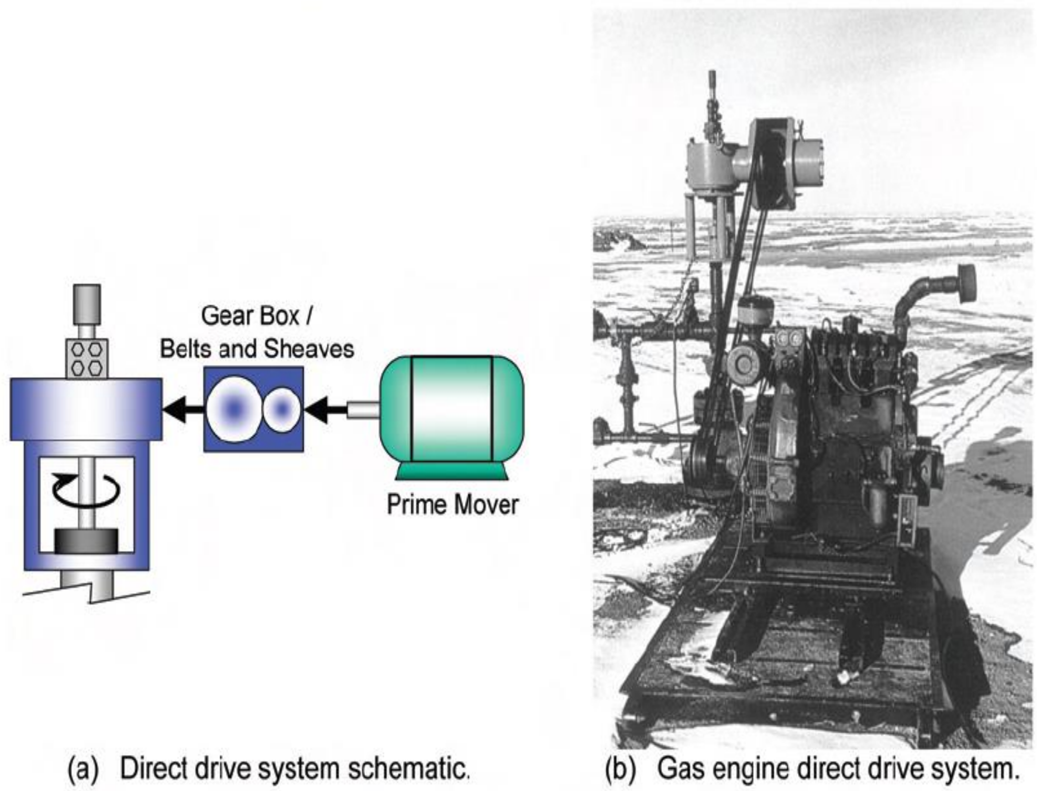


Figure (2. 6) Hydraulic drive system equipment (Larry,2006) 20

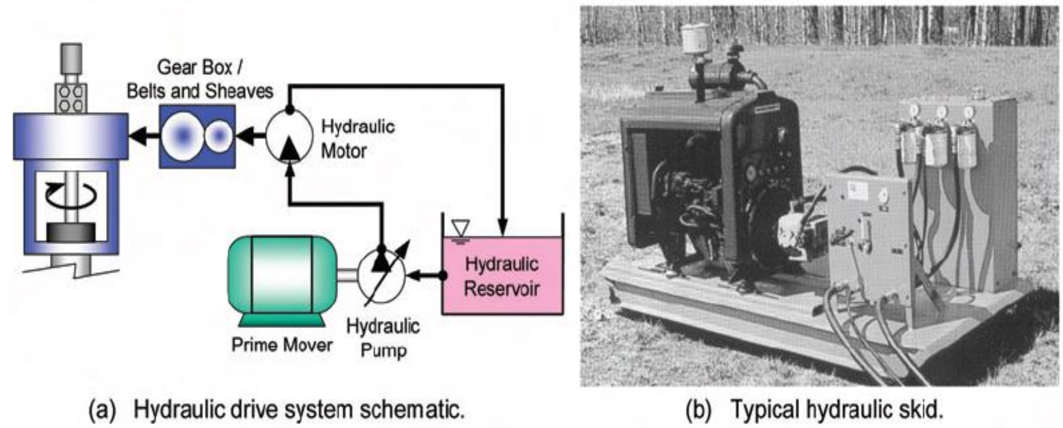


Figure (2. 7) Direct drive power transmission systems (Larry,2006)

Although hydraulic systems are typically less efficient than direct electric drives, they generally require little field infrastructure and have a high variable-speed turndown rate, which makes them popular for low-rate, high-viscosity applications in which prime-mover speeds are much higher than pump speeds and flexible speed control is desirable. The simplicity of mechanical fixed- and variable-speed systems makes them practical for applications in which fluid rates are relatively stable and speed adjustment requirements are limited. The direct-electric drive systems typically have better energy efficiency than hydraulic drives, although they typically are more expensive and can be more difficult to repair. Field electrification is usually required for effective use of electric-drive systems (larry,2006).

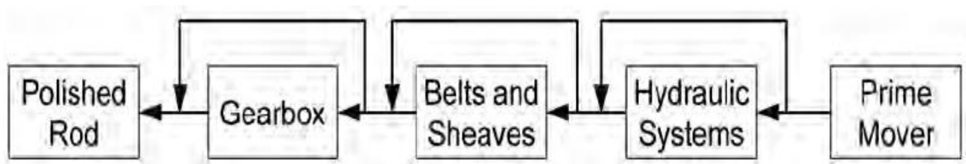


Figure (2. 8) Alternative configurations of power transmission equipment.(Larry,2006)

2.1.1.2.3 Prime Mover:

The prime mover provides the energy to drive the surface equipment and ultimately the rod string and downhole pump. The amount of power that the prime mover must deliver depends on the power demand at the polished rod and the efficiency of the power transmission system. Typical prime-mover power ratings range from 4 to 75 kW [5 to 100 hp], although higher capacity wellhead units designed to accommodate twin electric motors providing power up to 225 kW [300 hp] have recently been introduced by several vendors in conjunction with new large displacement PC pumps. The two types of prime movers commonly used to drive PCP systems are internal combustion engines and electric motors. Internal combustion engines have the advantages of a simple setup with minimum capital investment and variable-speed capability. They are often used on wells in remote areas where electricity is not available. In some situations, depending on gas production and composition, it is possible to fuel the engine with produced gas. Nevertheless, electric motors are the most common form of prime mover used for PCP systems because of low maintenance requirements, high efficiency, low energy costs, easy operation, and low noise levels(Larry,2006).

2.1.2 PC Pump Installation:

The process of installation progressive cavity pump (from PCM MOINEAU OILFIELD Services) includes the following:

- Pre – operational Checks
- Pre – commissioning inspections
- Pump and Drive-head installation
- Close monitoring of the PCP upon commissioning
- Installation & Maintenance Training
- Installation report
- 1 or 2 PCM Engineer (s) for a duration of 5 to 6 days

Timing:

1. Run in Hole Tubing String (Set the torque anchor 4,0 hrs) 22
2. Run in Hole Rotor String (Tag the Rotor on Stop Bushing 4,0 hrs)
3. Space out (Measure for length adjustment 0,5 hrs)
4. Connect the Polished rod (0,5 hrs)
5. Install the Drive head (1,5 hrs)
6. Install motor support assembly (1,0 hrs)
7. Install motor (and electrical connections) (0,5 hrs)
8. Install and Adjust the Belt and the Pulleys (0,5 hrs)
9. Install Flow lines and sensors – open the valves (1,0 hrs)
10. Connect VSD /VFD (1,5 hrs)

START THE PUMP **Total 15/16 hrs**

Run In Hole Tubing String :

- Tubing Hanger

- Tubing Drain
- Cross over Tubing / Pup Joint
- Pup Joint
- Collar Pup / Stator
- Stator (1, 2 or 3 element's)
- Tag bar / Stop Bushing
- Torque Anchor / Packer
- Cross over to tail joint

NOTE: Other DH tools maybe included; (Ex: Gas Separators, Tubing Drain, DH Gauges)

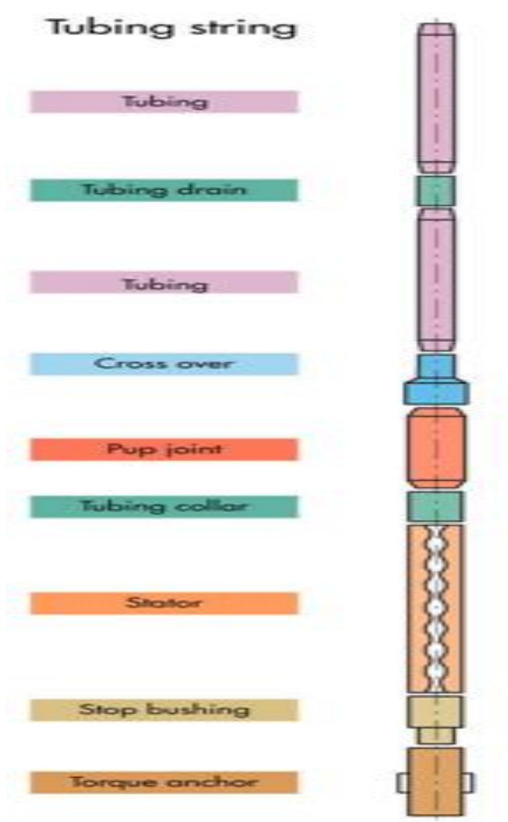


Figure (2. 9) Tubing string. (PCM MOINEAU OILFIELD)

Setting the torque anchor

- Before setting the tubing hangar it is important to set the Torque Anchor

- At approximately 50 – 60 cm before the hangar is set, turn the tubing with a pipe wrench clockwise.
- Hold that position until the Tubing Hangar is firmly set**.**

Figure (2. 10) setting torque anchor (PCM MOINEAU OILFIELD)

Rod String Standard – Configuration:

- Rotor + Rotor Coupling
- Pony rod – 10ft or 12ft / Coupling
- Centralizer / Coupling
- Sucker Rod + Coupling
- Centralizer + Coupling

- Sucker Rod + Coupling
- Centralizer + Coupling
- Rod String to surface + Coupling

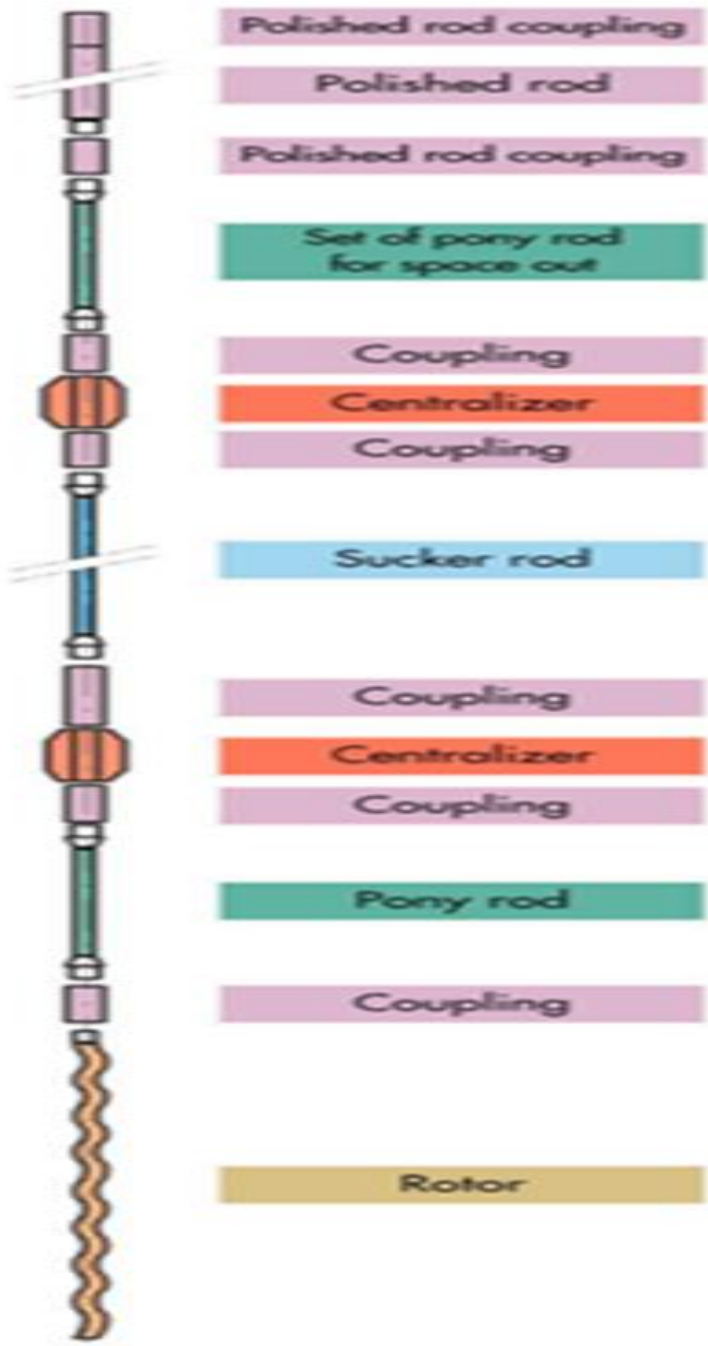


Figure (2. 11) rod string (PCM MOINEAU OILFIELD)

Running Rotor in the Hole

ROTOR

- Make sure that the Rotor is clean and free from any foreign elements / damages.
- Make sure that the bottom of the Rotor is protected at all times.
- For new Stator's it is advisable to lubricate the Rotor with grease. To avoid any dry contact between the Elastomer of the Stator & the Rotor
- Do not drag the Rotor on the Catwalk or the Rig Floor

Figure (2. 12) running rotor in hole (PCM MOINEAU OILFIELD)

Sucker Rods

- Check all the threads on Sucker Rods, pins and couplings to avoid down time and unnecessary fishing due to damaged threads
- These Checks should be carried out even when the Sucker Rods are new
- Put in place all the centralisers at this point to ensure correct installation of the rod string

• Lay out the exact number of rods according to the depths and tally the rod string as it is RIH.

Table (2. 1) Sucker Rod Sizes and Threads

API sucker rod size	in	3/4	7/8	1	1 c/w 7/8 pin	1 1/8	1 ¼ c/w 1 pin	1 ½ c/w 1 1/8 pin
Thread size	in	1 1/16	1 3/16	1 3/8	1 3/16	1 9/16	1 3/8	1 9/16
Length of sucker rod	ft	25,30	25,30	25,30	25	25,30	25	25
Length of pony rod	ft	1,2,4,6,8,10,12	1,2,4,6,8,10,12	1,2,4,6,8,10,12	2,4,6,8,10	1,2,4,6,8,10,12	2,4,6,8,10	2,4,6,8,10
Tightening torque	Lbs-ft	350	510	800	510	1100	1600	2400

Space Out – The Rod String :

Spacing out done by the following steps :

- Once the Rig Weight Indicator r shows ZERO, it would suggest that the Rotor is sitting on the Stop Bushing.
- At the Well Head- Use a Paint Marker and tag the Sucker Rod
- This tag will be the “Zero String Weight Tag”
- Continue to run in & out of the stator a few times – To be sure that the Zero String Weight Tag is always in line with the well head.
- After marking the Ze0ro String Weight Tag, pick up the Rod String very slowly until the Total String Weight is observed again.
- At this point, the Rotor is still inside the Stop Bushing but not sitting in it.
- Tag the Sucker Rod – This tag will be the “Total String Weight Tag”
- Pick up the Rod String another 30 cm more and tag it.
- This tag will be the “Stop Bushing Tag”
- This indicates that the Rotor is out of the Stop Bushing
- The last tag of the space out will be the value calculated by PCM’s Win Petro

- Software + a safety margin of 25 – 30 cm.
- This last tag will be the "Space Out Tag" and break one or 2 rods depending on the location of the last tag.

Polished rod string

STANDARD ASSEMBLY from Top:

- 2ft Pony for lifting
- Full Size Coupling

NOTE: Coupling must be bigger than Hex Shaft

- Hexagonal Shaft – Pin on top
- Hex clamp on the Hex shaft @ 15 cm from top

NOTE: The bolts must be cross tightened.

- Polished Rod PR

NOTE: Must be tightened on the Hex Shaft with a pipe wrench and measure the torque

- Bullet on the bottom of PR – Thread protection

Polished rod SPACING OUT

- Lay the Polished Rod Assembly beside the Sucker Rod which was Tagged and place the Last Tag (Tag 4) parallel with the Polished Rod Tag.
- If the length of the Polished Rod exceeds the length of the Sucker Rod – Break out another Sucker until it exceeds the length of the PR.
- Add a Centraliser at the end of the PR and fill in the remaining length with Pony Rods. NOTE: Pony Rods should not exceed the Sucker Rods.
- Add the Pony Rods to the Rod String.

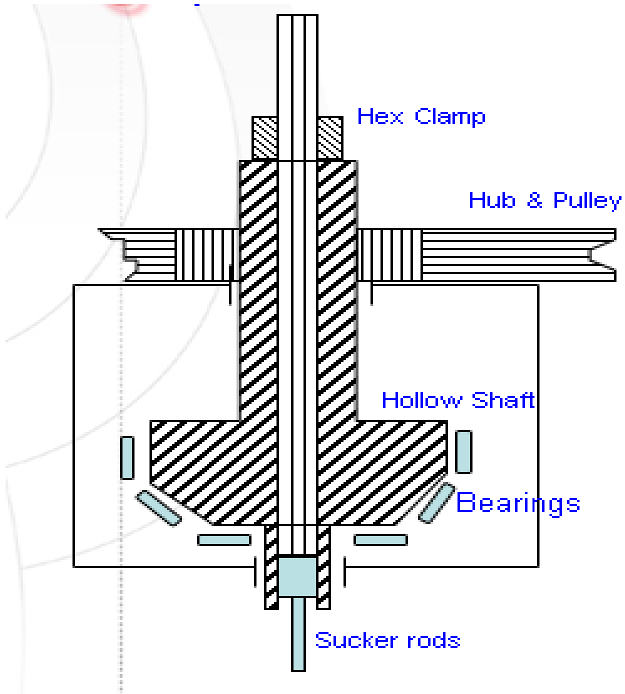


Figure (2. 13) space out the polished rod (PCM MOINEAU OILFIELD)

2.2 Progressive Cavity pump Studies over the World:

Most of The previous studies focused on progressive cavity pump parts and optimization of Progressive cavity pump performance.

- Michael W. Glier in 2011 Texas A&M University, presented study under title (the experimental Examination of Progressing Cavity Pump operating at very High Gas Volumes Fracture) focused on testing progressing cavity pump model manufactured by seepex at half and full speed by Using air-water mixture with gas volume fractions to show the effect of high gas volume fractions on pump's volumetric flow rate .

- Mohammed Bashir et, al.in 2009 Sudan university of science and technology presented study under title (Optimization of progressive cavity pump), this study discussed optimization of PCP focused on selection of the optimum parts of the pump which achieve the optimum performance and productivity according to the various condition of the producing wells.

- Cesar Ivan Medina-Chavez et, al. 2005 The University of Texas presented study under title (Design Standards, Special Specifications, and Monitoring Plan for PCP in Texas) focused on the effective application of the required procedures for the final design and construction of the new PCP and also on the development evaluation and monitoring plans for both short-term and long term performance of the PCP.

- Jose Gamboa et,al. in 2003 in 2003 Research and Development Institute of Petroleos de Venezuela S.A ,presented study under title (Understanding the Performance of Progressive Cavity pump with a metallic Stator) focused on Analytical and Experimental studies carried on progressive cavity pump fitted with a metallic stator with affixed positive clearance around the helical rotor.

Chapter three

Chapter 3

Methodology

3.1 PIPESIM:

PIPESIM is a steady-state, multiphase flow simulator used for the design and analysis of oil and gas production systems. With its rigorous simulation algorithms, PIPESIM helps you optimize your production and injection operations.

PIPESIM is most often used by reservoir, production or facilities engineers as an engineering user type to model well performance, conduct nodal (systems) analysis, design artificial lift systems, model pipeline networks and facilities, and analyze field development plans and optimize production. The PIPESIM graphical user interface (GUI) allows you to easily construct well and network models within a single environment(PIPESIM USER GUIDE, Schulumberger,2015).

3.1.1 Applications:

1. Accurate flow modeling over the complete lifecycle of system.

2. Operating oil and gas gathering system while honoring multiple system constrains.

3. Determine the optimal locations for pumps and compressors.

4. Designing and operating water or gas injection network.

5. Calculation filed full deliverability to ensure contractual delivery rates are met.

6. Analyzing hundreds of variables such as pressure, temperature and flow assurance parameters through complex flow paths.

3.1.2 Objectives:

Pipe sim can build the following basic models :

- pipeline and facilities
- production well
- single completion well
- Multiple completion well
- Horizontal completion well
- Injection well
- Subsurface and surface networks
- Gathering system
- Looped System
- Distribution systems
- Multilateral wells

3.1.3 Key features:

A. Gas lift design accounts for changing condition and hydraulic effect of the total system.

B. Gas lift diagnostics analyzes performance of gas lift value system.

C. Perforation design determines perforation gun selections phasing and spacing.

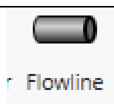
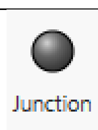
D. Data matching automatically tunes multiphase flow and heat transfer coefficient.

E. Advanced network solver helps solve complex network problems.

3.2 Model Building by PIPESIM:

3.2.1 Physical component of the model :

Table (3. 1) Physical Component Of The Model (PIPESIM USER GUIDE, Schulumberger)

Button	Function
	A well where fluids exsists (production well) or enters (Injection well) the network .
	Placing the tubing object in the allow modeling of vertical or near vertical flow (production or injection) in the wellbore
	Placing a flow line in the model allow modeling horizontal or near horizontal flow (up or down hill).
	Is location in the model where two or more branches meet, the fluids from the incoming branches are then mixed at the junction, the junction itself has no associated pressure drop
	Is a point in the network where the fluid leaves the system normally used to represent a surface out flow opposed to an injection well.

3.2.2 Model Design procedures

In this case study the system was designed by the following procedures :

1- **Collection of inserted Data**:

The first step in the design process is to gather information for the application of interest; fluid properties, reservoir parameters and production data from testing reports for example :

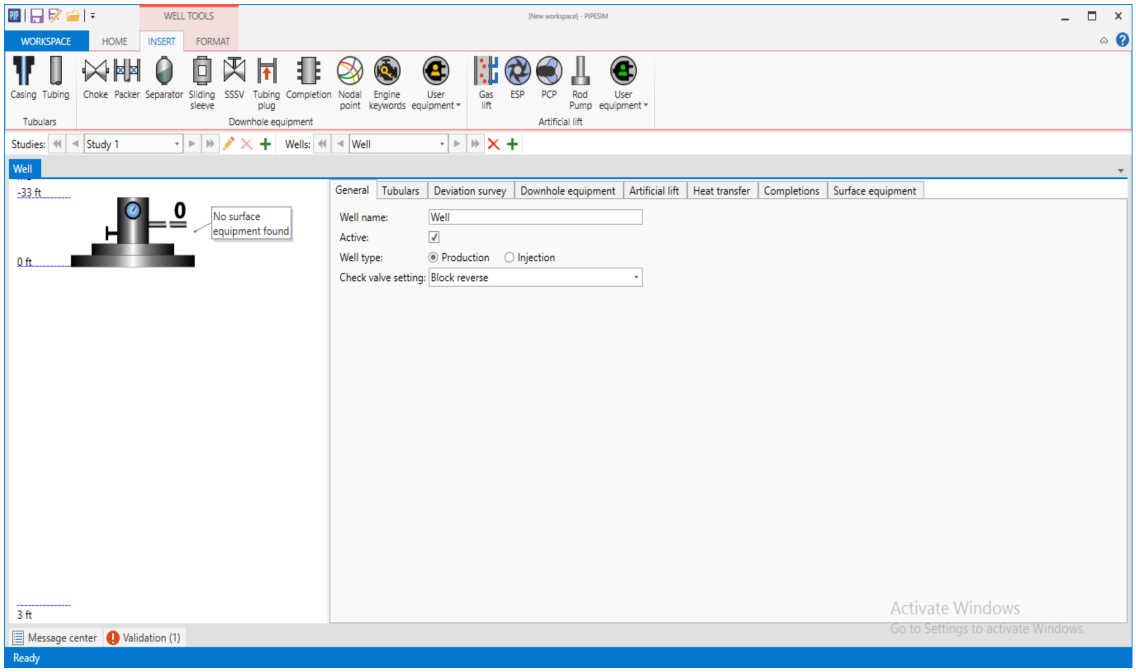
Parameter	Well data
Casing (ID) (in)	7
Casing depth (ft)	5679
Tubing(ID) (in)	3.5
Tubing Depth (ft)	5220
Initial Reservoir Pressure (psi)	2134.7
Reservoir temperature (˚F)	194
Oil gravity (API)	24
Ambient temperature (˚F)	95
Perforation Depth (ft)	5220
Pump Depth (ft)	5183
Pump speed (rpm)	250

Table (3-2) Example of Inserted Data in PIPESIM

2- **Define the physical component of the model by the following steps** :

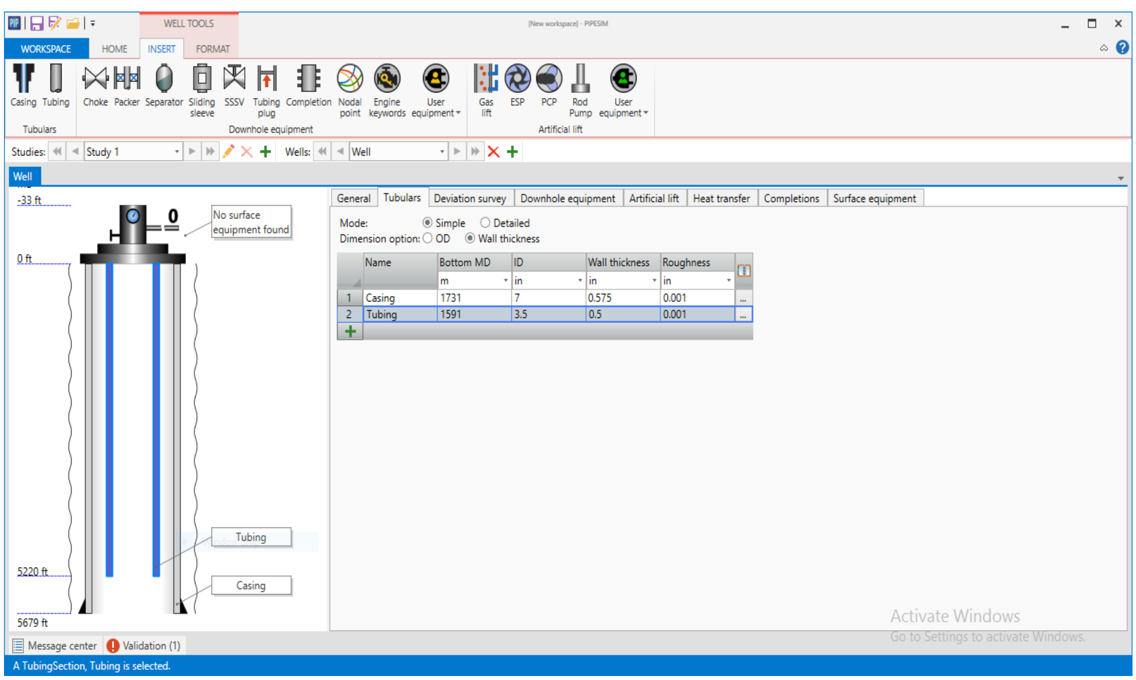
Step 1 : **General data**

From the workspace screen of pipesim select the option create new network and select well type (production or injection) and well name .



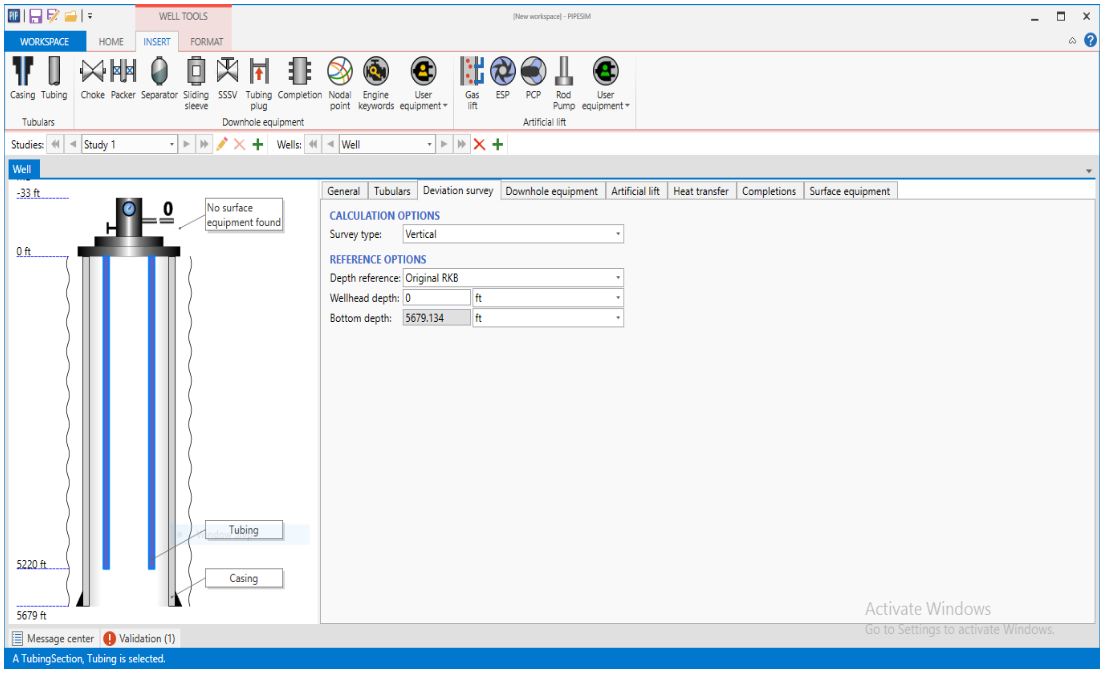
Step 2: **Tubular data**:

Choose the well description mode (simple or detailed), insert the measured depth and the inside diameter of casing and tubing.



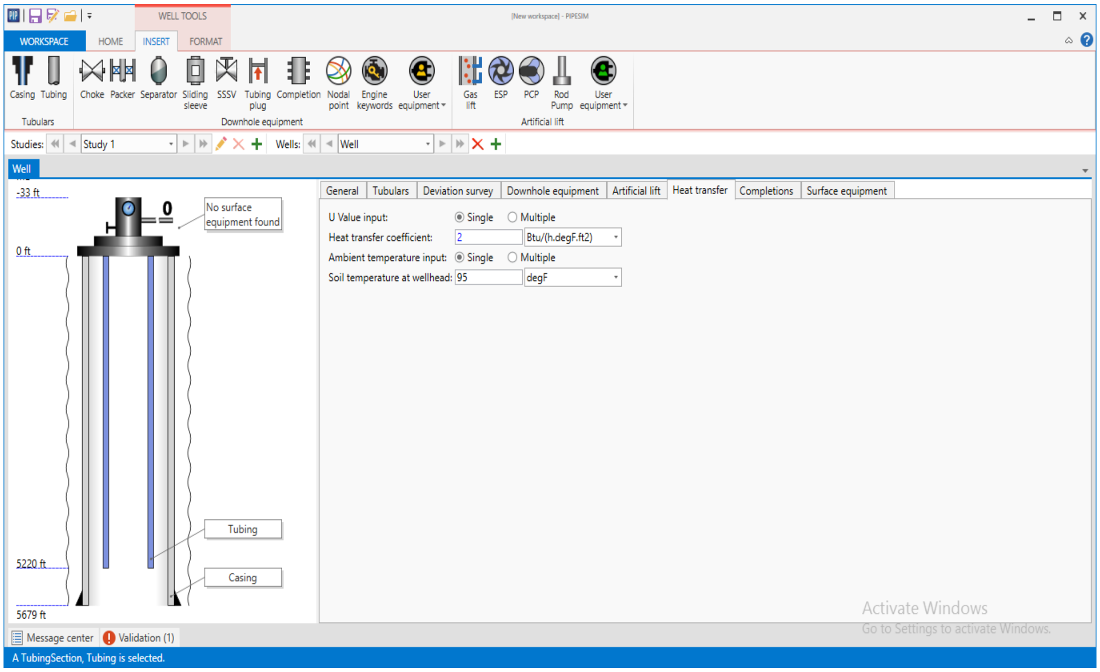
Step 3 : **Deviation survey**:

Select the survey type (vertical or horizontal) and enter the bottom hole depth.



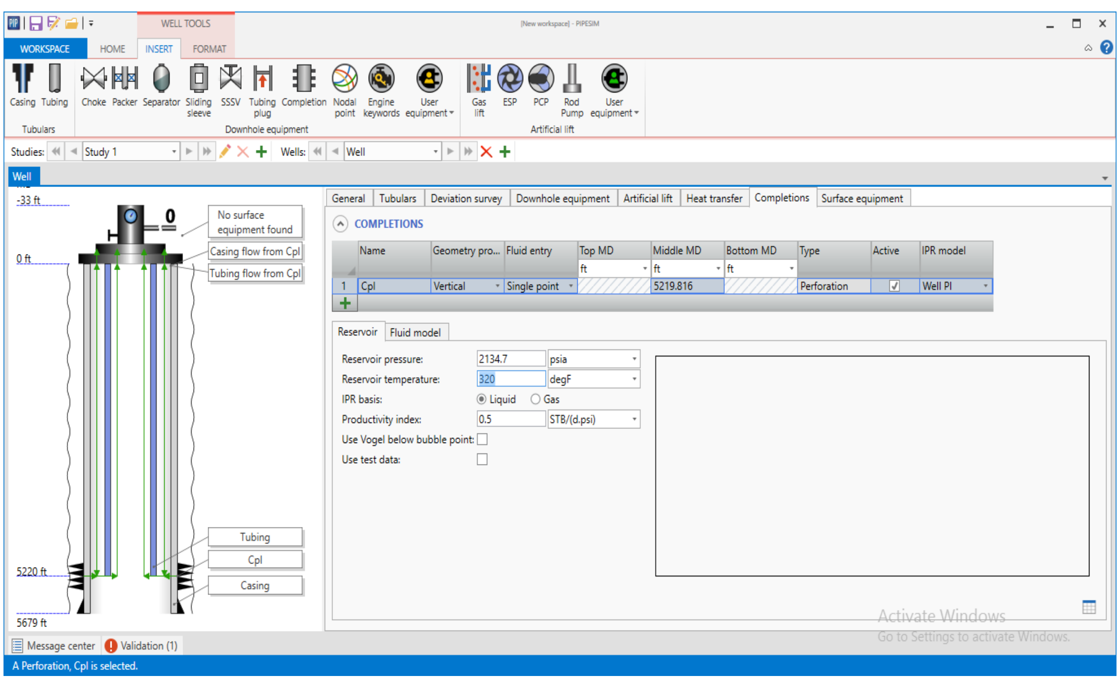
Step 4 : **Heat transfer data**:

From this window insert the ambient temperature, total measured depth and bottom hole temperature.



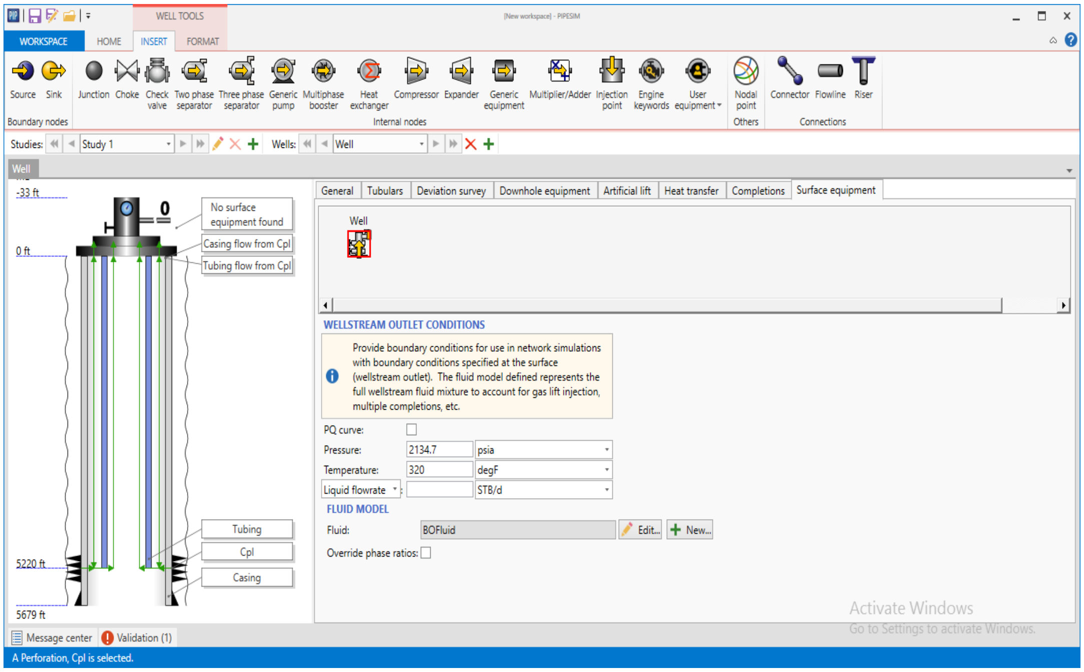
Step 5 : **Completion data**:

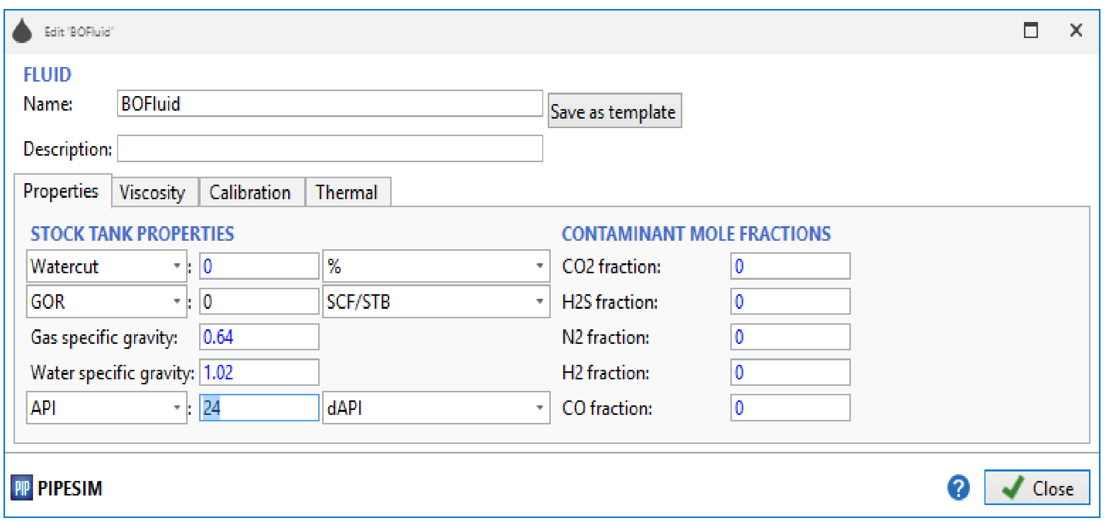
Select the perforation depth and choose the inflow performance relationship model (well PI) and insert its data (reservoir pressure and temperature, IPR basis (liquid or gas).



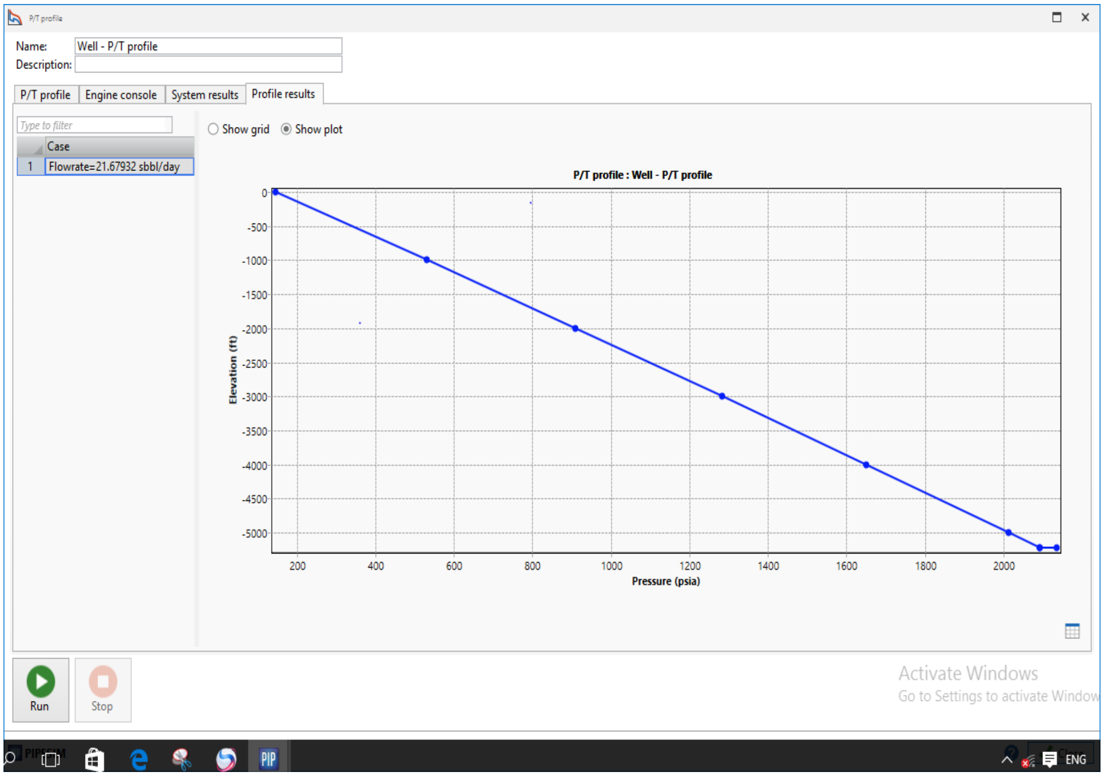
Step 6: **Surface equipment**:

Insert its outlet pressure and temperature and fluid parameters in fluid model



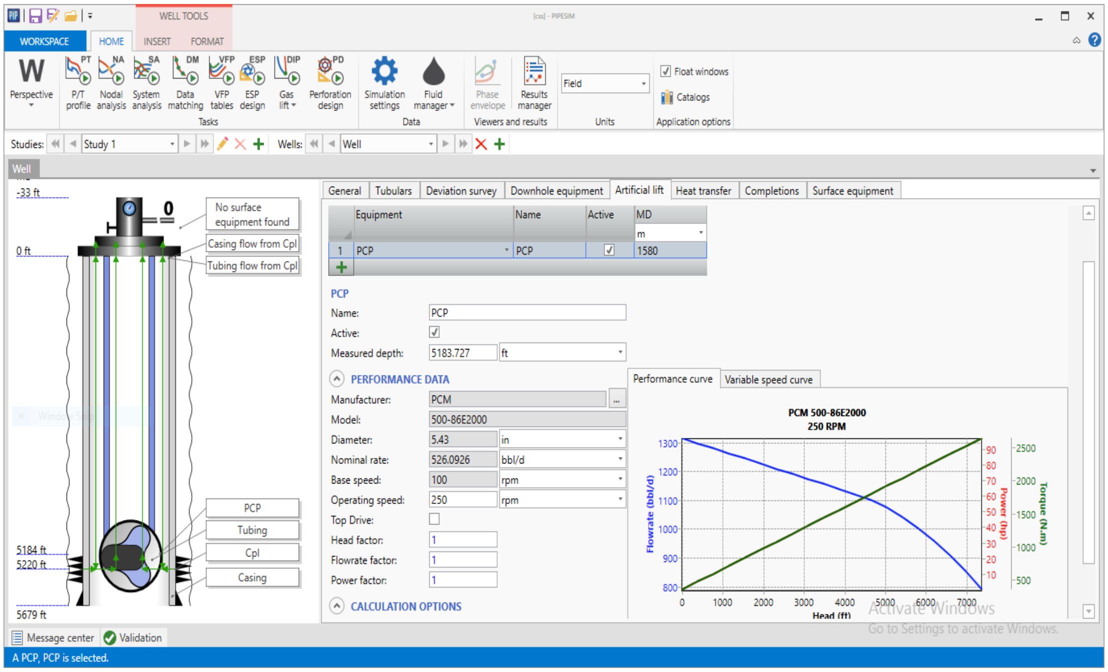


Step 7: **Run model** in pressure / temperature (P/T profile) to show the natural production of the well.



Step 8: **Select Artificial lift method (PC Pump)**and insert its data as follows:

- Name
- Measured depth
- Performance data:
- Manufacturer (PCM or wheatherford)
- Model (the most common type of PCM is 500-86E2000)
- Diameter (5.43inch)
- Nominal rate (526.0926 bbl /day)
- Base speed (100 rpm)
- Operating speed (250 rpm)



3.2.3 Tubing size selection:

One of the most important components in the production system is tubing string. As much as 80 percent of the total pressure loss in an oil well can occur in moving the fluids from the bottom of the hole to the surface.

The procedures:

1. Selection a node in the well (bottom hole or intake).
2. Dividing the system at this point in to two section.
3. Determine the drop as function of flow rate for this point.
4. Calculate the node pressure from the two direction of the flow starting with the fixed pressure (H.Dale,1991)

Thus:

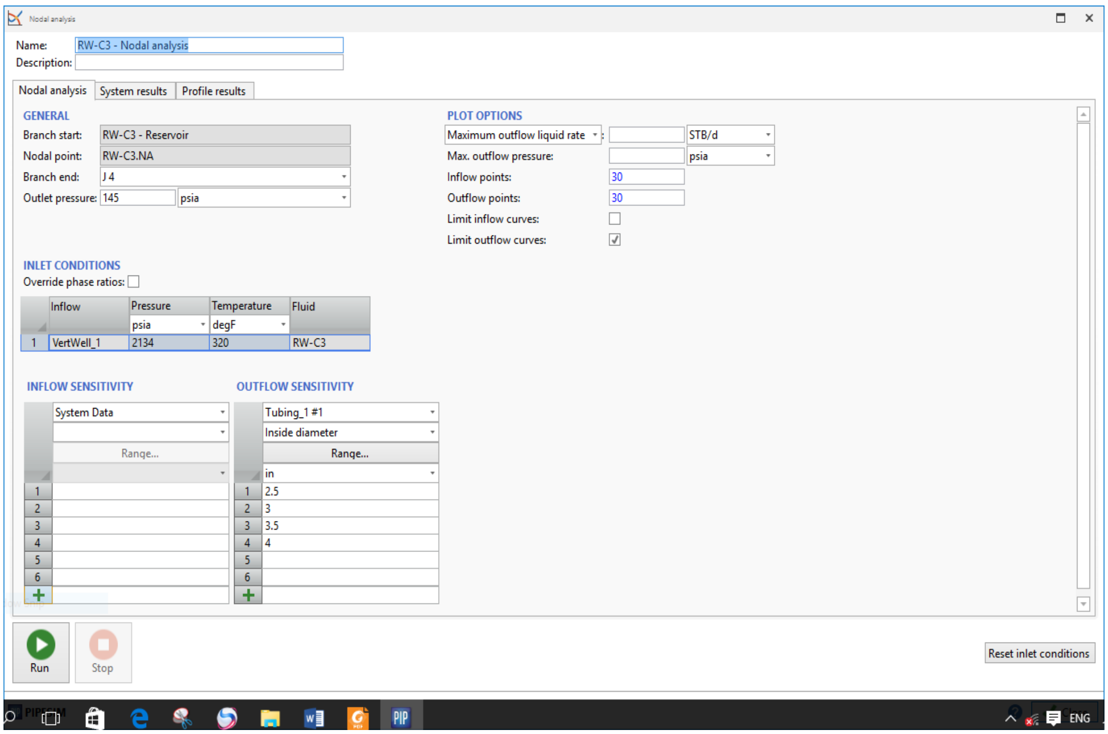
The inflow to the node:-

$$Pr - \Delta P(resistance) = Pwf$$

The out flow from the node:-

$$Pwh + \Delta P(tubing) = Pwf$$

Nodal Analysis by PIPESIM to study the effect of tubing size on oil flow rate :



3.2.4 Effect of water cut:

Relative permeabilities can be used to calculate separately the flow of both oil and water.

$$Ko = K * Kro \qquad Kw = K * Krw$$

$$Kro \equiv relative\ perm\ to\ oil \qquad Krw \equiv relative\ perm\ to\ water$$

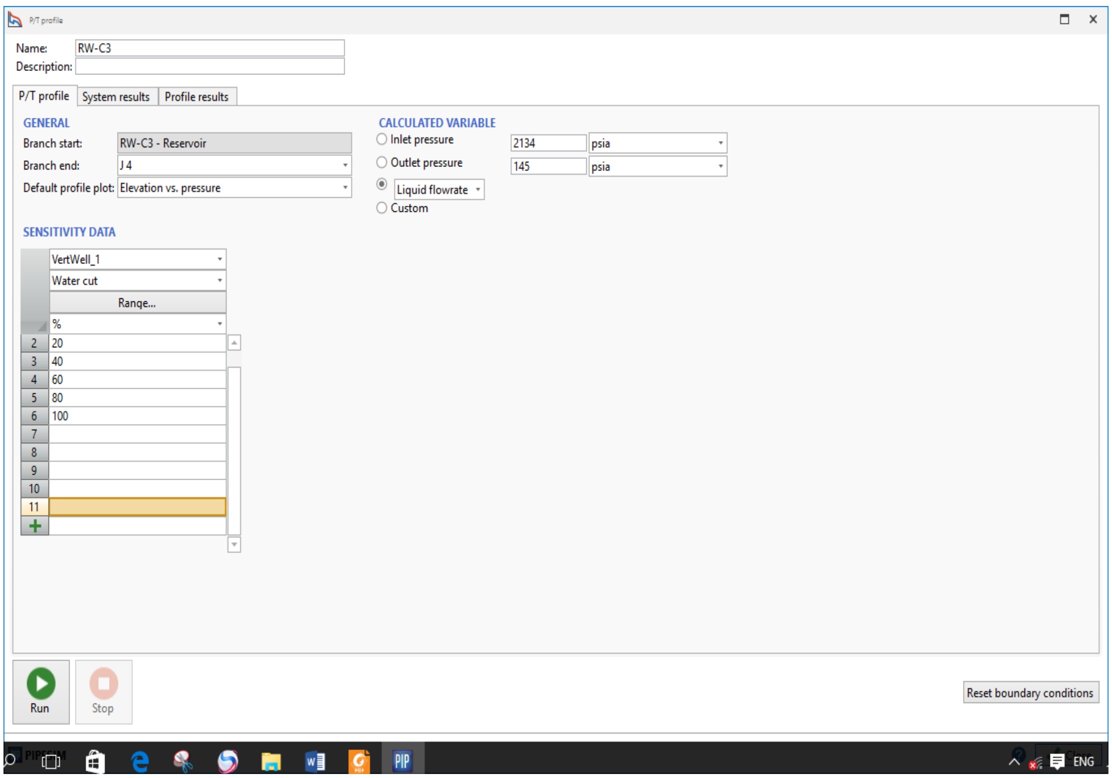
Since the relative permeabilities are function of oil and water saturations of reservoir so are the flow rates of the oil and water can be calculated from (Tarek,2010) .

$$Qo = \frac{0.007082Koh(P - Pwf)o}{\beta o\mu o(\ln(^{r}/_{rw}) + s)} \qquad Qw = \frac{0.00708Kwh(P - Pwf)w}{\beta w\mu w(\ln(^{r}/_{rw}) + s)}$$

Water fraction can calculated from the following equation:43

$$fw = \frac{Qw}{Qw + Qo}$$

Water cut % Sensitivity by PIPESIM :



3.2.5 Pump Speed design:

➢ Pump speed should be kept as minimum as practical for high viscous cruder. Even though rpm as high as 500 is possible for a PC Pump, try to select a speed in the med range, say 200-300 rpm.

- While selecting speed, it is better to have different manufactures product catalogues in hand, to verify the pump dimensions capable of producers the required rate at the selected rpm(NETZSCH,2005).

$$theoretical\ displacement = cross\ section\ area * stator\ pitch\ length$$

$$v = a * p = 4 * e * d * p$$

$$e \equiv eccentricity \qquad d \equiv rotor\ diameter$$

$$theoretical\ flow\ rate = theoretical\ displacement * pump\ speed$$

$$actual\ flow\ rate = theoretical flow\ rate - slippage$$

$$volumetric\ efficiency = \frac{actual\ flow\ rate}{theoretical\ flow\ rate}$$

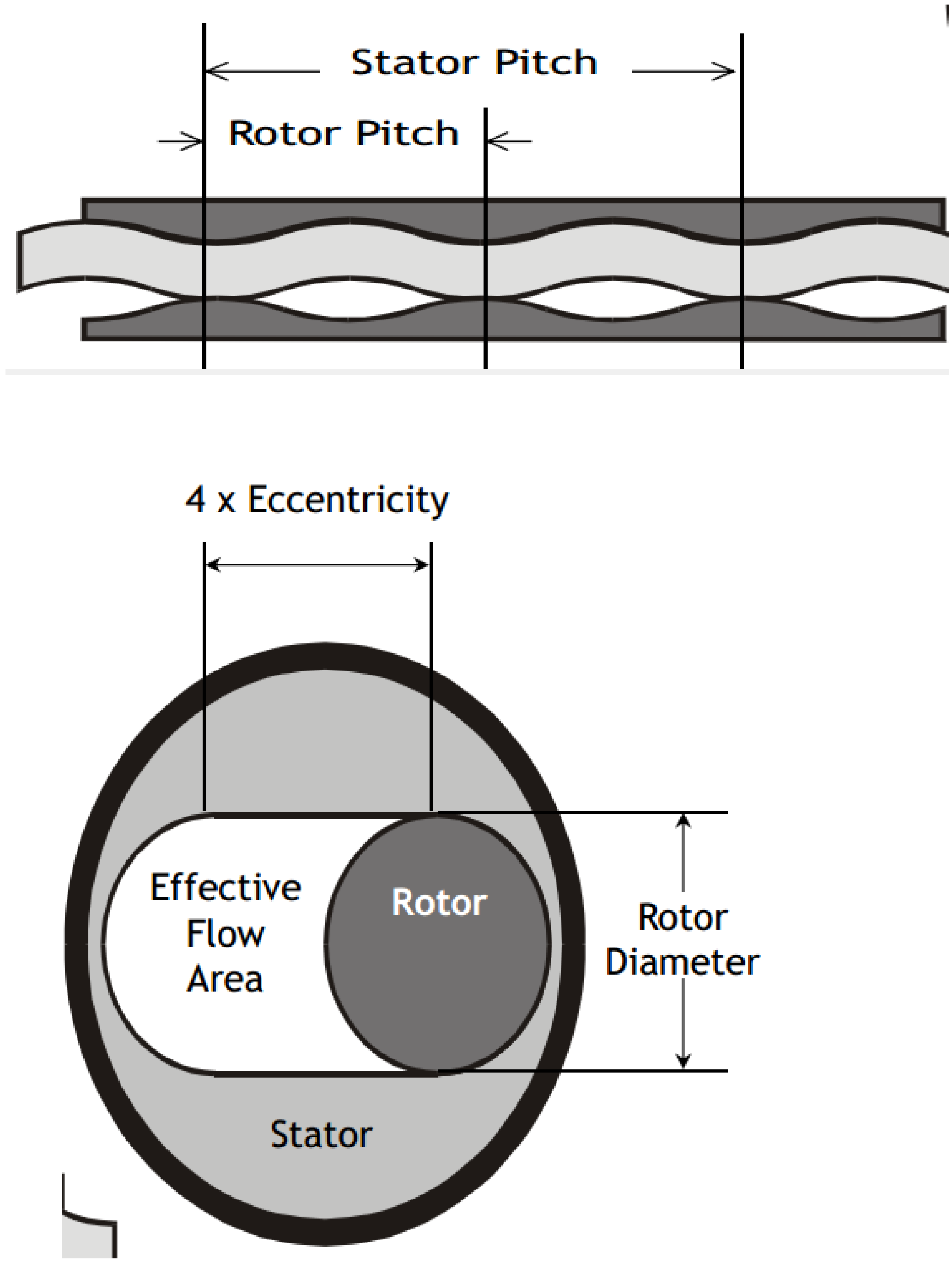
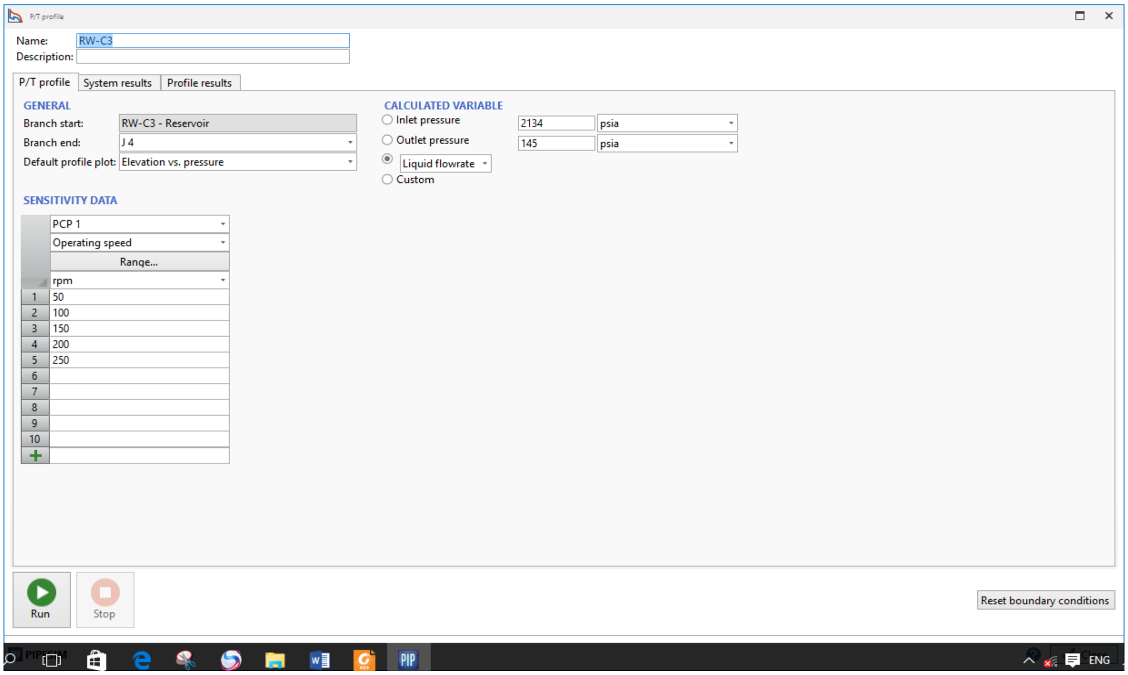


Figure (3. 1) Rotor & Stator Geometry (NETZSCH,2005).

Pump speed Sensitivity by PIPESIM:



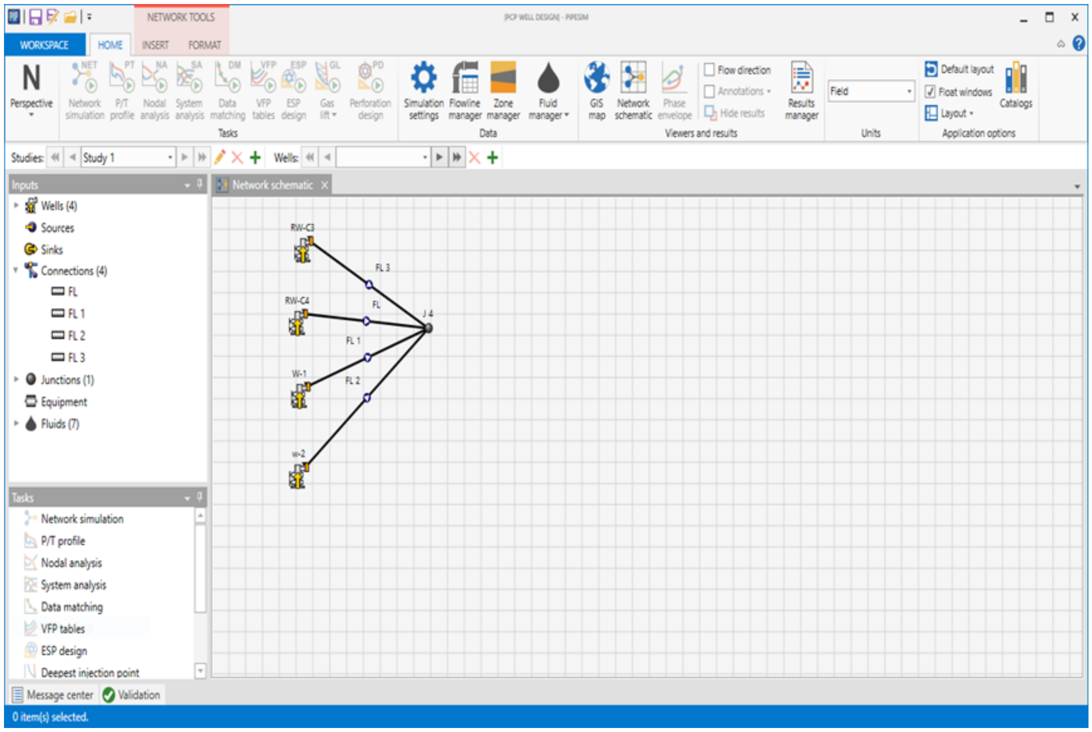
After completing data collection , data entering , and sensitivity tests repeat the previous procedures for each well and the results are shown in the next chapter.

3.3 Network design:

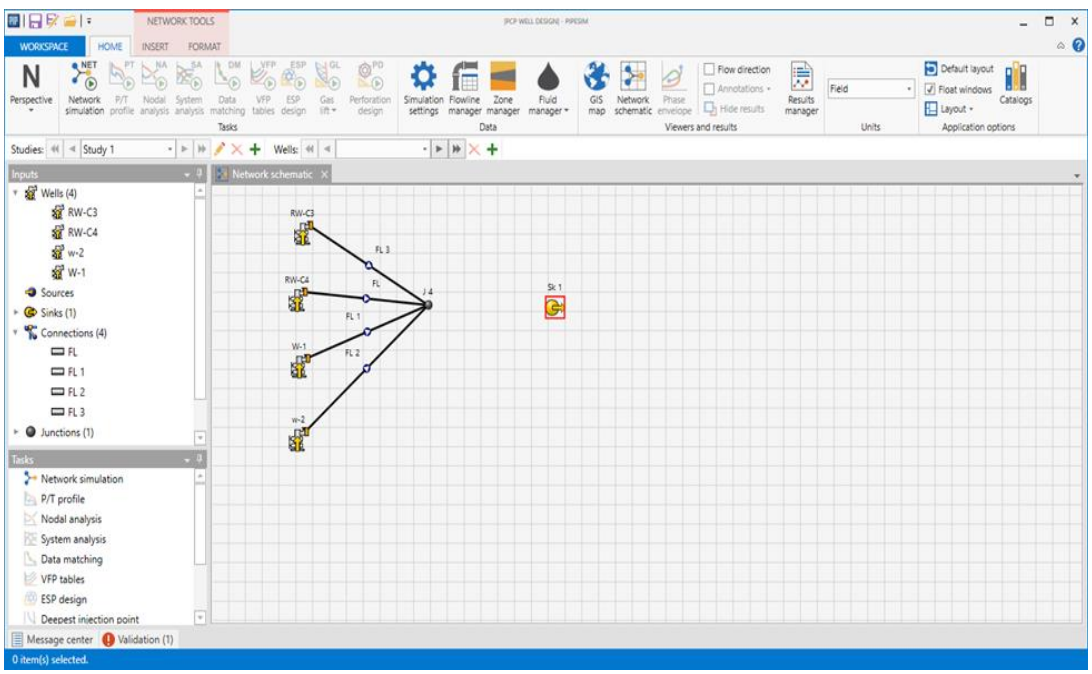
Last upgrades of PIPESIM Makes that its capable of modelling complete field developments including ; inflow performance , tubing , complex flow line systems and field equipment through to production facilities.

The procedure

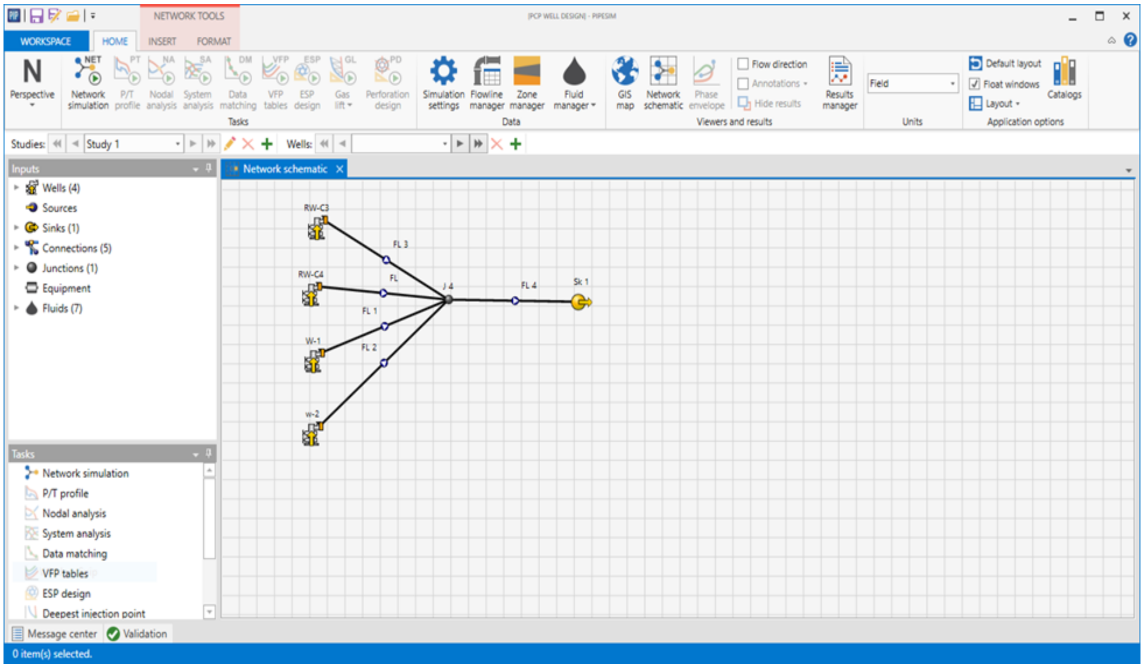
- From the existing work space select new junction to work as oil gathering manifold (**OGM**).
- From each single branch (**well**) make flow line with 2000m length and connect it with the junction (**OGM**).



- Select new sink to work as field processing facilities (**FPF**).



- From the junction (**OGM**) make flow line with 2000 m length connected to the sink (**FPF**)
- Calculate the flow rate after entering the boundary condition.


NETWORK TOOLS
WORKSPACE
HOME
INSERT
FORMAT
Perspective
Network simulation
P/T profile
Nodal analysis
System analysis
Data matching
VFP tables
ESP design
Gas lift
Perforation design
Tasks
Simulation settings
Flowline manager
Zone manager
Fluid manager
Data
GIS map
Network schematic
Phase envelope
Flow direction
Annotations
Hide results
Results manager
Viewers and results
Field
Units
Default layout
Float windows
Layout
Catalogs
Application options
Studies:
Study 1
Wells:
Inputs
Wells (4)
Sources
Sinks (1)
Connections (5)
Junctions (1)
Equipment
Fluids (7)
Tasks
Network simulation
P/T profile
Nodal analysis
System analysis
Data matching
VFP tables
ESP design
Deepest injection point
Network schematic
RW-C3
FL 3
RW-C4
FL
J 4
FL 4
Sk 1
FL 1
W-1
FL 2
w-2
Message center
Validation
0 item(s) selected.

3.4 Design process as flow diagram

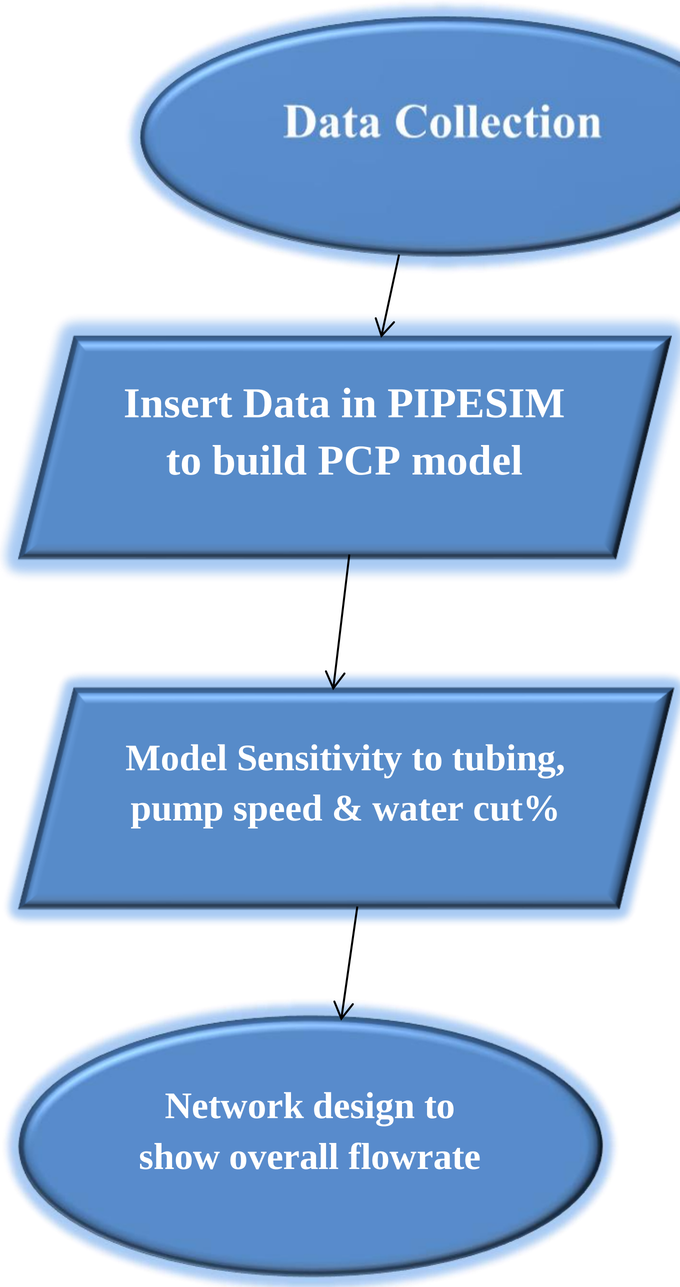


Figure (3. 2) Design flow diagram

Chapter 4

Chapter 4

Results

4.1 Data collection:

Table (4. 1) Inserted Data in PIPESIM™

Parameters	Rawat-C3	Rawat-C4	Wateesh-1	Wateesh-2
Casing (ID) (in)	7	7	7	7
Casing depth (ft)	5679	5675	8058	8061
Tubing(ID) (in)	3.5	3.5	3.5	3.5
Tubing Depth (ft)	5220	5192	7847	7556
Initial Reservoir Pressure (psi)	2134.7	2192.5	3174.9	3292
Reservoir temperature (˚F)	194	195	224	225
Oil gravity (API)	24	24	24	24
Ambient temperature (˚F)	95	95	95	95
Perforation Depth (ft)	5220	5192	7847	7556
Pump Depth (ft)	5183	5151	7815	7513
Pump speed (rpm)	250	150	250	250

4.2 Results:

4.2.1 Oil flow rates results:

Table (4. 2) Oil Flow Rate Results

Well Name	Natural flow Flow rate (bbl/Day)	PC pump Flow rate (bbl/Day)
Rawat C-3	24.004	954.536
Rawat C-4	35.083	929.416
Wateesh -1	84.953	1006.382
Wateesh -2	178.805	1122.014

4.2.2 Nodal Analysis Results depending on different sizes of Tubing:

Table (4. 3) Nodal Analysis Results Depending On Different Sizes of Tubing

Well name	Oil Flowrate (bbl/day) at Tubing (ID=2.5inch)	Oil Flowrate (bbl/day) at Tubing (ID=3 inch)	Oil Flowrate (bbl/day) at Tubing (ID=3.5inch)	Oil Flowrate (bbl/day) at Tubing (ID=4 inch)
Rawat C-3	954.7998	953.765	951.699	951.598
Rawat C-4	929.416	927.523	926.125	925.511
Wateesh -1	1006.369	1004.459	1003.004	1002.245
Wateesh -2	1122.009	1120.354	1119.256	1117.134

The above results are shown in figures below :

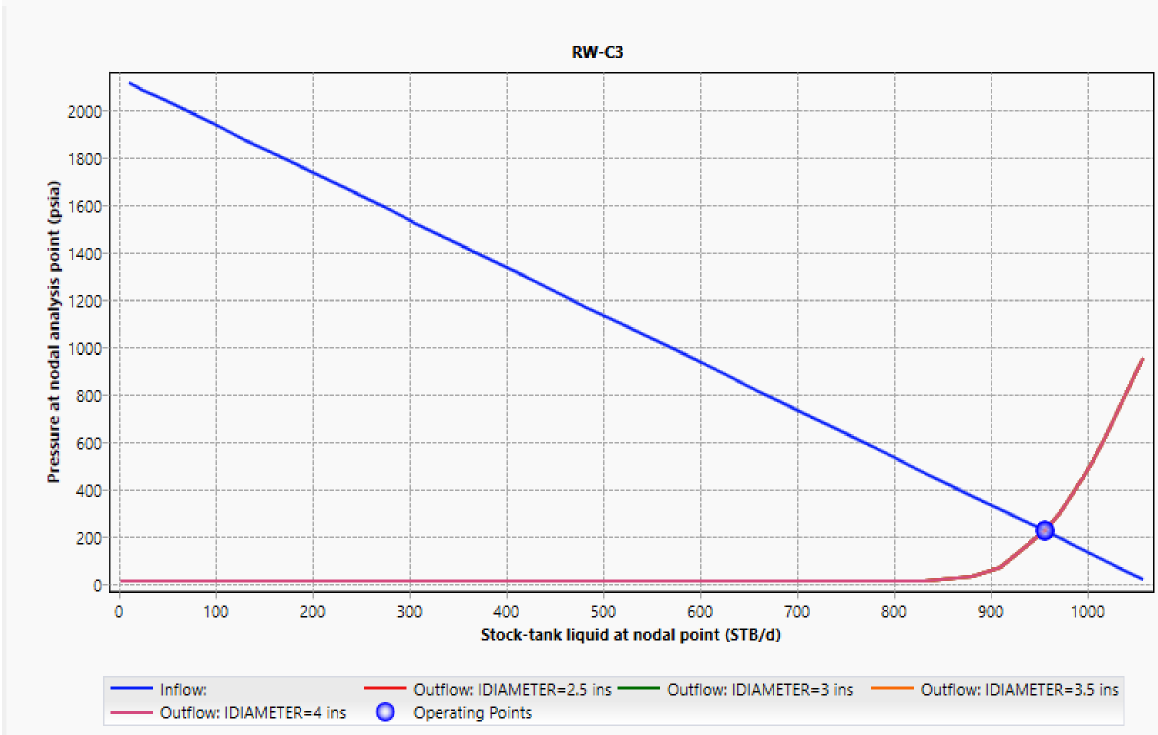


Figure (4. 1) Rawat C-3 Tubing sensitivity profile

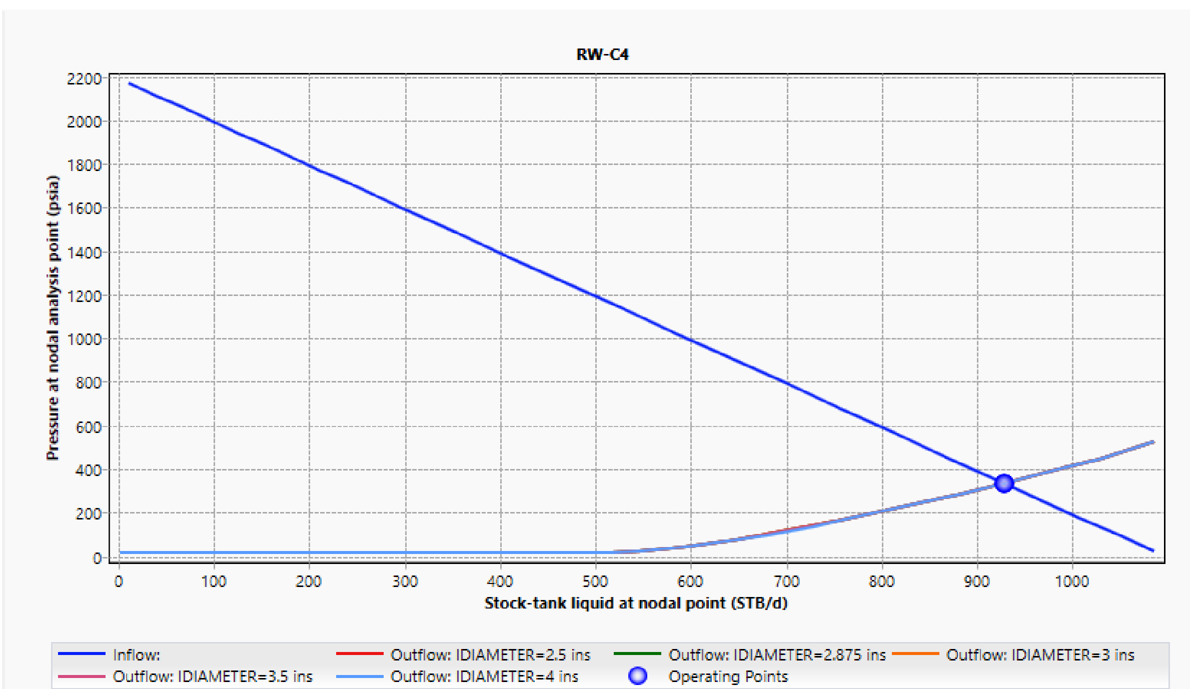


Figure (4. 2) Rawat C-4 Tubing sensitivity profile

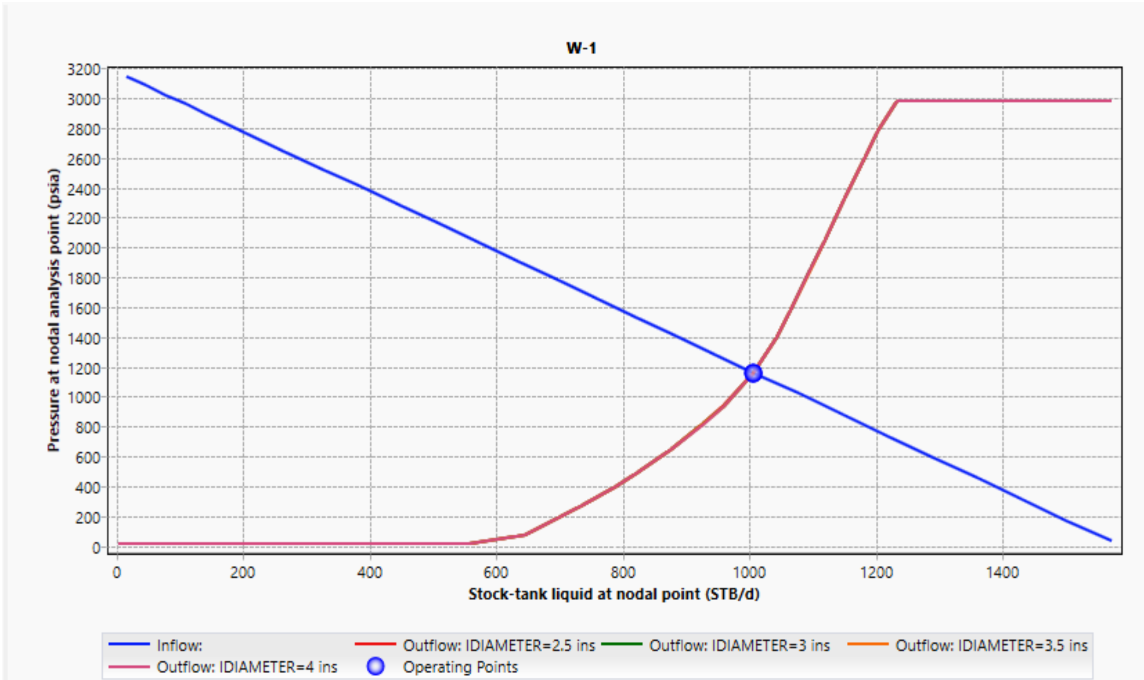


Figure (4. 3) Wateesh-1 Tubing sensitivity profile

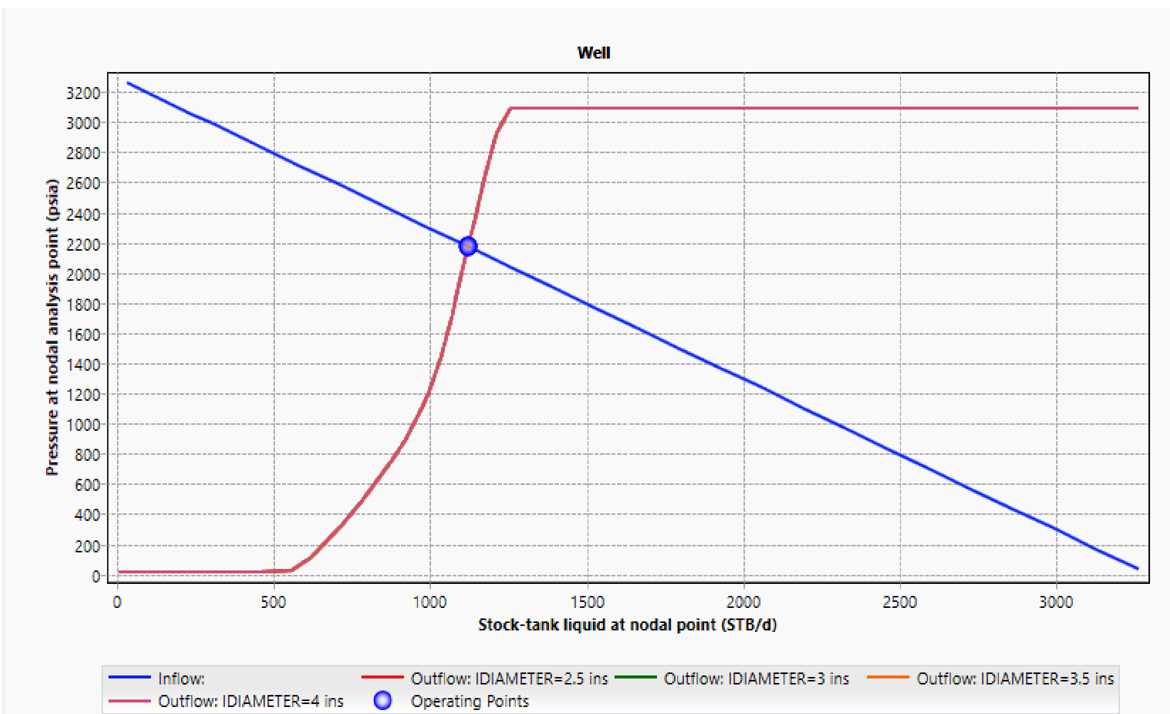


Figure (4. 4) Wateesh-2 Tubing sensitivity profile

4.2.3 Sensitivity Results depending on different pump speeds :

Table (4. 4) Sensitivity Results Depending On Different Pump Speed

Well name	Oil Flowrate (bbl/day) at Pump Speed =50 rpm	Oil Flowrate (bbl/day) at Pump Speed =100 rpm	Oil Flowrate (bbl/day) at Pump Speed =150 rpm	Oil Flowrate (bbl/day) at Pump Speed = 200 rpm	Oil Flowrate (bbl/day) at Pump Speed = 250 rpm
Rawat C-3	198.0238	391 .3636	584.1196	776.1 528	954.8037
Rawat C-4	351 .4651	685.2849	929.4126	1088.022 (IC)ˣ	1088.022 (IC)ˣ
Wateesh -1	216.33	416.3269	615.7154	814.82	1006.382
Wateesh -2	239.5014	460.7016	681.4914	901.8799	1122.014

(IC= ill conditioned pump speed, that's mean it's not recommended to use pump at this speed)

The above results are shown in figures below :

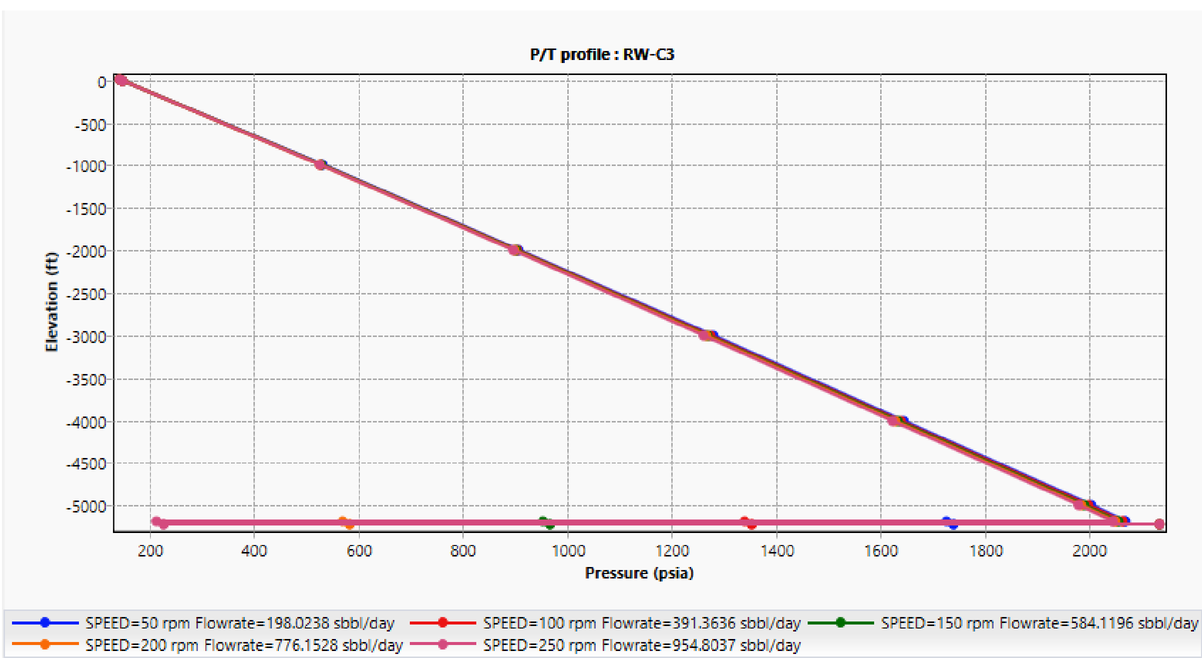


Figure (4. 5) Rawat C-3 Pump speed sensitivity Profile

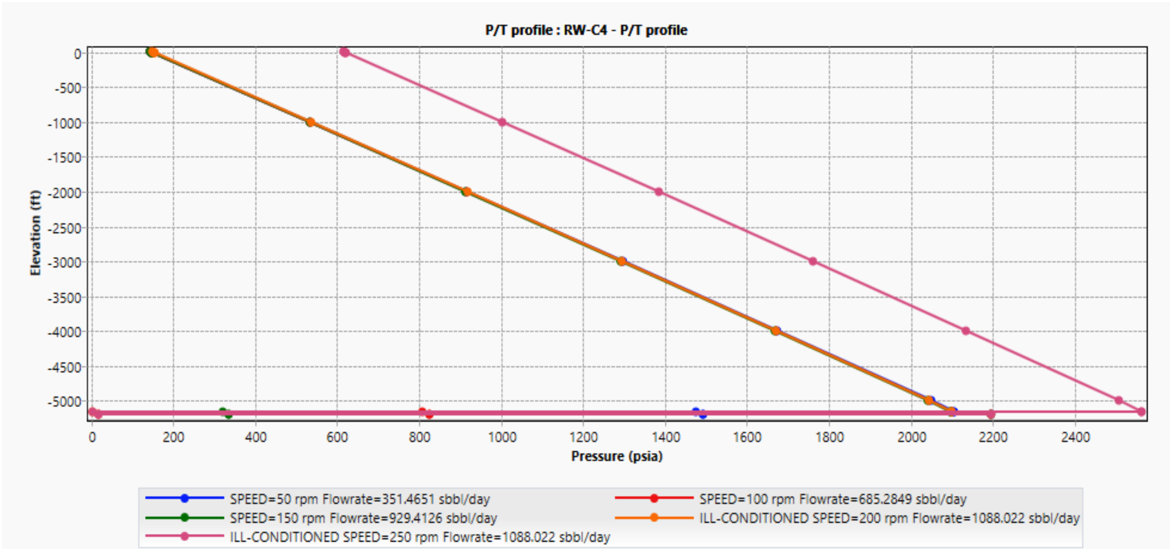


Figure (4. 6) Rawat C-4 Pump speed sensitivity Profile

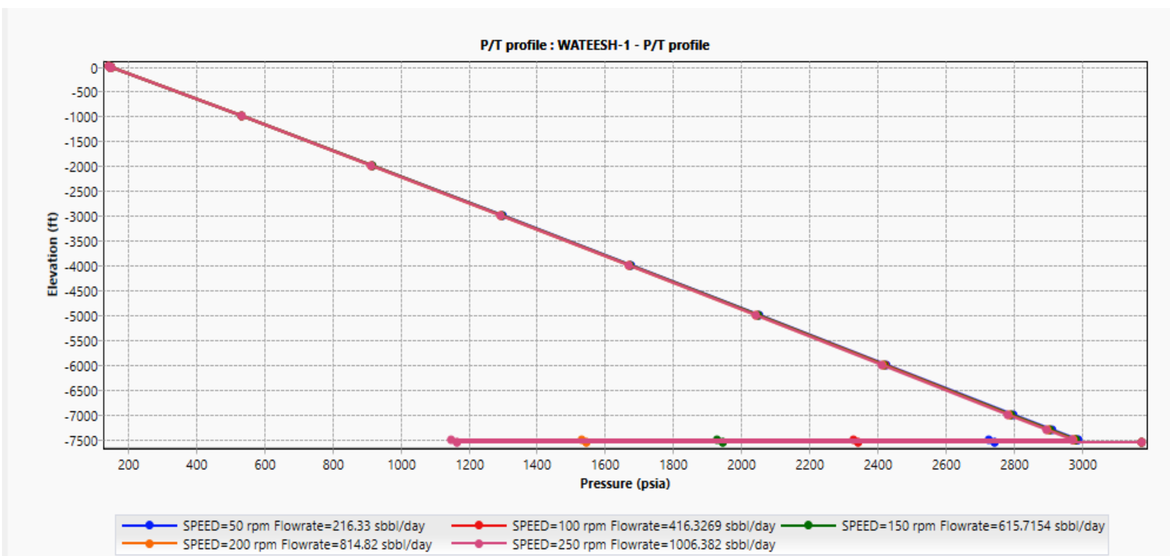


Figure (4. 7) Wateesh-1 Pump speed sensitivity Profile

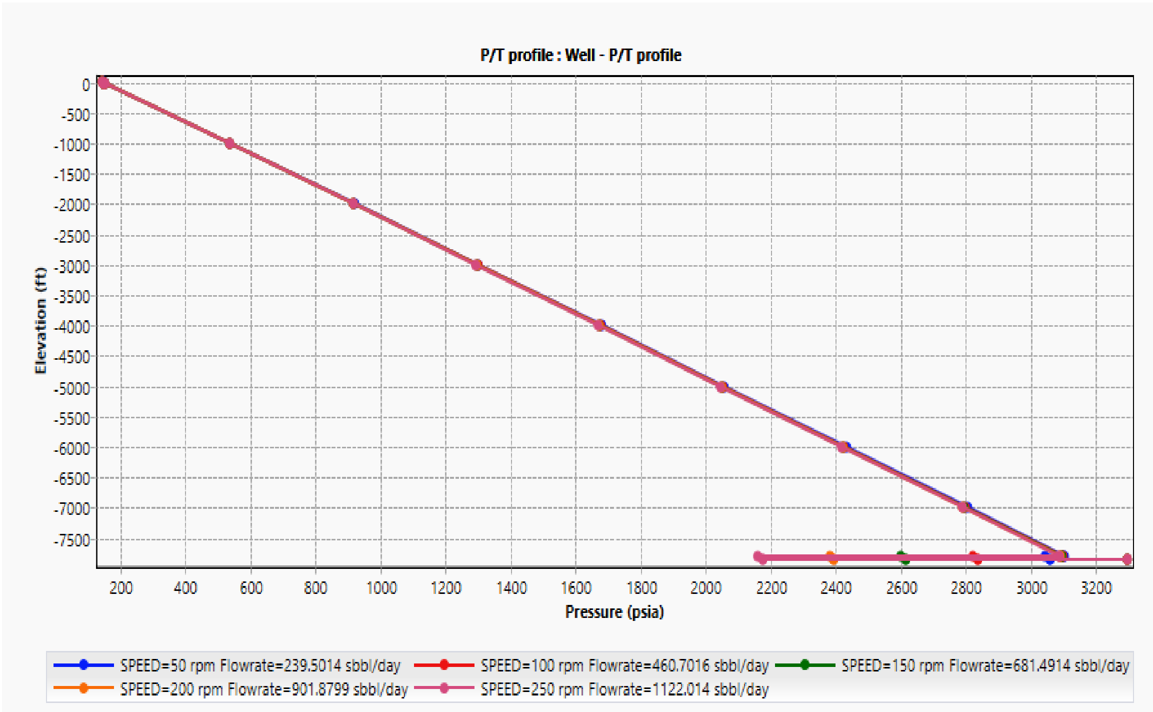


Figure (4. 8) Wateesh-2 Pump speed sensitivity Profile

4.2.4 Sensitivity results depending on different water cut %:

Table (4. 5) Sensitivity Results Depending On Different Water Cut %

Well name	Oil Flowrate (bbl/day) at Water cut= 0%	Oil Flowrate (bbl/day) at Water cut= 20%	Oil Flowrate (bbl/day) at Water cut= 40%	Oil Flowrate (bbl/day) at Water cut= 60%	Oil Flowrate (bbl/day) at Water cut= 80%	Oil Flowrate (bbl/day) at Water cut = 100%
Rawat C-3	954.8037	956.5871	958.0061	959.2377	960.5004	961.5677
Rawat C-4	929.4126	930.5746	931.5347	932.1733	932.9965	933.2O96
Wateesh -1	1006.382	1007.527	1007,906	1007.881	1007.985	1007.85
Wateesh -2	1122.014	1122.299	1122.442	1122.61	1123.005	1123.349

the above results are shown in figures below :

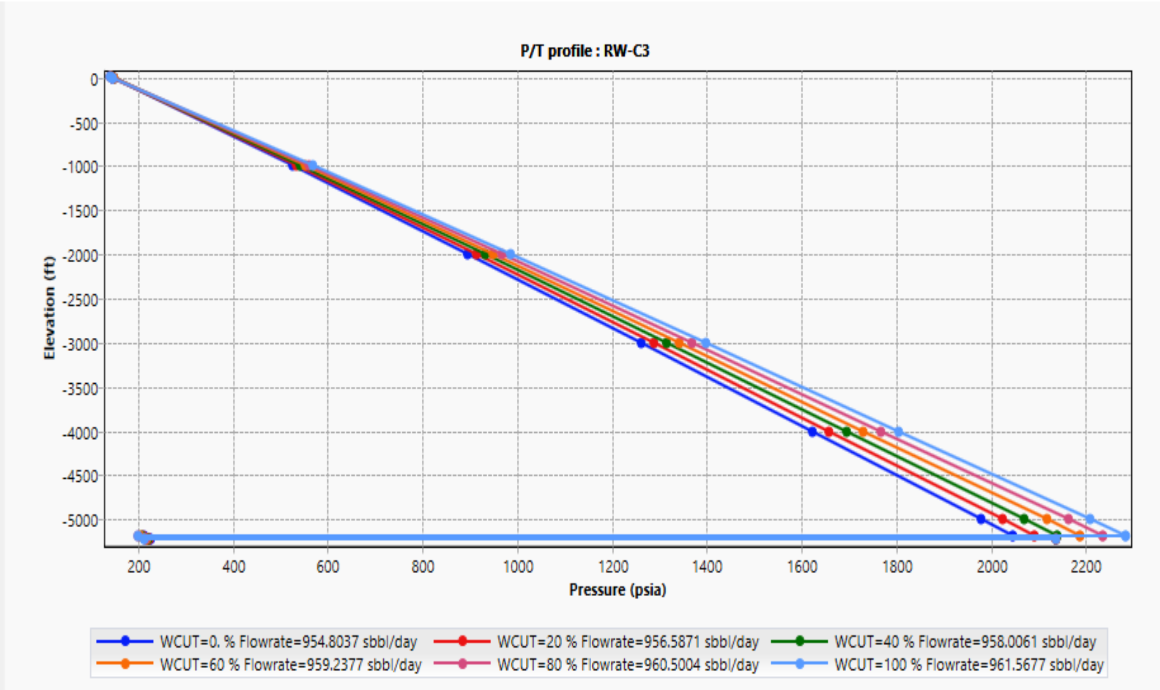


Figure (4. 9) Rawat C-3 Water cut % sensitivity Profile

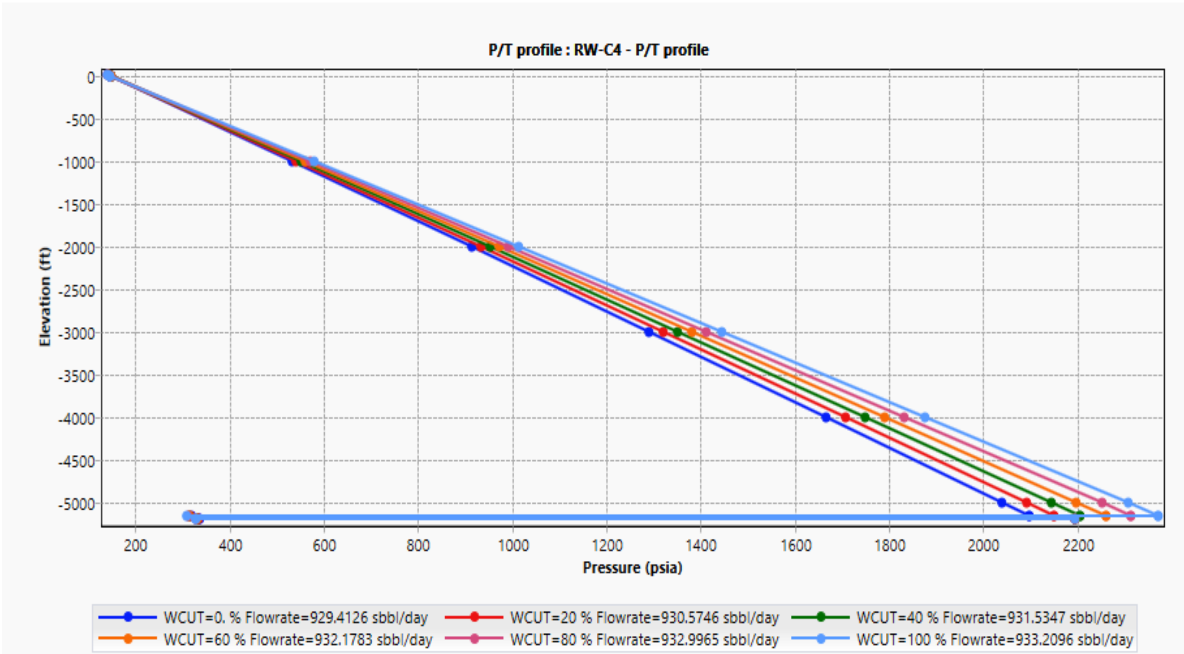


Figure (4. 10) Rawat C-4 Pump speed sensitivity

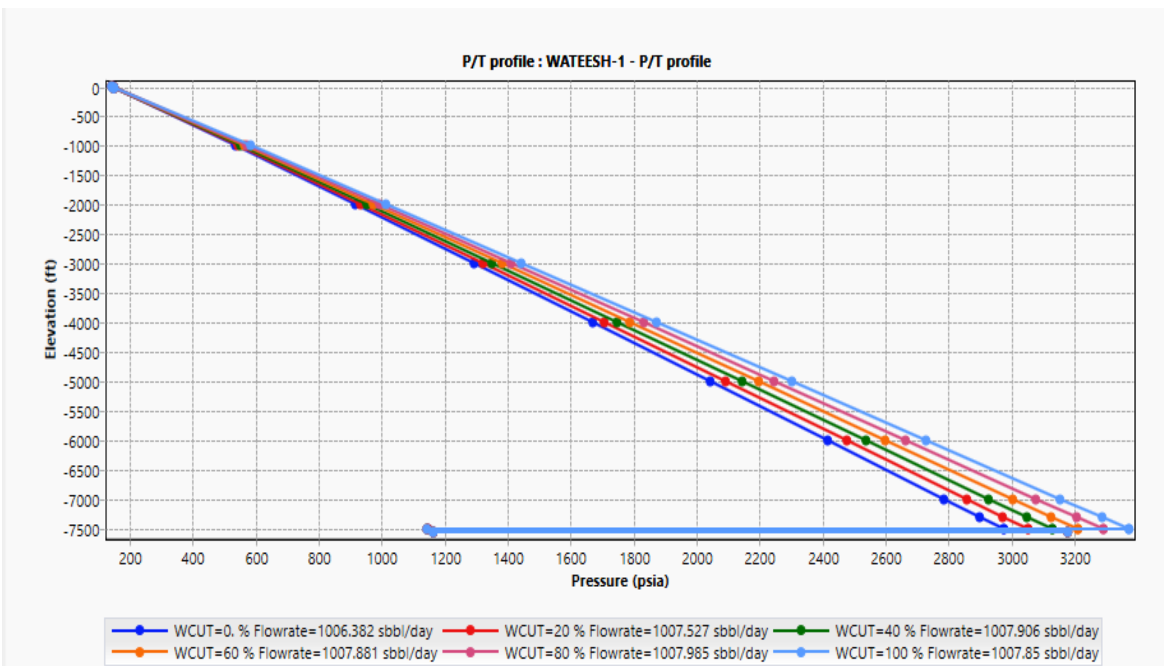


Figure (4. 11) Wateesh-1 Pump speed sensitivity Profile

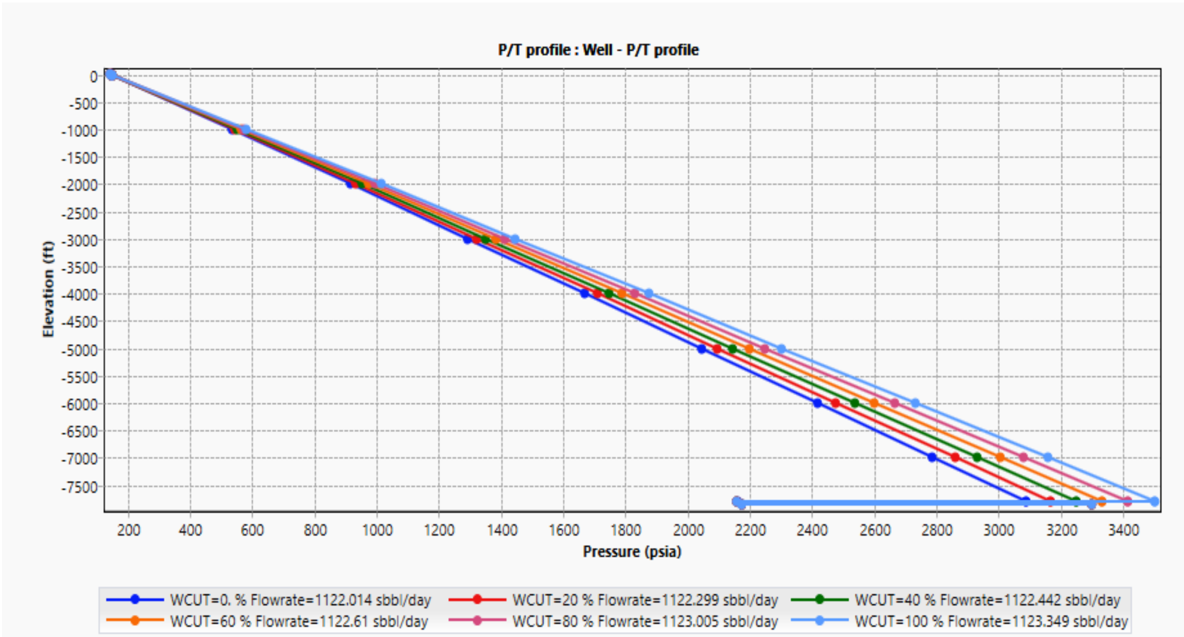


Figure (4. 12) Wateesh-2 Pump speed sensitivity Profile

4.2.5Network result:

- The Network Design shows that the total oil flowrate in the sink (Considered as field processing facilities FPF) is **4012.348** bbl/day.

Chapter Five

Chapter 5

Conclusion and Recommendations

Conclusion

The main purpose of this study is to design PC Pump and a Network by using PIPESIM in order to estimate production of alrawat high viscous oil and analyze the effect of some important parameters (e.g. pump speed) on pump performance ,and present a design process in a simple way.

The estimation Results from PIPESIM Design shows that the amount of production by Natural flow from RawatC-3, RawatC-4, Wateesh-1, Wateesh-2 is : 24.004, 35.083, 84.953, 178.805 bbl/day respectively ,and the amount of production by Progressive Cavity Pump (PCP) are 954.536, 929.416, 1006.382, 1122.014 bbl/day respectively , this results shows that the natural flow production is small and not feasible because Alrawat crude oil is high viscous crude (200 cp) , so the Using of Progressive cavity pump increases the amount of production to economical values.

Discussions:

- All the development operations that had done to alrawat field considered before the field enters to the general production of the country according to that the oil is considered dead oil and GOR value neglected.
- Nodal analysis results show that the effect of changing the inside diameter of the tubing is minimum or can be negligent.
- Sensitivity analysis results which based on water cut values show that the effect can be considered minimum.
- Sensitivity analysis results which based on different speed pump values show that the maximum flow rate of the PCP can be obtained from the high speed of the pump.

- In critical ill conditions the speed of pump reduced to moderate values (100 -150 rpm) In (AlrawatC-4).

Recommendations

- The study recommend to do more experiments, researches and implement more accurate sensitivity analysis On different parameters to obtain the desired design.
- This study highly recommend in the future to take in mind the effect of GOR.
- The study recommend more studies must be focusing on the ill conditioning Reasons.
- The study suggest to Use heaters in production system which can achieve good results.
- Further researches for more complex production systems using PIPESIM software are obtained.

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