بسم الله الرحمن الرحيم

Sudan University of Science and Technology
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Optimum Selection & Application of Hydraulic Jet Pump (HJP)

تطبيق والاختيار الامثل للمضخه النفاثه الهيدروليكيه

Graduation Project submitted in partial fulfillment of the requirement for the Bachelor technology of Engineering (Horns) Degree in petroleum Engineering

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الاستهلال

بسم الله الرحمن الرحيم

وَيَسۡـَٔلُونَكَ عَنِ ٱلرُّوحِۖ قُلِ ٱلرُّوحُ مِنۡ أَمۡرِ رَبِّى وَمَآ أُوتِيتُم مِّنَ
ٱلۡعِلۡمِ إِلَّا قَلِيلٗا ﴿٨٥﴾

سورة الاسراء الآية (85)

DEDICATION

Dedicated to our parentswho always devising us,nothing of this could be done without them.

To everyone who inspired our creativity, who always were with us step by step

To anyone who taught us how to breath in this life.

ACKNOWLEDGEMENT

First and foremost, we would like to thank the supervisor Mr. Mohanned Khairy for his support, outstanding guidance and encouragement.

We would also like to express our gratitude appreciation to all doctors and all teachers in Sudan university and technology for all the help and guidance they provided through our education and to the other members of our teaching assistant.

ABSTRACT

Hydraulic jet pumpit’sone of the artificial lift method. The conept of this pump depends on creating a pressur difference at the bottom hole by pumping the power fluid with a larg pressure and flow rate, and the pressure difference occurs as a result of a change in diameter between nozzle and throatwhich works to produce reservoir fluid.

The decreasing in pressure with time as a result of the depletion of the reservoir itcan be caused a problem if itdon’t control in a way that enables us to produce most of the hydrocarbon available for produced .Therefore, itrecommended to apply artificial lift methods with a high production capacity,Hydraulic jet pump is distinguished pump,and through it can be design optimal selection of parameters by various combinationsby using completion data forx well in block 6 oil field.

In this research hydraulic jet pump can be selected because it have high productivitywhen it compare with othertype of pumps and it can be usePIPESIMsoftware tosimulate and design hydraulic jet pump model includes nodal analysis before and after represent it, and a system analysis in several cases that includes analysisof Cavitations ratio -Critical Flow Ratio & Efficiency-jet pump power volumetric.

From the result,can beget nozzle-throat combinations(6H-7I-8I-8J), which have the same production rate (800 STBD), 8J it is the bestoption because it hada best criteria of (Cavitations ratio -Critical Flow Ratio & Efficiency).

التجريد

تعنبر المضخة الهيدروليكية النفاثة واحدة من طرق الرفع الصناعي ومفهومها هو إحداث فرق ضغط في أسفل حفرة البئر عن طريق ضخ مائع الطاقة نتيجة لتغير القطر بين الفوهة والحلقة مما يعمل على إنتاج موائع المكمن.

نقصان الضغط مع الزمن يحدث نتيجة لإستنزاف المكمن وهذا يسبب مشكلة إذا لم يتم التحكم فيه وإنتاج معظم الهيدروكربون المتاح وبالتالي من المحبذ تطبيق نوع من الرفع الصناعي لديه سعة إنتاجية عالية والمضخة النفاثة لديها تلك الخاصية ومن خلالها يمكن التصميم والإختيار الأمثل للخصائص من مجموعات مختلفة بإستخدام بيانات الإكمال للبئر (س) في حقل مربع 6.

PIPE SIMفي هذا البحث تم تصميم وإختيار أمثل لمعايير المضخة عبر تمثيلها ببرنامج

(8I,8J,7I,6H)ونتيجة لذلك تم التحصل على ان مجموعات الفوهه والحلقه لديها نفس معدل الانتاج وهو 800 برميل في اليوم 8J هي افضل خيار وذلك لأنها تمتلك افضل معدل تجويف ومعدل جريان حرج وكفاءة.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVATIONS

ALS	Artificial lift Systems
HJP	Hydraulic jet pump
SRVP	self-reciprocating valve pump
SL	slick line
NPT	non-productive time
CFD	computational fluid dynamics
RANS	Reynolds-Averaged Navier-stokes
SPM	Side Pocket Mandrels
JP	jet pump
JEMS	Jet Evaluation and Modeling Software.
Cr	cavitation ratio
Vcr	critical flow ratio
AMS	minimum throat annulus area
IPR	In flow performance relationship

CHAPTER ONE
INTRODUCTION

1.1. Introduction

Hydraulic jet pump

is a device in which a fluid flows through a driving nozzle which converts the fluid pressure into a high-velocity jet stream; fluid is continuously entrained from the suction section of the jet pump by the jet stream emerging from the nozzle. In the mixing tube the entrained fluid acquires part of the energy of the motive fluid. In the diffuser the velocity of the mixture is reconverted to pressure.

1.3.1. Advantages

- High volumes can be produced from great depths
- Pumps can be changed (circulated out) without pulling the tubing
- Heavy and viscous fluids are easier to produce after mixing with lighter power fluids

1.3.2. Disadvantages

- Vulnerable to solids
- Least efficient lift method

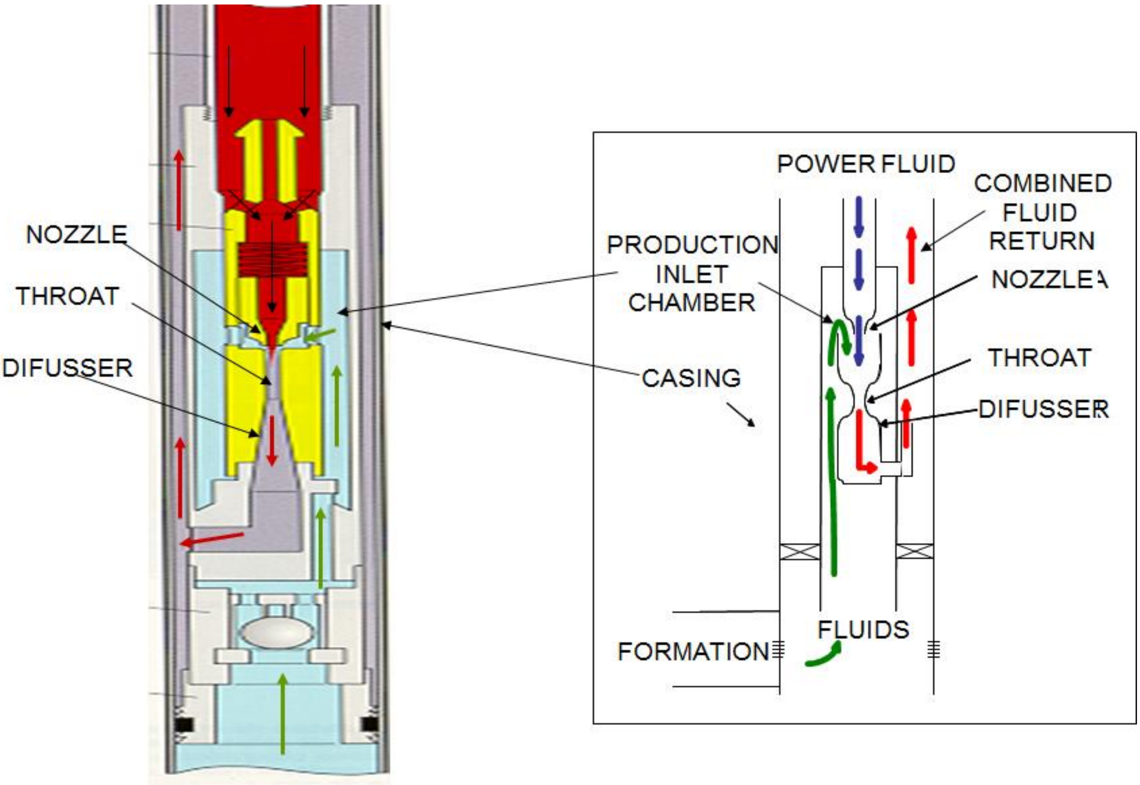


Figure.1.2.the inner shape of **Hydraulic pumping (HJP)(**Matthew Amao2013**)**

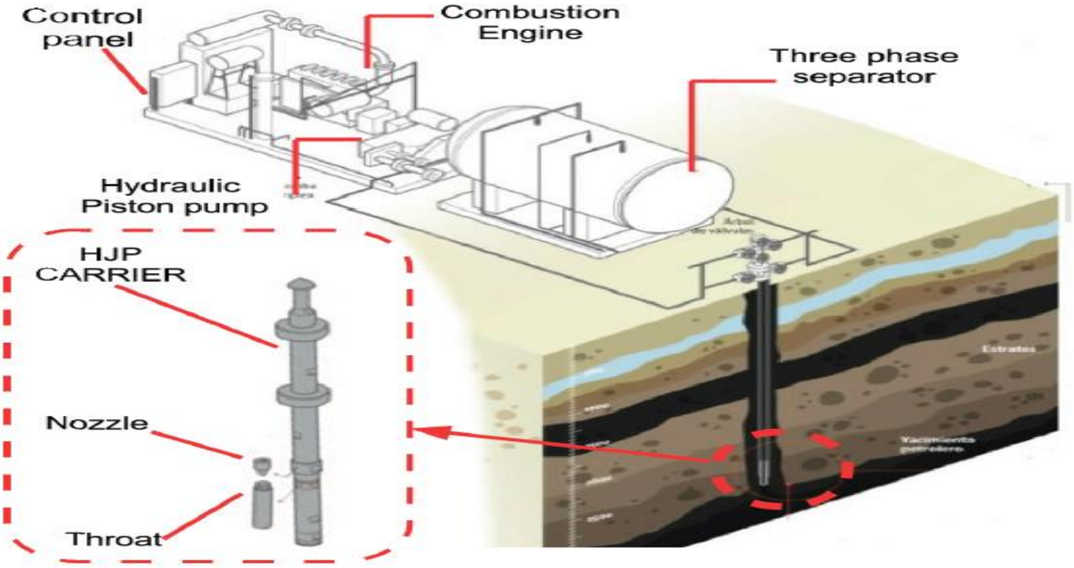
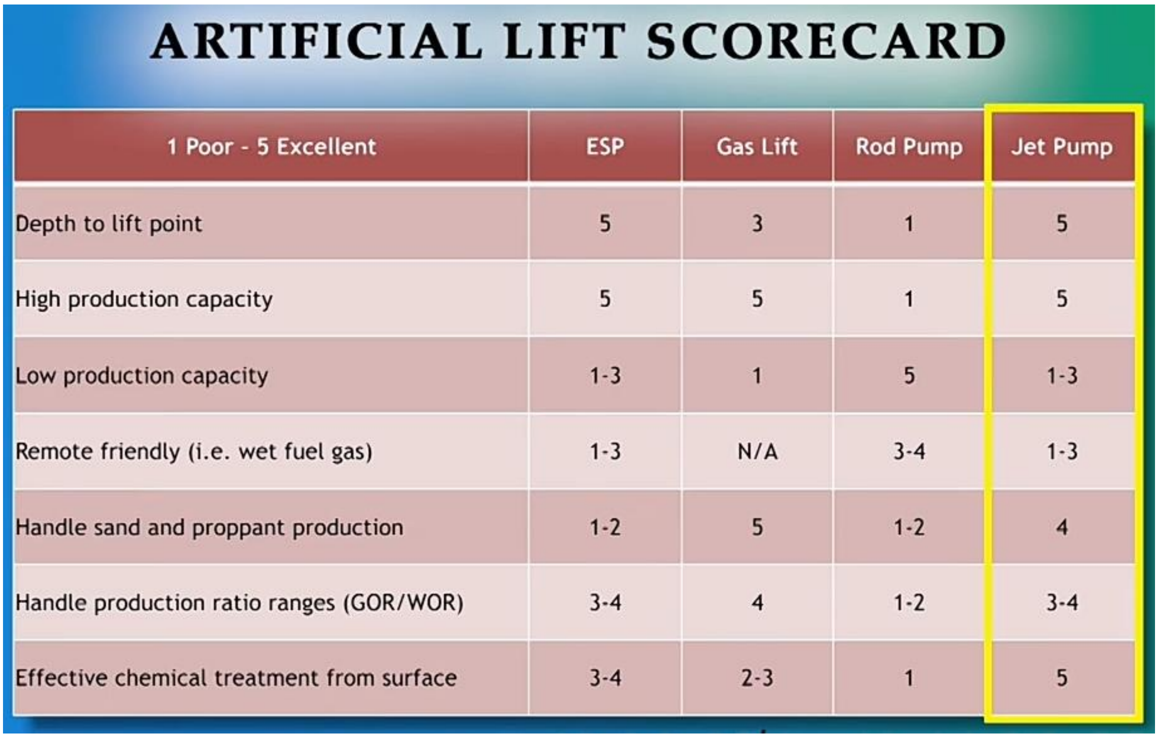


Figure .1.3.surface equipment for **Hydraulic pumping (HJP)**(Rogelio de Jesús & others2019)

1.4.Why the Jet Pump?

in cmparison with artificial lift (ESP,cas lift,Rod pump) methods we find that HJP has aprefential advantage over other methods but the economic aspect of choosing HJP must be taken into account .if its choice is not economically feaible ,it must be removed from production options.

table(1.2) artificial lift scoecard(Chris W.elc. 2014)



ARTIFICIAL LIFT SCORECARD

1 Poor - 5 Excellent	ESP	Gas Lift	Rod Pump	Jet Pump
Depth to lift point	5	3	1	5
High production capacity	5	5	1	5
Low production capacity	1-3	1	5	1-3
Remote friendly (i.e. wet fuel gas)	1-3	N/A	3-4	1-3
Handle sand and proppant production	1-2	5	1-2	4
Handle production ratio ranges (GOR/WOR)	3-4	4	1-2	3-4
Effective chemical treatment from surface	3-4	2-3	1	5

at the beginning of production (initial production) it is high but decreases with time (terminal decline rate)as shown in the production decline rate , by selecting HJP we ensure that this gradient is reduced the maximum possible degree due to the large capacity enjoyed by HJP

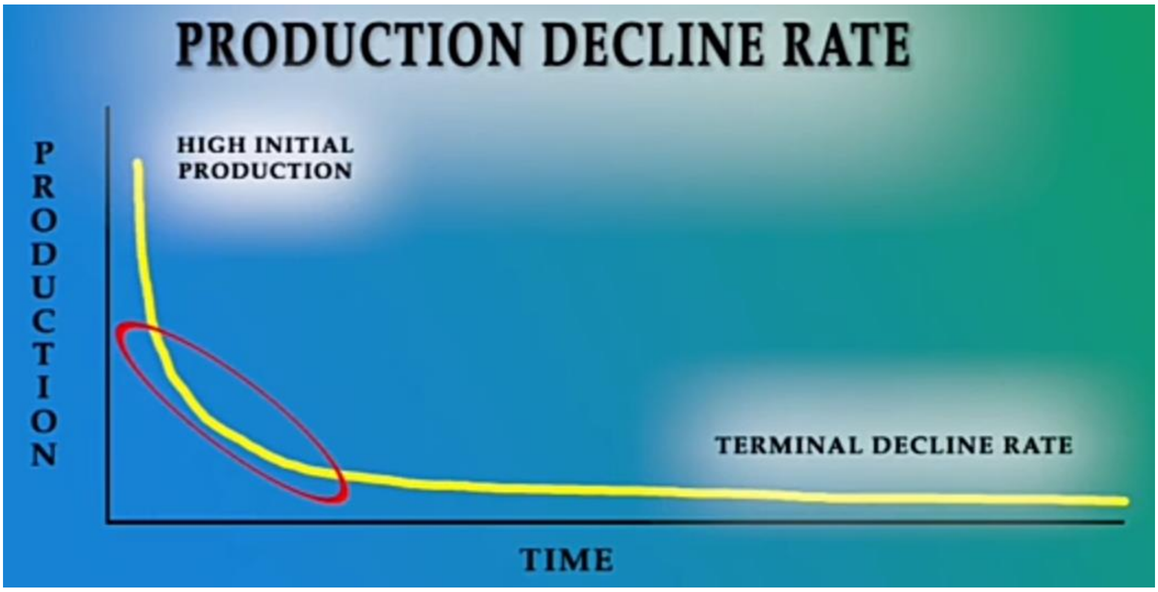


Fig.(1.5.)production decline rate (Chris W.elc 2014)

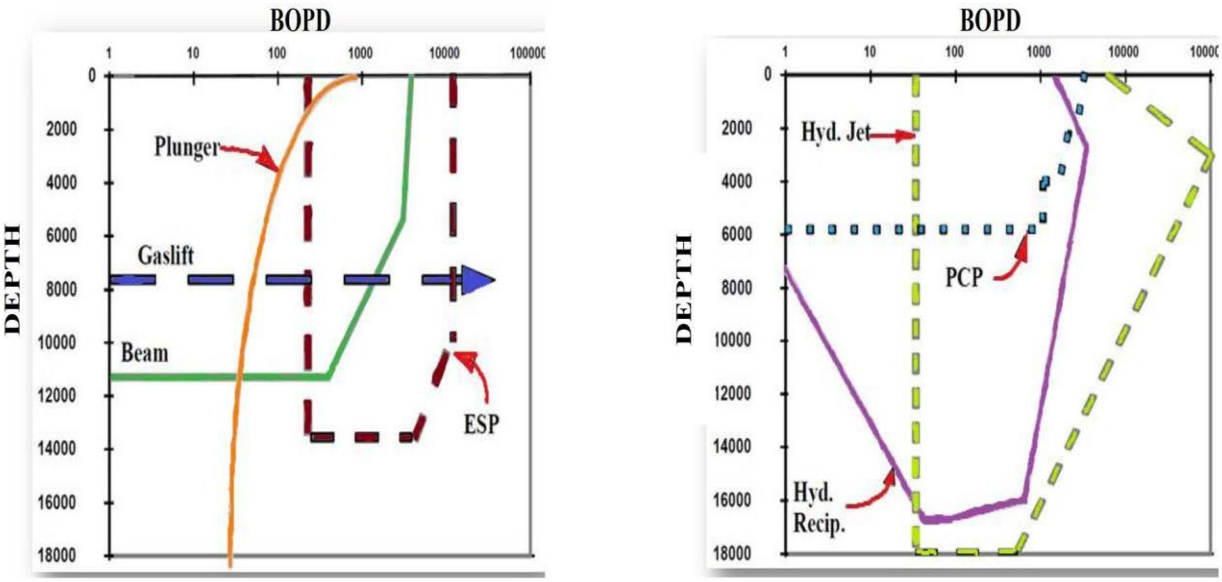


Fig.(1.6).Rate VS depth method(Chris W.elc 2014)

1.5. Problem Statement

with the passage of time production decreases, and thus it becomes necessary to choose a type of artificial lift that has a large production capacity

1.6. Objectives

- To designing wells for **HJP** using completion data for the selected well.

- To optimum Selection of **Hydraulic jet pump (HJP)**design parameters by various combinations.
- Choose a suitable parameter to achieve the basic goals and we mean that**:**
    - Cavitation Ratio
    - Critical Flow Ratio
    - Efficiency

CHAPTER TWO

THEORETICAL BACKGROUND AND LITERATURE REVIEW

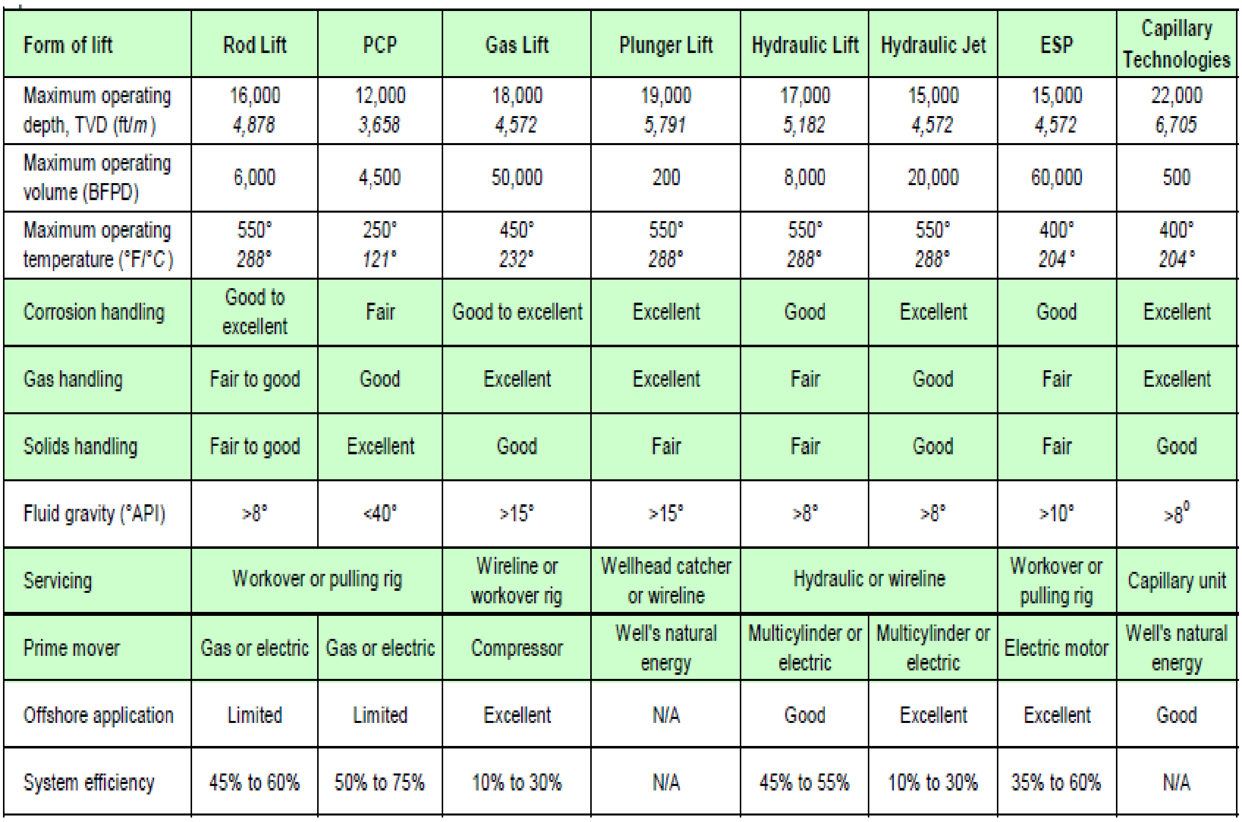
2.1Theoretical background:

Production strategy optimization and design has a great importance in the oil industry and must be applied to achieve different objectives. Sometimes, the main purpose of this process is to select an adequate production strategy to be applied in the reservoir development planning. In other instances, the objective is to utilize a detailed optimization procedure in order to obtain accurate results to support complex decisions. Another possible objective can be the optimization of mature fields in order to increase profitability or to adequate the production to a new economic Scenario. The objectives are established by the management regarding the importance of the project and the technical and economic resources available and the decision making process must lead to lucrative results and high revenues, considering the physical and operational restrictions for each particular project. Hence, it is very important to develop new procedures to minimize risks and maximize profits in recovery strategy arrangements.

The use of reservoir simulation is very important to provide reliable production forecast and correct predictions for field recovery potential. However, during the initial field development phase the amount of available information for the reservoir is very restricted and it is very difficult to obtain a correct reservoir model. Therefore, the use of simplified simulation models provides more appropriate and lead to better results. (Mezzomo.2000)

As pressure in the reservoir declines, the producing capacity of the wells will decline. The decline is caused by a decrease in the ability of the reservoir to supply fluid to the well bore. Methods are available to reduce the flowing well bottom hole pressure by artificial means.

Table (2. 1) artificial lift criteria (weatherford 2006)



Form of lift	Rod Lift	PCP	Gas Lift	Plunger Lift	Hydraulic Lift	Hydraulic Jet	ESP	Capillary Technologies
Maximum operating depth, TVD (ft/*m*)	16,000 *4,878*	12,000 *3,658*	18,000 *4,572*	19,000 *5,791*	17,000 *5,182*	15,000 *4,572*	15,000 *4,572*	22,000 *6,705*
Maximum operating volume (BFPD)	6,000	4,500	50,000	200	8,000	20,000	60,000	500
Maximum operating temperature (°F/°*C*)	550° *288°*	250° *121°*	450° *232°*	550° *288°*	550° *288°*	550° *288°*	400° *204°*	400° *204°*
Corrosion handling	Good to excellent	Fair	Good to excellent	Excellent	Good	Excellent	Good	Excellent
Gas handling	Fair to good	Good	Excellent	Excellent	Fair	Good	Fair	Excellent
Solids handling	Fair to good	Excellent	Good	Fair	Fair	Good	Fair	Good
Fluid gravity (°API)	>8°	<40°	>15°	>15°	>8°	>8°	>10°	$>8^0$
Servicing	Workover or pulling rig		Wireline or workover rig	Wellhead catcher or wireline	Hydraulic or wireline		Workover or pulling rig	Capillary unit
Prime mover	Gas or electric	Gas or electric	Compressor	Well's natural energy	Multicylinder or electric	Multicylinder or electric	Electric motor	Well's natural energy
Offshore application	Limited	Limited	Excellent	N/A	Good	Excellent	Excellent	Good
System efficiency	45% to 60%	50% to 75%	10% to 30%	N/A	45% to 55%	10% to 30%	35% to 60%	N/A

2.1.2 Artificial lift

- Gas Lift Systems.

Gas Lift involves the supply of high pressure gas to the casing/tubing annulus and its injection into the tubing deep in the well. The increased gas content of the produced fluid reduces the average flowing density of the fluids in the tubing, hence increasing the formation drawdown and the well inflow rate.

  - Sucker-rod pumping System.

- The pumping unit at surface converts the rotational movement of the prime mover in vertical reciprocating movement which is transmitted to the subsurface pump through the rod string. The subsurface pump is positive displacement pump.

- Progressing Cavity Pumping Systems.
- Interference fit between the rotor and stator creates a series of isolated cavities Rotation of the rotor causes the cavities to move or "progress" from one end of the pump to the other

- Electric submersible pumping system.
- Systems incorporate an electric motor and centrifugal pump unit run on a production string and connected back to the surface control mechanism and transformer via an electric power cable.

- Jet pumping System.
- In which a pressure difference is mad at the bottom hole by pumping the power fluid at a certain pressure and flow rate, thus producing the reservoir fluids.

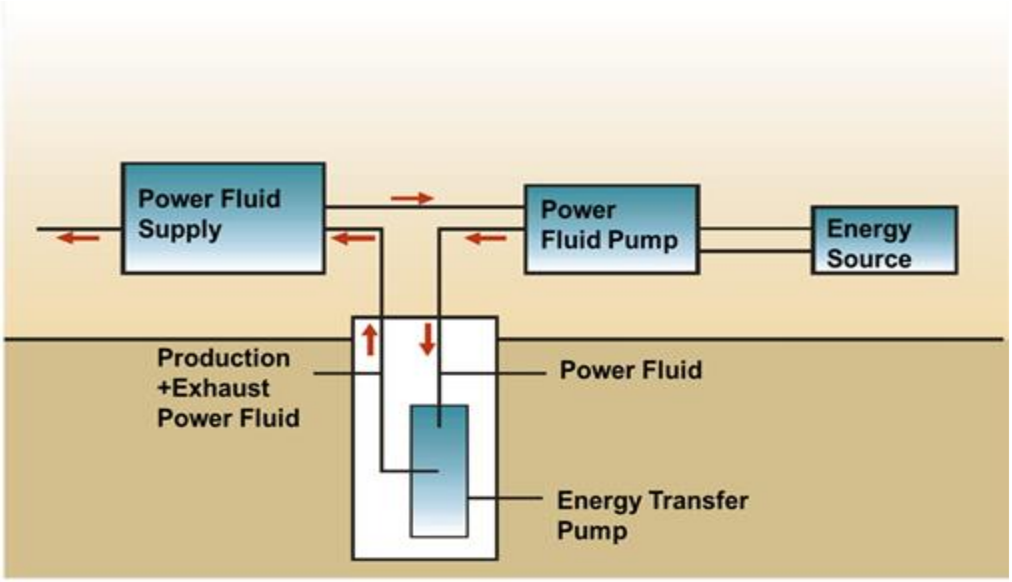


Figure.2.1.Jet pumping concept(Chris W.elc 2014)

- In the fact that more than 95% of the world's oil wells use some Artificial lift (ALS), starting from the oldest and simplest one such as mechanical pumping and pneumatic pumping, to the most technologies such as Electrical Submersible Pumping and hydraulic pumping In this research, we focus on the ALS of Hydraulic pumping (HJP)

2.2. Literature Review:

A novel hydraulically powered, self-reciprocating valve pump (SRVP) was piloted in a western Colorado gas well for deliquifi- cation operations. The objective was to pump liquids from a deep gas well and later retrieve and redeploy the SRVP without a work- over rig.

The SRVP is installed downhole inside a concentric tubing string, and is powered by injecting a high-pressure liquid. The injected (power) fluid causes the SRVP to reciprocate, driving a piston pump to produce formation fluids and to power fluid back to the surface up the concentric-string/production-tubing annulus. The removal of the produced fluids decreases the backpressure on the formation, enabling gas production up the casing.

Three industry-first SRVPs were installed consecutively in a concentric flush-joint tubing string, and were powered with a com- pact surface pumping unit. The SRVP proved the ability to lift 20 to 40 BFPD net liquids up the concentric-string/production-tubing annulus from more than a 12,000-ft vertical depth while gas was produced up the casing. The SRVP was retrieved and redeployed several times either hydraulically and/or with slickline (SL). System design, operation, and performance were continuously improvedthroughthedurationofthepilotprogramRunlifesteadilyincreased tomorethan50dayswiththethirdinstallation

(M. C. Romer, 2017)

This paper describes a trial jet pump application for offloading a killed well. The Well-2A was naturally producing an average 1650 BCPD and 1.54 MMSCFD from two separate formations via dual strings of size 2-3/in. in a 7 in. casing. It later required a workover job because of tubing string and packer leakage. The well was recompleted with a single string of 3-1/2 in. tubing in order to produce both formations together. The well was killed and initially kicked-off by injecting nitrogen, but it was unable to flow even after continuous pumping of 4,000 gallons of nitrogen. Therefore, jet pumping technology was applied to offload the well.

Production results indicate that the killed well was successfully offloaded with cumulative production of 690 BPD, which was higher than the targeted production rates evaluated for this well. Freestyle jet pump deployment has achieved the expected performance and reliability. Moreover, the jet pump can easily be re-optimized by reversing it out to change the nozzle and/or throat without requiring a slick-line job. Hence, the jet pump was found to be the most economical artificial lift method and the trial achieved more than expected results.(Shuaib Ahmed Kalwar, 2018)

Digital computational fluid flow analysis is conducted to optimize the jet pump design to improve operational life of the jet pump and reduce non-productive time (NPT). Comprehensive laboratory testing is conducted and digital solutions are compared against the test data to validate the new jet pump technology. The operation of jet pump starts with flow of high pressure power fluid from surface into wellbore that travels through jet pump nozzle causing reduction in pressure which in turn draws in the reservoir fluid into jet pump throat. The low pressure generated at throat due to venturi effect can cause cavitation in certain scenarios and leads to reduced operational life of jet pump. To address this issue an alternative inverse jet pump is proposed that reverses the flow path of power fluid and production fluid. Numerical analysis is conducted to evaluate the feasibility of inverse jet pump design. Three-dimensional computational fluid dynamics (CFD) simulations are conducted using coupled algorithm with Reynolds-Averaged Navier-stokes (RANS) equation and k-ε turbulence model to predict the pressure and velocity flow field. Extensive laboratory testing is conducted in flow loop for the inverse jet pump design to validate the digital analysis results. CFD simulations are performed for different configurations of inverse jet pump by varying throat diameter and length of mixing chamber for operating production and power fluid flow rates. CFD results underscored the pressure and velocity profiles along the flow paths and based on digital analysis using CFD it is observed that innovative inverse jet pump design reduces probability of cavitation. Laboratory testing corroborated with digital analysis results and indicated improvement in operational life for inverse jet pump technology. Extensive usage of advanced computational modeling in this work assisted in optimizing design quickly and reduced time and cost associated with laboratory testing. This work elucidates use of digital solutions for design optimization of new production technology and underscores simulation-based-design as faster and cost effective method.(Kedar Deshpande,2019).

Well-A was a deviated well with 3-1/2-inch single string completion. The tubing-string was equipped with three Side Pocket Mandrels (SPM). Based on preliminary screening for Artificial Lift Systems (ALS) against the provided well data, the jet pump system was found the most suitable ALS method. Jet pump was evaluated for its efficiency in reviving a dead well with rig less installation using Jet Evaluation and Modeling Software (JEMS).

The power fluid was then injected through casing which entered the JP to create the drawdown required to bring the formation fluid through tubing to the surface. The dead well was produced successfully at different injection pressures and rates for four months. The production results were compared to the theoretical model of JEMS to assess the JP performance.

The Well-B was a newly side tracked well where customer intended to use a jet pump for offloading the kill fluid of well from its last zone. A 2-7/8-inch bottom hole assembly of JP was run at 9,348 ft depth during the well completion. Jet pump was freely dropped in the well to offload the kill fluid and revive the production. Rig pump was used to inject power fluid at high pressure in the tubing and returned fluids were taken from the annulus. Constant samples of produced liquid were taken to ensure the kill fluid has been offloaded and the reservoir started contributing its fluid. Jet pump was retrieved with the help of slick line once satisfactory results were received at the surface. The well was successfully offloaded at around 900 bbl. of gross fluid using JP technology(Haris Shakeel Abbasi, 2020).

CHAPTER THREE

METHODOLOGY

The design of jet pumps involves selecting an appropriate throat and nozzle size for current and future operating conditions. The procedure for designing a jet pump using :

3.1 Manual Design

Jet pump nozzle and throat sizes from the catalog. From the nozzle and throat diameters, we can determine the corresponding areas. The effective suction area is the throat area minus the area of the nozzle jet. If this area is too small, there is risk of cavitation.

To calculate jet pump performance, must be used the standard approach summarized by Belarby1 which describes the methods elaborated largely

It should be noted that various publications describe the same quantities using different nomenclature and the nomenclature adopted by Bellarby will be used here. The equations are referenced based on the reference and equation number in that reference (e.g. [1-6.12]) means that the equation is taken from the Bellarby reference (1) and refers to the equation numbered 6.12 in that reference).Equations specific to this implementation and simply numbered sequentially with an “A” prefix (e.g. [A-3]). If the equations appear different from the source reference, it is because a different variable nomenclature has been used here.

Based on the input data described above, several dimensionless parameters may be defined as follows:

Table (3. 1) Jet Pump dimensionless parameters

Parameter	Description	Formula
Fan	nozzle-throat area ratio	$\mathrm{Fan} = \frac{An}{At}$
Fρ	density ratio	$\mathrm{F\rho} = \frac{\mathrm{\rho s}}{\rho p}$
Fq	volumetric flow ratio	$\mathrm{Fq} = \frac{\mathrm{qs}}{\mathrm{qp}}$
Fm	mass ratio	$\mathrm{Fm} = \mathrm{F\rho\ Fq}$
rp	pump compression ratio	$\mathrm{rp} = \frac{\mathrm{Pd} - \mathrm{Ps}}{\mathrm{Pp} - \mathrm{Pd}}$
B	geometric factor to simplify calculations	$\mathrm{B} = \frac{(1 - 2\mathrm{Fan})\mathrm{Fan2}}{(1 - \mathrm{Fan})2}$

The pump compression ratio may be calculated as follows:

$r\dot{p} = \frac{2Fan+BF^2m-(1+Ktd)F^2an(1+Fm)^2}{(1+Kn)-nmerator}$ ---------------------> **Eq 3.1**

Using the definition of pump compression ratio [1-6.16] and solving for pressure differential between the discharge and suction:

$dP = (Pd - Ps0 = \frac{(rpPp+Ps)}{(1+rp)} - Ps$--------------------------------------> **Eq 3.2**

The efficiency can then be calculated as:

$E = \left(\frac{Pd-Ps}{Pp-Pd}\right)\left(\frac{qs}{qp}\right) = rp * Fq$---> **Eq 3.3**

The power required to pump the power fluid at the surface can be calculated as:

$$hp = \frac{qp * pps}{52910}$$ -----------------------------------> **Eq 3.4**

3.1.1 Choked flow:

There are two conditions that may lead to choked flow:

1. Cavitation:

At low throat-entrance pressures (Pe), the vapor pressure of the produced fluids will be reached and vapor cavities will be formed at the throat entrance. Further downstream as the pressure increases these cavities implode which is called cavitation. This blocks any further increase in rate and may seriously damage the pump.

2. Sonic velocity:

The velocity of sound in a gas/liquid mixture can reach low values. In jet pumps handling gas, velocities at the throat entrance can become so high that they may exceed the speed of sound. When this happens, the suction flow rate does not respond to further reductions of the throat suction pressure (Pe). To avoid critical flow when the production contains free gas, values ofPe /Ps should generally be higher than 0.5.

The cavitation limit (a dimensionless number) may be calculated as follows:

$$cavitiation\ limit = (\frac{1-Fan}{Fan})\sqrt{\frac{(1+Kn)Ps}{1.35(Pp-Ps)+Ps}}$$ -------------> **Eq 3.5**

If the dimensionless flow ratio (Fq) is more than the cavitation limit, cavitation is predicted to occur. Recall that the dimensionless flow ratio is the ratio of the source (well) fluid to the power fluid and therefore relatively low rates of power fluid will result in high dimensionless flow ratios and thus increase the risk of cavitation

It is therefore useful to express a dimensionless cavitation ratio (which indicates cavitation is likely for values above 1.0:

$cavitiation\, ratio\ (Cr) = \frac{Fq}{cavitiation\ limit}$-----------------------------> **Eq 3.6**

To calculate the sonic velocity at the throat entrance, first the throat entrance pressure must be calculated explicitly. The equation to calculate the ratio of the throat entrance pressure to suction pressure:

$\frac{Pe}{Ps} = 1 - \left[\frac{Fm^2 Fan^2}{(1-Fan)^2(1+Kn)}\right]\left[\frac{Pp}{Ps} - 1\right]\left[\frac{1}{Fp}\right]$------------------------> **Eq 3.7**

Note: the above equation is corrected from the original source as reported in reference 9.

Which knowing Ps , can be easily solved for Pe.

The mixture fluid is then flashed at conditions of the throat entrance pressure and temperature to determine the sonic velocity (Vs) and density (ρs) of the fluid based on the fluid properties defined in PIPESIM. The actual velocity of the fluid is calculated by:

$ve = \frac{m\rho * m}{At}$--------------------------------> **Eq 3.8**

The critical flow ratio (Mach number) then becomes:

$Vcr = \frac{ve}{vs}$---> **Eq 3.9**

Therefore, if either the cavitation ratio (Cr) or the critical flow ratio (Vcr) are greater than 1.0, choked flow is likely and the design should be adjusted to avoid such conditions. It should be noted that increasing the power fluid rate will increase the likelihood of critical flow while decreasing the likelihood of cavitation

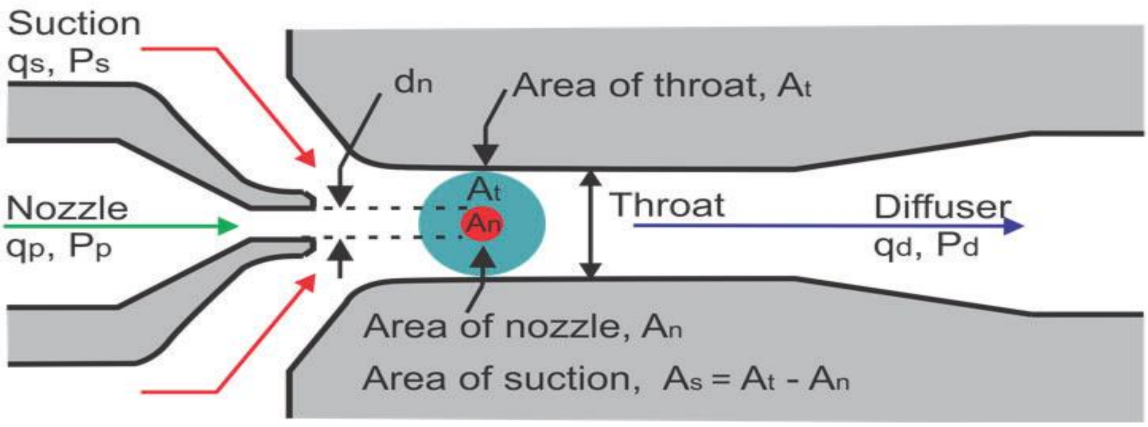


Figure 3.1minimum throat annulus area(Noronha, F.A.elc 1998)

a. Determine the minimum throat annulus area to avoid cavitation using this formula:

$$AMS = .01327qs\sqrt{\frac{1}{Ps(API+131.5)}}+\frac{(100-WC)GOR}{2465Ps}\text{---------------->}\ \textbf{Eq 3.10}$$

Where:

Table (3. 2) minimum throat annulus area parameter

Parameter	Description	Unit
AMC	Minimum throat annulus area to avoid cavitation	in^2
AS	Throat annulus area = $At - An$	in^2
API	API gravity of produced oil	deg
WC	Water cut	%
GOR	Gas Oil Ratio	${}^{SCf}/_{STB}$

Note: the above equation is modified from the original source in order to use API gravity instead of production fluid gradient.

$AS = At - An > AMS$

$0.23 < Fan = \frac{An}{At} < 0.6$---> **Eq 3.11**

F_{an} values at the lower end of the range favor higher production rates whereas Fan values at the higher end of the range favor higher pressure differential.

Typically, Fan values of greater than 0.5 are only appropriate for deep wells (> 10,000 ft. MD).

Generally, the smallest pumps that will satisfy the throat annulus area requirements are candidates for selection. The accompanying spreadsheet displays all possible combinations of nozzle-throat pairings for several manufacturers and is useful for quickly screening candidates.

3. Given several candidate jet pump sizes, selecting the best configuration is a trade-off between power fluid rate, injection pressure and operating efficiency. Additionally, conditions leading to choked flow should be avoided in the design.

Flow ratios (ratio of well to power fluid) may range broadly from about 0.2 to 4. A flow ratio of0.25 is common for low production wells otherwise suited for rod pumps while a flow ratio closer to 1 is common for high PI wells.

An injection pressure typically range from 1,500 to 4,000 psi and is limited by the operating capacity of triplex pumps. The surface injection pressure is limited to about 3,500 psi for water and 4,000 psi for oil.

Additionally, Grupping2 suggests that maximum efficiency is achieved for a ratio of throat entrance pressure (P_e/P_s) to pump intake pressure of 0.3 to 0.7, though Singh9 reports that the upper limit should be extended to 0.85 based on observed field data.

3.2PIPESIM software design

3.2.1 Review PIPESIM software

PIPESIM is built and innovated by Schlumberger (Schlumberger,2012), it’s a way use to simulate individual well and network models. PIPESIM combines best-in-class science with an unparalleled productivity environment to enable engineers to optimize production systems from the reservoir to the sales point. These release notes describe the most significant enhancements and known limitations.

3.2.2 Steps of Design HJP in PIPESIM software

3.2.2.1 insert HJP parameters

To simulate **HJP**, PIPESIM* maintains a database of manufacturers and models from which we can select. For each model the nozzle &throatdiameter, nozzle & throat loss coefficient, power fluid flow rate& pressure -temperature, A performance plot of the **HJP** is also available.

Table (3. 3) HJP parameters

Jet Pump Parameter	Description
Fluid Model	Fluid model for the injection fluid (usually water)
Nozzle diameter	Nozzle diameter
Throat diameter	Throat diameter
Nozzle loss coefficient	Loss coefficient for the Nozzle (typically .03 - .15) - check with vendor
Throat-diffuser loss Coefficient	Loss coefficient for the Throat-diffuser (typically .2 - .3) - check with vendor
Power fluid pressure	Power fluid pressure at surface (will be corrected for down hole based on static head only)
Power fluid volumetric rate)	Power fluid volumetric rate at surface (standard conditions
Power fluid temperature	Power fluid temperature at injection point (usually the temperature is only known at the surface, so this may be adjusted if required if the fluid is expected to heat significantly when traveling down hole. The effect is generally small)
Depth	Depth of injection in TVD (used to calculate power fluid pressure at injection point).

Table (3. 4) To model a jet pump with PIPESIM, various jet pump specifications must be defined

Jet Pump Parameters			
Parameter	**Description**	**Unit**	**Variable source**
dn	Diameter of nozzle	in	user specified
dt	Diameter of throat	in	user specified
An	Area of nozzle	in^2	calculated
At	Area of throat	in^2	calculated
Kn	nozzle loss coefficient (default = 0.03)		user specified
Ktd	throat-diffuser loss coefficient (default = 0.2)		user specified
D	true vertical depth of pump	ft	user specified

3.2.2.2 Running Simulations:

Jet Pumps are used in all PIPESIM simulation tasks. For PT Profile, Nodal Analysis and System Analysis tasks, we will select any Jet Pump property as a sensitivity variable which is essential in performing a Jet Pump design.

3.2.2.3 Results of Running:

A number of calculated variables are provided as output. These include:

Table (3. 5) Results of running

Jet Pump Result	Description
Temperature differential (DT)	Temperature change between the mixed fluid exiting the Jet Pump and the production fluid at the suction
Pressure differential (DP)	Pressure change between the mixed fluid exiting the Jet Pump and the production fluid at the suction
Pressure Ratio (PR)	Pressure ratio across the jet pump (outlet pressure/inlet pressure
Set T	Outlet temperature of jet pump
Dimensionless mass ratio	Reservoir fluid mass rate/Power fluid mass rate
Dimensionless volume ratio	Reservoir fluid volume/power fluid volume. Typically this number ranges between .25 and 1.0
Compression ratio	Difference between discharge and suction (well fluid) pressure / difference between power fluid and discharge pressure. (See definition in dimensionless parameter table below).
Cavitation Ratio	Dimensionless volume mass ratio/ cavitation limit. Should be below 1 to avoid risk of cavitation.
Critical Flow Ratio	Max. Velocity in pump/Sonic velocity. Same as Mach number.
Efficiency	Mechanical efficiency of jet pump. A “good” efficiency for

	a jet pump is between 30 and 35%.
Power	Power required at surface triplex pump
Throat entrance pressure	Pressure at the throat entrance at the mixing point of the power fluid and reservoir fluid (Pe). This is the point of lowest pressure in the jet pump and the location where cavitation may occur if the pressure is below the vapor pressure of the well fluid
Throat entrance pressure ratio	Ratio of throat entrance pressure to pressure of source (well) fluid. Grupping (ref 2) states that this value should be between0.3 and 0.7 for efficient jet pump operation

3.2.2.4running the nodal analysis before install HJP

Run a Nodal Analysis on the well without a lift system installed, with the nodal analysis point located at the intended jet pump location, which should be as deep as possible. Based on the inflow curve, select a target production rate (qs) and corresponding suction pressure (Ps).

3.2.2.5 Select the Valid Pumps Types

Each Case Group represents specific nozzle-throat combinations.

3.2.2.6 system analysis

3.2.2.7.1 Perform a System Analysis with the following configured:

Table (3. 6) system analysis parameter

Parameter	Description
Inlet Pressure	Specify inlet pressure (for multiple completions, specify the pressures in the completion)
Outlet pressure	Well outlet pressure at surface
Liquid Flow rate	Target liquid rate from reservoir (excluding power fluid added)

Custom Variable (selected)	Object: Jet Pump Variable: Power Fluid Pressure Min. Value: 500 psia Max. Value: 5000 psia (or limit) Proportionality: direct
Sensitivity configuration	Change in step with Variable 1
X-axis variable	Jet Pump power fluid (select about 20 or so points such that Fq ranges roughly from .25 to 4)
Variable 1	Nozzle diameter
Variable 2	Throat diameter (corresponding to matching nozzle diameter in same row)

Run the model. On the resulting system plot, configure the following:

Table (3. 7) resulting system plot

Axis	Variable
X	Jet Pump dimensionless volume ratio
Y left	Jet pump – power fluid pressure
Y right	Jet pump Inlet liquid volume rate
Y custom	Jet Pump efficiency

Each Case Group on the plot represents specific nozzle-throat combinations. The plot with all case

groups selected contains too much information to be analyzed, so use the Case Group selected to the left of the plot to select individual case groups.

In the region of maximum efficiency (highlighted above), inspect the plot to ensure the following:

- Max efficiency is above 25%
- Target liquid rate is achieved
- Surface injection pressure is less than limit (e.g. 4000 psia)

3.2.2.7.2 Eliminate candidate nozzle-throat combinations for cases in which the above is not true.

Next, to screen for critical flow or cavitation, change the plot axis highlighted below in green:

Table (3. 8) screen for critical flow or cavitation

Axis	**Variable**
X	Jet Pump dimensionless volume ratio
Y left	**Jet pump – cavitation ratio**
Y right	**Jet pump – critical flow ratio**
Y custom	Jet Pump efficiency

If the cavitation ratio or critical flow ratio is greater than 1 in the region of peak efficiency, further eliminate nozzle-throat candidates.

3.2.2.7 Nodal analysis after install HJP

In this step determent the operating pointsbyintersection of inflow and outflow

3.2.2.8 final result parameter

We will also wish to reduce the range of power fluid injection rates and rerun the system analysis.

For the remaining cases, it is useful to record the results at peak efficiency in tabular format:

Table (3. 9) final result

Nozzle-Throat combination	Peak efficiency (%)	Q liquid	Q inject	P inject	Power	(Pe/Ps) ratio	Cavitation ratio	Critical flow ratio
Candidate 1								
Candidate 2								
Candidate 3								
Candidate 4								

Generally, the optimal design will select the smallest pump such that:

- Cavitation ratio < 1
- Critical flow ratio < 1
- Power is minimized

3.3 Technical Description

In a jet pump, high pressure power fluid is injected through a nozzle and mixed with a lowpressure production fluid. Kinetic energy is transferred from the high pressure fluid to the low pressure fluid, and the mixed fluid is expelled at an intermediate pressure. In wells, some of the production fluid can be pumped back down the annulus to a jet pump to help lift the production fluid in the tubing.

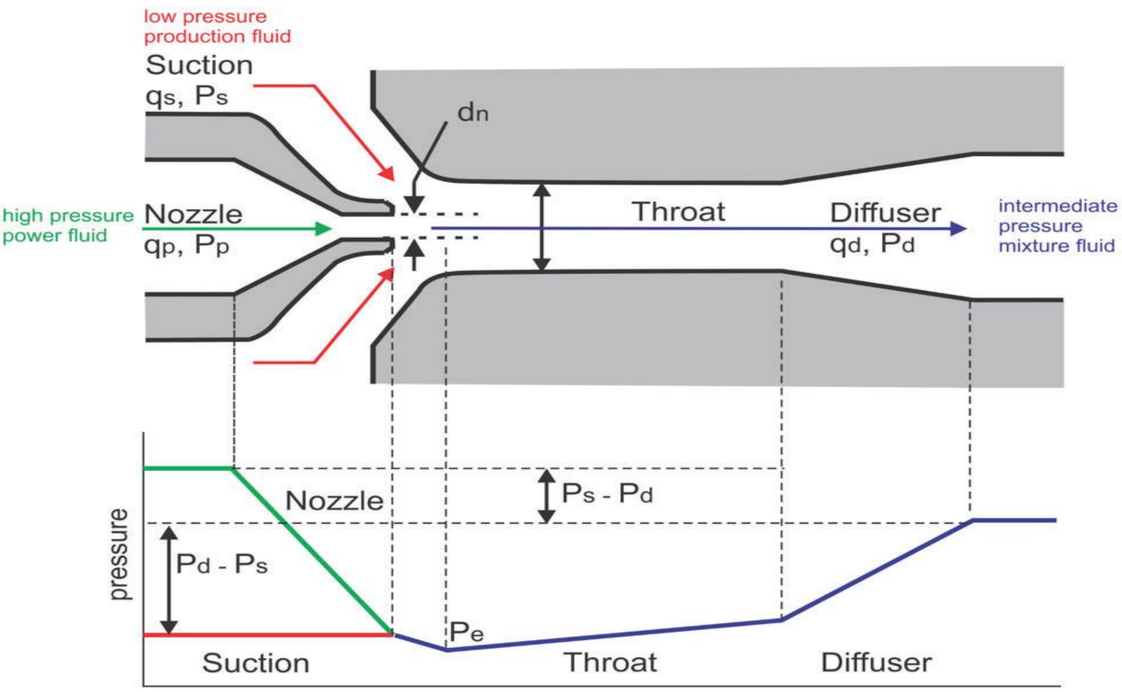


Figure 3.2.Technical Description(Noronha, F.A.elc, 1998)

Table (3. 10) fluid data operating condition

Parameter	Description	Unit	Variable source
qs	suction (reservoir) fluid volumetric rate	BPD	PIPESIM
qp	power (injection) fluid volumetric rate	BPD	user specified
ps	Reservoir fluid pressure at pump suction	psia	PIPESIM
Pps	power fluid pressure (at surface)	psia	calculated
Pp	power fluid pressure (at injection inlet)	psia	user specified
Pe	Throat entrance pressure	psia	calculated

Pd	Pressure at diffuser exit	psia	calculated
Tpi	power fluid temperature (at injection)	F	user specified

3.4Data collection

From block - 6 completion data for well

Table (3. 11) Data collection

properties	**value**
Average Formation Top (mKB)	1755
nitial Reservoir Pressure, Mpa (psi)	2538.2
Temperature ,°C	77.3
Porosity ,%	19
Permeability ,mD	133
Oil Gravity, °API	36.5
Viscosity @ 50°C, cP	40
Formation Volume Factor, RB/STB	1.18
TAN (mgKOH/g)	1.68
Pour Point (°C)	7.8

Kelly Bushing (KB)(m)	553.29	
TVD(mKB)	2400	
Production Casing (Hanger)	OD (mm)	139.7
	ID (mm)	124.3
	Grade	N80
	Depth m	1591.51-2398.0
Intermediate Casing	OD (mm)	245.5
	ID (mm)	224.4
	Grade	N80

	Depth m	0-1709.99
Tubing	length m	1952.57
	ID	2 7/8 "
Avg Formation thikness	17m/2zones	
Avg perforation Depth	1988	

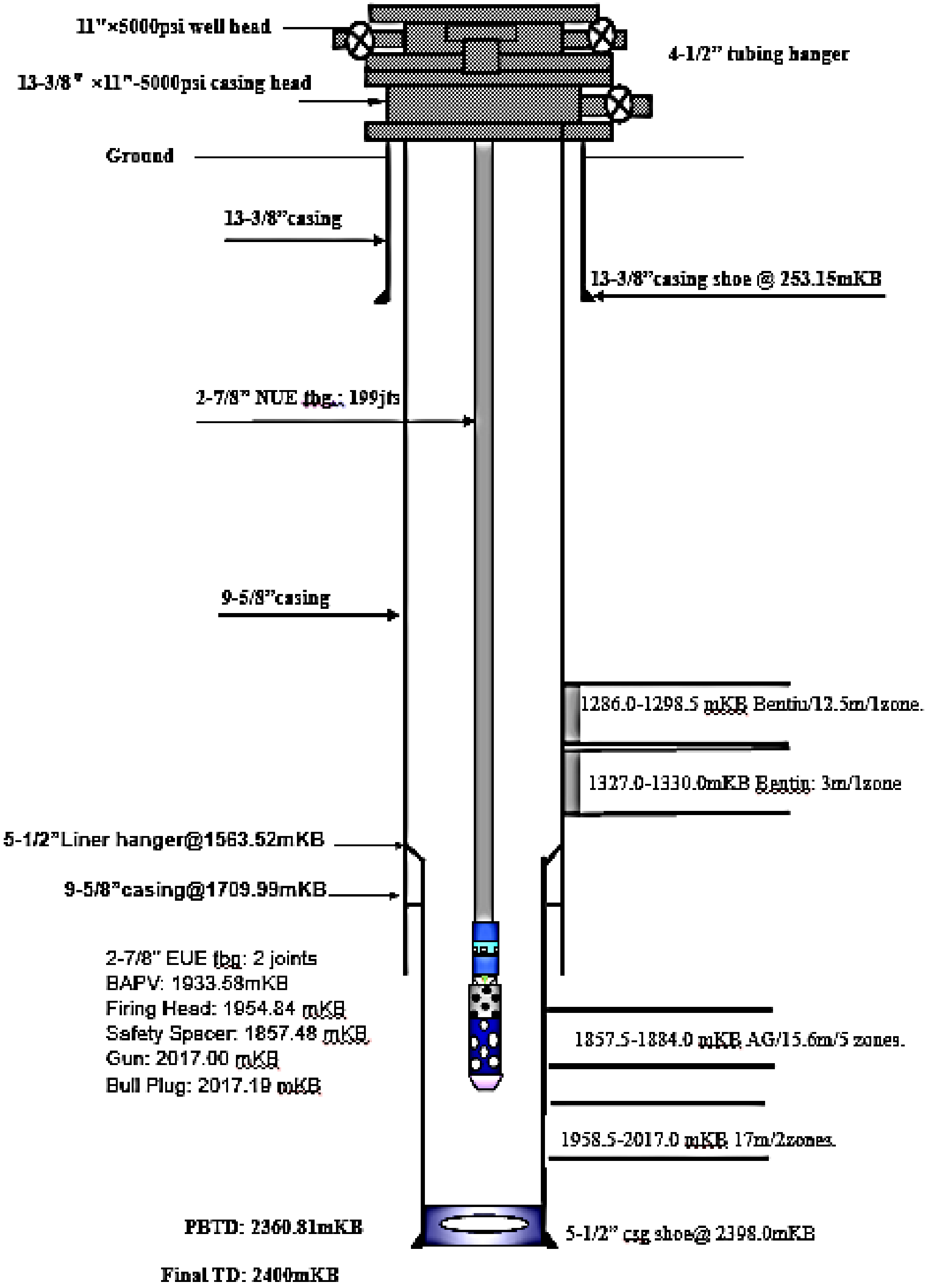


Figure 3.3completion well

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Discusiion And Results

In this chapter we will present the results, analyze them before and after HJPrepresentation, study the pump using nozzle-throat combinations and perform a nodal analysis before and after pump simulation on the PIPESIM program

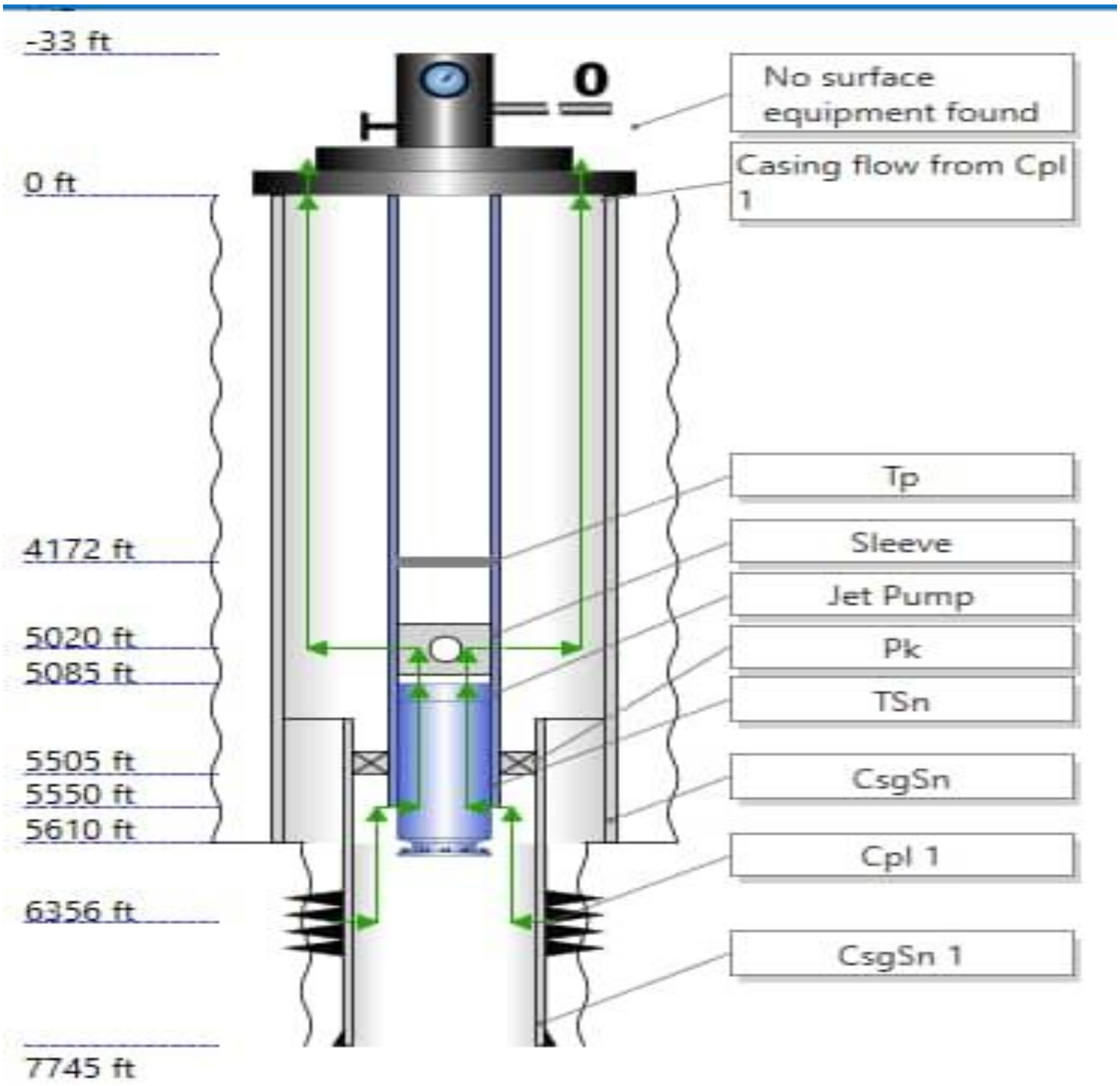


Figure 4.1.shTubing plug and a sliding sleeve door added to the **HJP** model

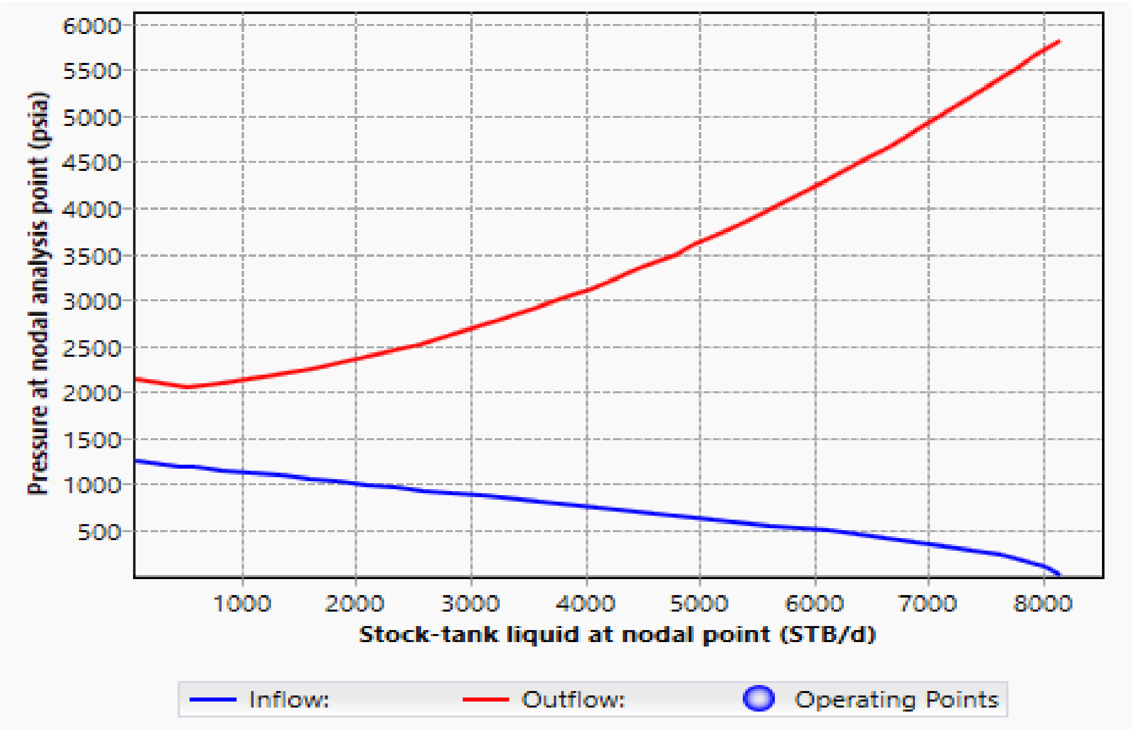
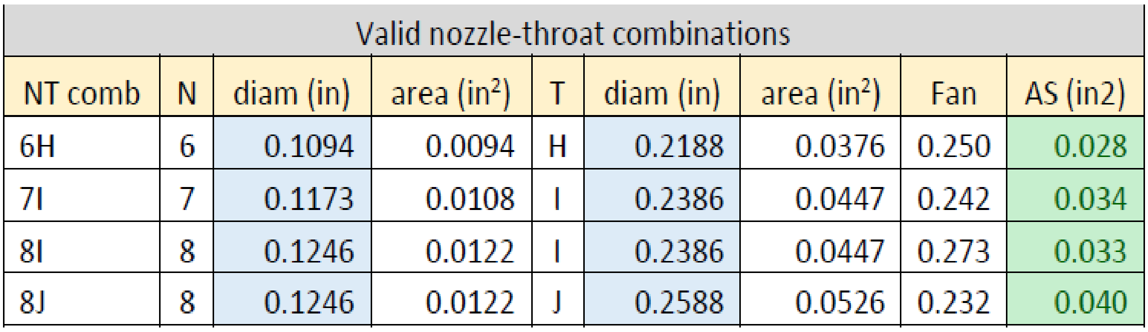


Figure 4.2. Nodal Analysis before HJP running

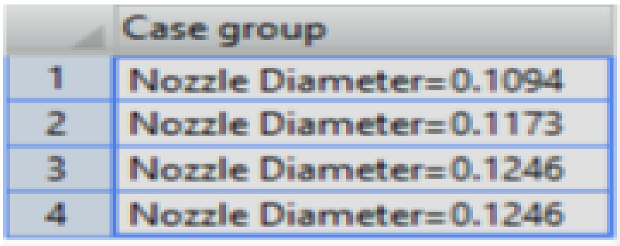
From Figure (4-2) before HJP running we determined the node Location at the bottom hole and performed nodal analysis on it using an IPR curve and it became clear to us that the well does not produce in this circumstance(there is no intersection of inflow and outflow).

Table (4. 1) Valid Pumps Types



Valid nozzle-throat combinations								
NT comb	N	diam (in)	area (in^2)	T	diam (in)	area (in^2)	Fan	AS (in2)
6H	6	0.1094	0.0094	H	0.2188	0.0376	0.250	0.028
7I	7	0.1173	0.0108	I	0.2386	0.0447	0.242	0.034
8I	8	0.1246	0.0122	I	0.2386	0.0447	0.273	0.033
8J	8	0.1246	0.0122	J	0.2588	0.0526	0.232	0.040

FromTable (4-1) consider Jet pump models from Sertecpet. The excel spreadsheet with the Jet Pump catalogs includes a tab that lists all valid nozzle-throat combinations for Sertecpet pumps that allows candidate models to be flagged. The four smallest pumps were examined as a filter



	Case group
1	Nozzle Diameter=0.1094
2	Nozzle Diameter=0.1173
3	Nozzle Diameter=0.1246
4	Nozzle Diameter=0.1246

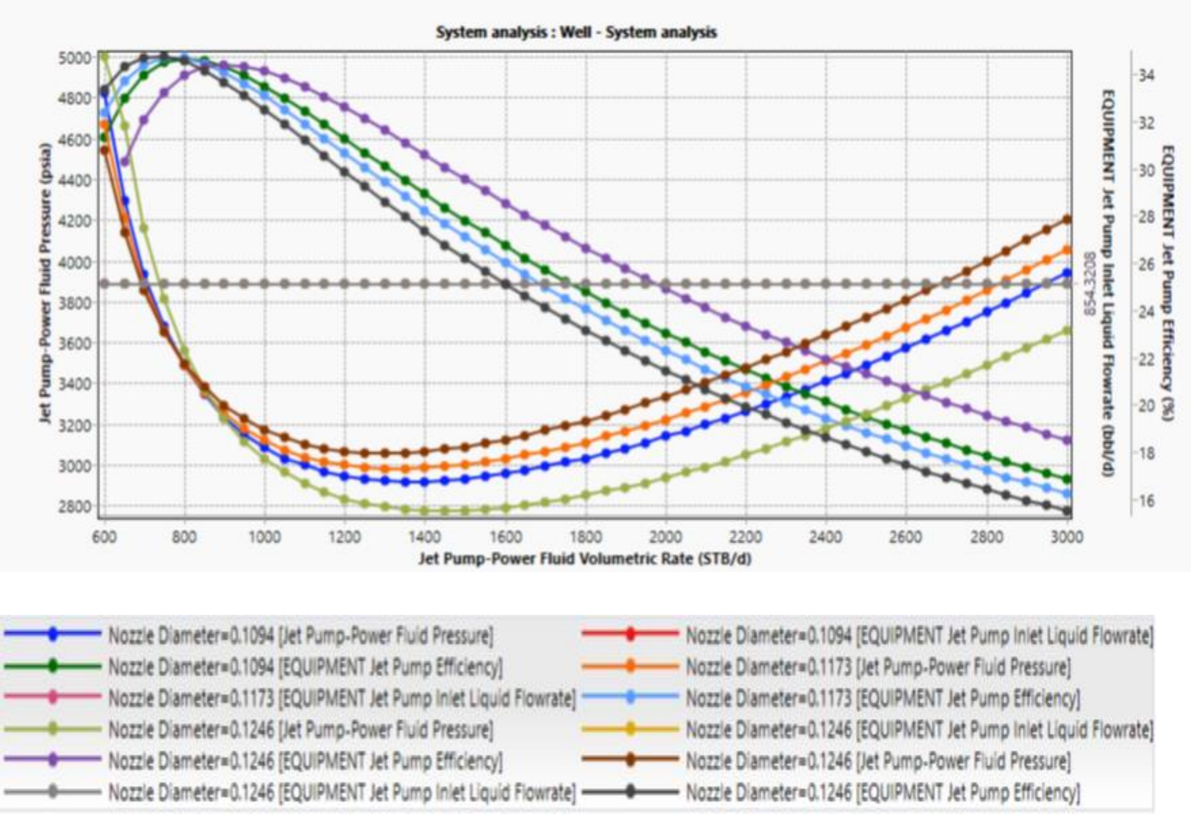
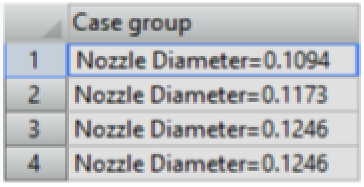


Figure (4-3) plot, the effect of different nozzle diameter on the fluid flow rate.Power fluid pressure.& Power fluid volumetric rate as case group

From Figure (4-2) it appears that all nozzle-throat combinations are able to achieve the reservoir flowrate (800 BPD) at some injection pressure. However, at the extreme high and low ranges of injection rate, the required injection pressure exceeds our limit (4000 psi) for the surface pump.



	Case group
1	Nozzle Diameter=0.1094
2	Nozzle Diameter=0.1173
3	Nozzle Diameter=0.1246
4	Nozzle Diameter=0.1246

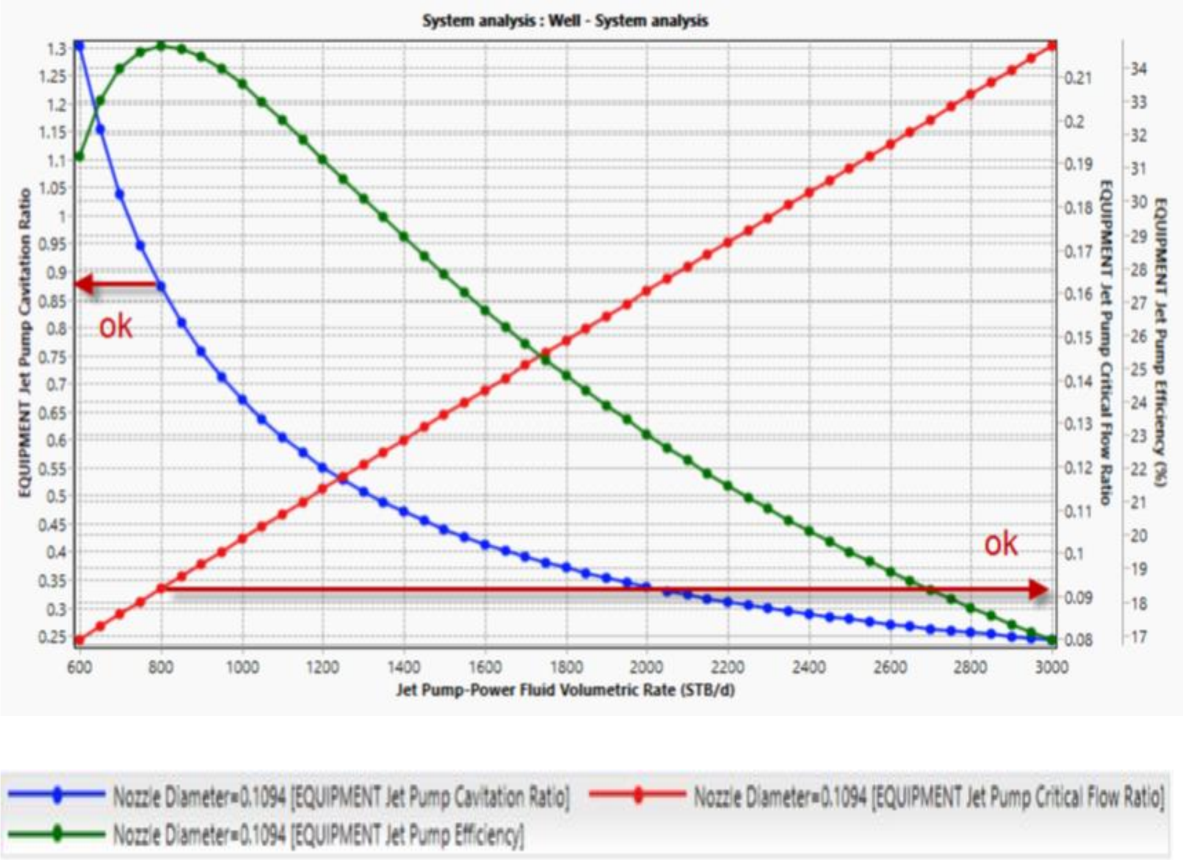


Figure 4.4. Left Y-axis to Cavitation ratio and Right-Y axis to Critical Flow Ratio & Efficiency –X axis jet pump power volumetric by using (0.1094 in) nozzle diameter

optionally (0.1094 in) nozzle diameter and the flow rate(800 STBD) we find that :

- Cavitation ratio 0.87
- Critical Flow Ratio 0.09
- Peak efficiency (%) 34.6

Table (4. 2) the results of using several types of HJP

Nozzle-Throat combination	Peak efficiency (%)	Q liquid (STBD)	Q inject (STBD)	P inject (psia)	Power (Hp)	(Pe/Ps) ratio	Cavitation ratio	Critical flow ratio
6H	34.6	800	800	3488	52.7	.65	.87	.09
7I	34.7	800	750	3658	51.8	.63	.90	.07
8I	34.4	800	900	3226	54.9	.69	.85	.08
8J	34.7	800	750	3650	51.7	.63	.85	.06

The results are tabulated based on the injection rate and pressure at peak efficiency. Examination indicates that all jet pump candidates are capable of achieving the desired flow and that the performance is generally comparable. The 8J option has a slightly lower power requirement and cavitation ratio than the other candidates.

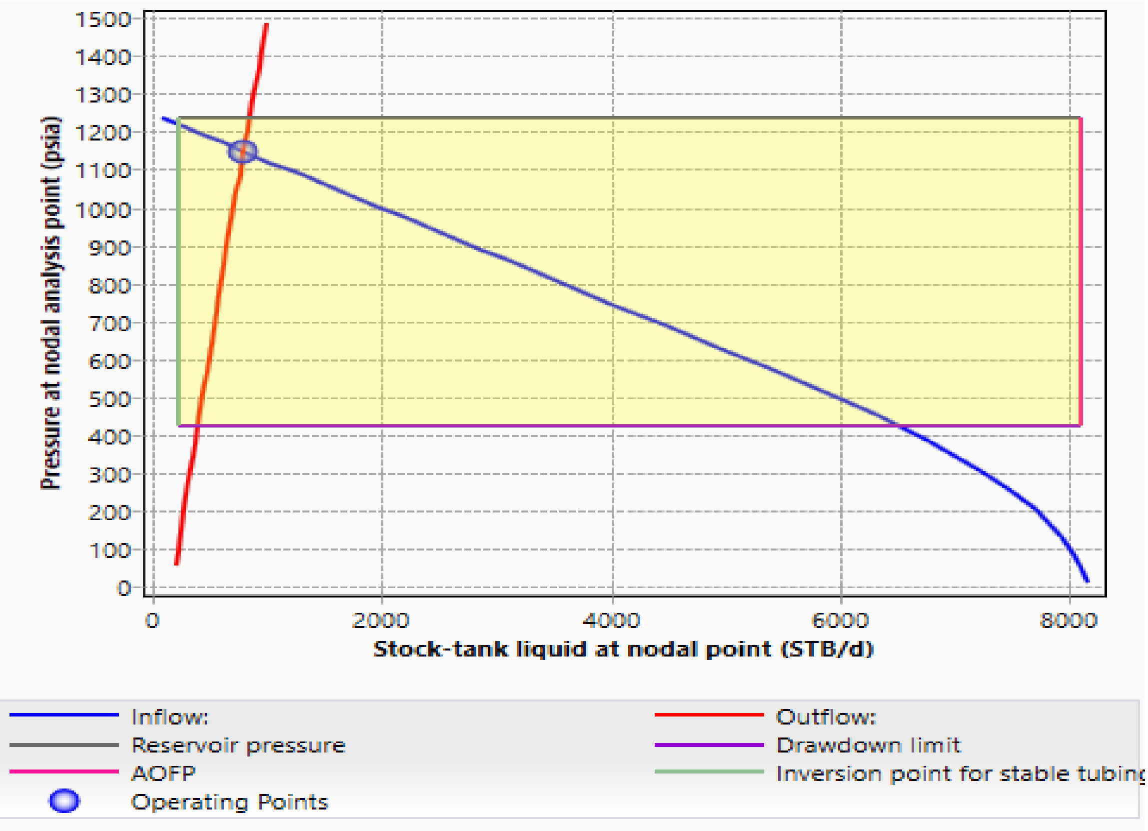


Figure4.5. showsNodal Analysis after HJP running there is intersection of inflow and outflow and a point of intersection called operating points

the pump is configured based on the injection rate and pressure at peak efficiency. Examination indicates that all jet pump candidates are capable of achieving the desired flow and that the performance is generally comparable

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1Conclusion

when building model with PIPESIM software by different nozzle-throat combinations (6H-7I-8I-8J) we note that it gives as the same production rate as the fluid produced (800 STBD) but we select 8J option combination because it have flowing characteristic (a slightly lower power requirement (hp)=51.7, less cavitation ratio than the other candidates=0.85, highest efficiency =34.7%, less power fluid flow rate =750 STBD).

5.2Recommendation

We recommend using the hydraulic jet pump especially in low bottom hole pressure to support productivity of well and thus increasing production

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