Optimizing Hydraulic Jet Pump Using Empirical Volumetric Efficiency Equation and Approaching Nozzle-Throat Combination Ratio in Sembakung Area, Indonesia

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Abstract. Sembakung Area is mature structure which discovered in 1975. It is situated in North Kalimantan, around 50 miles from Tarakan island and currently undertaken by PT Pertamina EP since 2013. During 30 years of operation, many types of artificial lift trial have been used, such as ESP, rod pump, and hydraulic jet pump. Considering the structure has a massive sand problem, and moreover, the area itself is located in a remote and swampy area, rig mobilization and operations are very costly and hard to operate. As a result, a rig-less well service is needed and HJP is one of the obvious choice.
Earlier, in the design of HJP in Sembakung, the size of nozzle and throat used is not common and not following the general rule, causing the general HJP design software commonly used cannot predict accurately the actual condition and find the optimal design for optimal production. The study presented herein describes how to find the problem that led to inaccuratibility of software used.
In the design process, it was found that Volumetric Efficiency equation (from M.B. Standings) that commonly used in designing HJP cannot be applied to Sembakung structure. Thus, an empirical Volumetric Efficiency equation should be made to design HJP specifically used for use in this structure. The uncommon nozzle and throat combination itself can be approached from the method which will be discussed herein. This method is proved to be able to find the ratio of the HJP nozzle-throat combination in Sembakung with the highest efficiency and relatively faster.

Keyword: Hydraulic Jet Pump, Artificial Lift, Production Engineering

1 Introduction

The structure of Sembakung, located in North Kalimantan Province, Indonesia, is an oil and gas field currently operated by PT. Pertamina EP Field Tarakan since 2013. With an area of 23.37 km^2, there are 70 production wells with 38 active wells. Sembakung area reached its peak production in 1978 with production of 11,500 BOPD but along with the natural production decline, the current average production of Sembakung structure is around 1400 BOPD.
The artificial lift method used in the Sembakung structure is the Hydraulic Jet Pump. Hydraulic Jet Pump is an artificial lift which is rarely used in oil and gas fields in Indonesia. This is because the efficiency of

the Hydraulic Jet Pump is relatively low compared to other artificial lifts. However, the location of the Sembakung Structure in remote areas and its swampy conditions is an obstacle to workover and well service activities using rigs. Therefore, the use of a Hydraulic Jet Pump whose maintenance can be done Rig Less (without using a rig) is very profitable. Besides, the condition of the production fluid of the Sembakung Structure which is sandy and the well profile can be overcome by the use of a Hydraulic Jet Pump.

Hydraulic Jet Pump is an artificial lift that does not have moving parts inside the subsurface but instead, uses momentum transfer between the power fluid and the production fluid. The power fluid will enter the pump through the tubing and will pass through the pump nozzle where all the discharge pressure applied will be converted to velocity head. The jet from the nozzle will cause the production fluid from the formation to be carried away and mix with the power fluid into the throat. Then from the throat, the mixed fluid will pass through the diffuser where the velocity head is converted back into pressure. This pressure will bring the mixed fluid to the surface through the return tubing.

Currently, there are lots of software available to design various artificial lifts, one of which is for the Hydraulic Jet Pump. However, not all fields can use the software to get suitable designs for them. One of them happened in Sembakung Structure. Various Hydraulic Jet Pump design software has been tried but it is not suitable for real conditions in the field.

The results of the Hydraulic Jet Pump combination design using the software in Sembakung are often different from actual results in the well. Based on several design trials that uses software, with the desired combination of nozzle-throat and production rate target, there is a gap between the design and the actual condition in the well. The differences from these designs are re-designed and overlooked in these methods:

- Developing Empirical Volumetric Efficiency for Sembakung Area
- Determining the method, so that the nozzle-throat combination will matches the Sembakung condition

Table 1. Differences in Hydraulic Jet Pump Design Using Software and Actual Condition

Well	N/C	Prod Target	DP Actual	DP Design	PF Actual	PF Design
SBK-02	C+7	154.1	2800	2020	1177	1050
SBK-05	E9	275.7	2800	2090	1950	1780
SBK-08	D7	167.9	2500	1700	1381	1220

2 Methodology

2.1 Well Requirement for Research Study

To select a well to be objected for this research study, this is the main criteria: wells are produced using HJP with a data from single production well (in Sembakung area normally 2 or 3 wells were operated from the same surface pump then the output production gathered in one flowline), this is to make sure the data is accurate enough for a subject of research

Furthermore, when designing the HJP pump for each well some input data is required as follows:

1. Surface pump type
2. Existing nozzle combination ratio
3. Surface pump pressure
4. Power fluid water cut
5. Oil produced specific gravity
6. Water produced specific gravity
7. Pump intake depth
8. Tubing pressure or vessel pressure
9. Casing pressure
10. Pump submergence (fluid level from sonolog data can be analysed)
11. Power fluid rate
12. Production rate
13. Producing water cut
14. Producing gas rate

From the requirement above, there are 9 wells from Sembakung Area that meet the requirement. This 9 well then selected to be object for this research, there are SBK-02, SBK-05, SBK-08, SBK-09, SBK-18, SBK-40, SBK-74, SBB-02, SBT-01.

2.2 Pattern Evaluation of Nozzle-Throat Ratio

The ratio of Nozzle-Throat Combination is a ratio of Nozzle Area (A_j) divided by Throat Area (A_t). For design purposes, the size of each Nozzle and Throat Area was made in various numbers but in the same pattern for each ratio (R). In order of that, there will be a ratio that works at high head and low rate and at the other hand, there will be a ratio that works at low head but in high rate. Commonly there are around 5 ratios for each HJP Nozzle-Throat manufacturer. For example, nozzle-throat from Brown using 5 ratios.

“A” Ratio, is a ratio between nozzle and throat, which have a same number (example: nozzle number 1 divided by throat number 1 will have the same ratio with nozzle number 3 divided by throat number 3, etc). And “B” ratio, is a ratio between nozzle and throat, which have 1 different number (example: nozzle number 1 divided by throat number 2 will have the same ratio with nozzle number 4 divided by throat number 5). “C” ratio, is a ratio between nozzle and throat, which have 2 different numbers (example: nozzle number 1 divided by throat number 3 will have the same ratio with nozzle number 2 divided by throat number 4, etc). And it has the same pattern for “D” ratio, which have 3 different numbers and “E” ratio which have 4 different numbers.

The explanation above is a common pattern of ratio for designing Hydraulic Jet Pump. Unfortunately, Guiberson HJP does not have the same pattern, Guiberson HJP is a Hydraulic Jet Pump manufacturer that PT Pertamina EP Sembakung Area has been using until now. The ratio of each nozzle-throat combination has a different value, as a result of that there will be a lot of ratio for specific nozzle and throat size in Guiberson.

Table 2. Brown Nozzle-Throat Combination

	Kode	
Throat	1	0.0[illegible]
	2	0.0[illegible]
	3	0.0[illegible]
	4	0.0[illegible]
	5	0.0[illegible]
	6	0.0[illegible]

Table 3. Brown Nozzle-Throat Combination

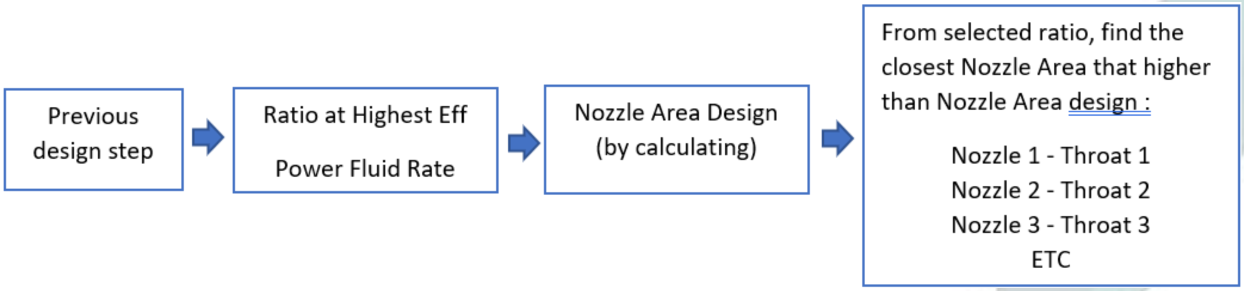
	Kode	
Throat	1	0.0143
	2	0.0189
	3	0.0241
	4	0.0314
	5	0.038
	6	0.0452

At Brown Nozzle-Throat table, a ratio for each pattern have the same values (marked with the same color). Otherwise at Guiberson Nozzle-Throat table, a ratio for each pattern have a different value. With that information the common HJP design step will not work to get optimum design. In order to get the optimum design for Guiberson HJP, it needs to add steps and modification to get the most efficient Nozzle-Throat combination, power fluid rate, and discharge pressure of surface pump.

2.3 Approaching Method for Guiberson Nozzle-Throat Optimum Design

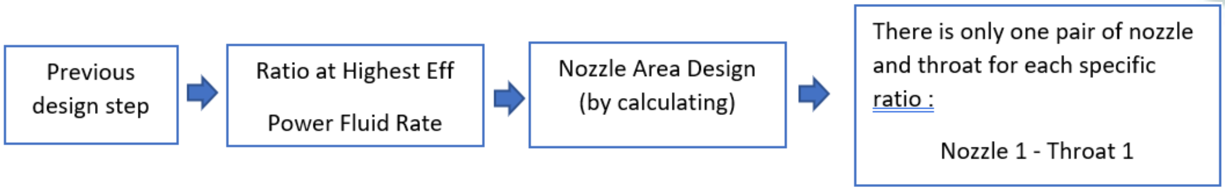
Illustration below shows the part of common step design for optimum HJP operation

Fig 1. Part of General HJP Design



Previous design step from the illustration above is a step from inputting data until getting values of H. From the illustration above, first select the ratio that contains a highest efficiency, calculated nozzle area design, then select a nozzle with the minimum difference between nozzle area design and actual nozzle area. Since the ratio have been selected before, therefore it must be a specific Throat for each Nozzle. This step does not applicable for Guiberson HJP type that have specific ratio for each nozzle-throat combination. See illustration below for Guiberson HJP type condition.

Fig 2. Part of general HJP design using Guiberson nozzle-throat combination



For Guiberson HJP type, after selecting a ratio which have highest efficiency, same as before, then compare the result of nozzle area from design and the actual nozzle area. If the difference is too far, then design process cannot be continued because for each specific ratio only have one pair of nozzle and throat. This condition makes Guiberson HJP type relatively hard to find the optimum design of HJP.

To solve this problem, it needs to change the step of design. Since Guiberson HJP type only have 1 pair of nozzle and throat for each ratio (it means the amount of ratio must be so high, in line with the total amount of nozzle-throat combination), then adding these 2 terms is a good step after choosing a ratio with highest efficiency. Selecting new ratio from all of the nozzle-throat combination which matches these 2 terms:

$$\left|R_{\max eff} - R_{new}\right| \leq 0.015$$
$$A_{j\,actual} - A_{j\,design} \approx minimum$$

Note that R_{new} is a function of $A_{j\,actual}$:

$$f(R_{new}) \rightarrow A_{j\,actual}$$

To make it brief, see illustration below that reflects the explanation above:

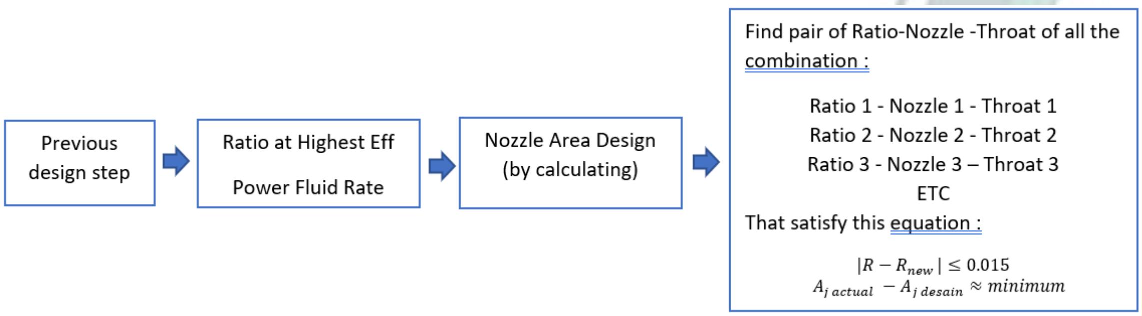


Fig 3. Part of general HJP design using approximate ratio and nozzle area calculation

The chosen ratio with highest efficiency will be a target ratio, as well the actual nozzle area for that ratio. Next step, find the closest ratio that also have nozzle area close with the target nozzle area. By adding this step, it can overcome the Guiberson HJP type weakness to find optimum HJP design.

2.4 Volumetric Efficiency Equation Evaluation

The present of gas in producing fluid makes the HJP design for single phase liquid need to be corrected. In Brown's book (see HJP design flowchart for multiphase flow), the values of M, which is the ratio of production liquid rate divided by power fluid rate, should be corrected by volumetric efficiency constant so that the design matches the actual condition. The parameter that affected Volumetric efficiency is GOR, production water cut, and pump intake pressure. Commonly the volumetric efficiency equation that used around the world was made by M.B Standings. Unfortunately, M.B Standings volumetric efficiency equation did not meet Sembakung area condition. When using this equation, design of HJP did not match the actual condition (see table 4 below).

Table 4. Actual Condition vs Design Using General Software

Well	Test Date	Rate Prod Actual	Rate Power fluid Actual	Rate Power fluid Design	DP Actual	DP Design	Ve Derive from Software
		bfpd	bfpd	bfpd	psi	psi	%
SBK-08	23-Dec-19	168	1381	1217	2500	1700	179
SBK-02	11-May-20	154	1177	1050	2800	2100	1484
SBK-05	06-Jun-20	276	1950	1780	2800	2090	139
SBK-09	25-Apr-20	278	1980	1867	2600	2600	30
SBK-18	11-May-20	79	1980	1757	2500	2000	156
SBK-40	23-May-20	259	1502	1303	2800	2150	593
SBK-74	23-Apr-20	61	1410	1200	2700	1600	27
SBB-02	16-Jul-20	55	1353	984	2700	1600	-136
SBT-01	24-Nov-19	126	1197	1012	2600	1850	-621

To approach an actual condition in Sembakung, it needs an empirical volumetric efficiency equation that satisfies Sembakung condition with its Guiberson HJP. With accurate volumetric equation, the result of design will be closer to actual condition so that production optimization will be easier to achieve.

2.5 Construction of Volumetric Efficiency Empirical Equation for Sembakung Area

It has been discussed above that volumetric efficiency equation from M. B Standings did not meet Sembakung condition, with this equation the comparison of the actual parameter versus the result of design parameter has a significant difference. To overcome this condition, we need to develop an empirical equation that matches Sembakung Area requirements.

First step to develop an empirical equation, we should know the parameters that affect the volumetric efficiency (see graphic below):

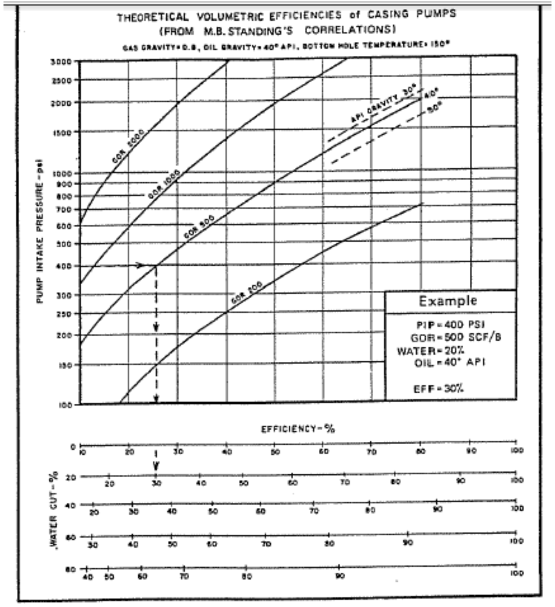


Fig 4. Graph of Volumetric Efficiency from M. B Standings

Fig. 4 is derived from M. B Standings equation to get volumetric efficiency without calculating. Actually, there are 4 parameters that affect volumetric efficiency: GOR, water cut, pump intake pressure, and API of oil. The last parameter can be neglected since Sembakung area only has one reservoir, thus have the same fluid parameter as well with an average API of oil around 40 API. To develop an empirical equation, we need the values of actual VE in each well condition as a targeted value for the constructed equation. By using the reverse calculation method, actual VE values can be obtained. Reverse calculation is a method which the calculation started from the last step of design by inputting the final output design (from actual data that measured or directly obtained, not calculating) then continues backward the calculation until the data that’s missing to be found. See the illustration below:

Fig 5. Illustration of Forward Calculation

Illustration shown above is a forward calculation, which to obtain the value of C, A value should be multiplied by B value. If the value of C has measured or obtained from field data, then reverse calculation can be done to obtain the values of B. See illustration below:

Fig 6. Illustration of Reverse Calculation

To obtain B value, can be done by dividing C of A. A is illustrated as a result of HJP design partial step until get M_{graph} . B is illustrated as VE, and C illustrated as M_{VE} (result of M_{graph} multiply by VE). From field data, the values of power fluid rate and production rate can be measured, thus the values of M_{VE} or illustrated by C value can be obtained $\left(M_{ve} = {}^{q_3}/_{q_1}\right)$. The value of A can be obtained as well by following the step design (forward design) until M_{graph} obtained. Since $M_{VE} = M_{graph}\, x\, VE$, then the values of VE (illustrated by B) can be obtained by dividing M_{VE} with M_{graph}. Table 5. show the value of VE from 9 well represented along with PIP, GOR, WC data.

Table 5. Actual VE from Reverse Calculation Method

Well	Test Date	PIP	GOR	WC	Actual Ve
		psi	scf/bbl	%	%
SBK-08	23-Dec-19	11	43	70	26
SBK-02	11-May-20	124	91	85	31
SBK-05	06-Jun-20	57	40	70	31
SBK-09	25-Apr-20	88	70	83	28
SBK-18	11-May-20	11	108	76	12
SBK-40	23-May-20	152	80	84	41
SBK-74	23-Apr-20	15	104	5	7
SBB-02	16-Jul-20	4	103	63	8
SBT-01	24-Nov-19	26	47	65	23

After the values of actual VE obtained, the next step is to develop empirical equations for VE. Multivariable regression method was chosen to develop the equation by targeting actual VE as dependent variable of parameter PIP, GOR, WC (independent variable). The result of multivariable regression was:

VE = 0.152 (PIP) - 0.206 (GOR) + 0.0728 (WC) + 25.642

Regression Statistics	
Multiple R	0.985228
R Square	0.970674
Adjusted R Square	0.953078
Standard Error	2.507725
Observations	9

The equation above is the empirical equation of VE for Sembakung Area. From the parameter R Square (0.97) the equation likely to have an accurate prediction of VE, which means that each parameter has a strong relation to VE. To check the accuracy of the equation, data from 9 representative wells was calculated to obtain predicted VE by using the equation. The result is shown in Table 6.

Table 6. Comparison of Actual VE vs Predicted VE

Well	Date	PIP	GOR	WC	Actual Ve	Ve Predicted	% Error
		psi	scf/bbl	%	%	%	
SBK-08	23-Dec-19	11	43	70	26	24	10%
SBK-02	11-May-20	124	91	85	31	32	3%
SBK-05	06-Jun-20	57	40	70	31	31	1%
SBK-09	25-Apr-20	88	70	83	28	31	10%
SBK-18	11-May-20	11	108	76	12	10	16%
SBK-40	23-May-20	152	80	84	41	38	6%
SBK-74	23-Apr-20	15	104	5	7	7	4%
SBB-02	16-Jul-20	4	103	63	8	10	23%
SBT-01	24-Nov-19	26	47	65	23	25	8%
						Average error	9%

From the table above, difference between actual VE and predicted VE was insignificant (less than 3%), and the average error only 9%. From the explanation above, it can be concluded that this empirical equation was acceptable for Sembakung area.

2.6 Software Development

After developing method to overcome weakness of Guiberson HJP type and also getting the accurate VE for Sembakung area, next step is developing a software so that design process and optimization can be done easier. For the purpose of piloting project, the software developed on Microsoft Excel that has been made (see fig. 7 screen capture of the software) and the result of design production matching will be discussed in the next chapter.

INPUT PARAMETER

Input IPR Parameter

Parameter	Value	Units
P res	1000	psi
Q max	500	bfpd
Desired Prod (q3)	200	bfpd
Pwf	750	psi

Input Well Parameter

Parameter	Value	Units
Pump depth TVD	3500	ft-TVD
Pump depth MD	3500	ft-MD
Perfo depth	3700	ft
Tubing ID 1	2.441	in
Tubing ID 2	1.995	in
P surface	2500	psi
Pwh	50	psi
Kapasitas pompa	3000	bfpd

Input Power Fluid Parameter

Parameter	Value	Units
SG Power Fluid	1	
WC Power Fluid	100	%

Input Reservoir Fluid Parameter

Parameter	Value	Units
SG Formation water	1	
SG oil	0.8415	
SG gas	0.725071	
Oil Viscosity	1	cp
T well head	80	F
T bottom hole	164.16	F
Gas Tubing	2200	SCF
WC (Res fluid)	0	%
GLR (Res fluid)	30	SCF/bbl
GOR (Res fluid)	30	SCF/bbl

Input Friction Coeficient HJP

Parameter	Value	Units
Kj	0.15	
Ks	0	
Kt	0.28	
Kd	0.1	

Input Rate Power Fluid (iteration)

Parameter	Values	Units
q1	549	bfpd

RESULT

At Power Fluid Tubing

Parameter	Value	Units
Fr 1	3.2690	psi/1000 ft
Fr loss 1	11.4414	psi
P1	4004.0586	psi

At Return Tubing

Parameter	Value	Units
q2	749	
P2	1,384	psi

At Hidrolik Jet Pump

Parameter	Value	Units
P intake pump	677.1261	psi
SG mix	0.8415	
Psi/ft mix	0.3644	psi/ft
WC @ pump	73.2977	%
GLR @ pump	8.0107	SCF/bbl
P3	677.1261	psi
H	0.2700	
M @eff max	0.9376	
Eff Max	25.31%	
R @eff max	0.2500	
Volumetric Eff	0.3882	
M ve	0.3640	
q1 new	549.4975	bbl
delta q1	0.50	bfpd
Stop iteration?	Okay	

Ukuran Luas N/C Exact

Parameter	Values	Units
Aj	0.0078	sq in
At	0.0314	sq in

Ukuran Luas Nozzle dan Throat Terpilih

Parameter	Values	Units
Aj	0.0095	sq in
At	0.038	sq in
Nozzle-Throat Combination	**B**	**5**
Kavitasi	**non-cavitation**	

Sizing Surface Pump

Parameter	Value	Units
Pump Discharge Pressure	2500	psi
HP Surface Pump	23.3	HP

Hydraulic Jet Pump Efficiency

Parameter	Values	Units
Effisiensi	25.31%	

Rate Power Fluid After Correction

Parameter	Values	Units
q1	665	bfpd

Fig. 7 Display of The Software

3 Result and Discussion

3.1 Design Evaluation with Existing Parameters

After developing the new software, an evaluation of the existing well parameters are conducted to see how the software performs in describing the actual condition. The result is shown on Table 7.

Table 7. Result Comparison between General Software vs Newly Developed Software

Well	N/C	Gross Actual	Pwf Actual	DP Actual	PF Actual	General Software			New Software		
						DP Design	PF Design	% Error	DP Design	PF Design	% Error
		blpd	psi	psi	blpd	psi	blpd	%	psi	blpd	%
SBK-08	D7	168	11	2500	1381	1700	1217	22%	2450	1303	4%
SBK-02	C+7	154	124	2800	1177	2100	1050	18%	2450	1037	12%
SBK-05	E9	276	57	2800	1950	2090	1780	17%	2530	1812	8%
SBK-09	E9	278	88	2600	1980	2600	1867	3%	2250	1691	14%
SBK-18	E9	79	11	2500	1980	2000	1757	16%	2380	1773	8%
SBK-40	D8	259	152	2800	1502	2150	1303	18%	2500	1299	12%
SBK-74	D7	61	15	2700	1410	1600	1200	28%	2750	1362	3%
SBB-02	C+6	55	4	2700	1353	1600	984	34%	2480	1075	14%
SBT-01	C+7	126	26	2600	1197	1850	1012	22%	2360	1048	11%
						Avg Error		**20%**	**Avg Error**		**9.6%**

From the Table above, the software uses the same parameter such as Nozzle Throat Combination (N/C) and Inflow Performance Relationship (IPR) derived from Gross Production and Well Flowing Pressure to compare the actual and design data of Power Fluid Rate and Power Fluid Pressure. As the result, the new software could minimize the average error twice than the old one from 20% to 9.6%.

3.2 Determination of the Optimum Parameters for the Design HJP of Sembakung Well

For the next step, the software then used to find the optimum parameter to design the HJP Parameter in Sembakung Well. To optimize the HJP for Sembakung Wells, there are several surface parameter limitations to be considered below:

1. Maximum Discharge Pressure of Surface Pump
2. Range of Surface Pump Rate
3. Other Surface Limit Diagram

Table 8. Surface and Subsurface Limitations Pressure

Well	Pump Type	Min Pump Rate	Max Pump Rate	Max Pump Press	Flowline Rating	Xtree Rating	Tubing Rating
					2" Pipe Sch 160		2-7/8" 6.4 ppf J-55
		blpd	blpd	psi	psi	psi	psi (for 1500 m wells)
SBK-08	J-130M (2")	900	2300	3000	6500	5000	5100
SBK-02	J-60M (1.75")	700	1500	3000	6500	5000	5100
SBK-05	J-130M (2")	900	2300	3000	6500	5000	5100
SBK-09	J-130M (2")	900	2300	3000	6500	5000	5100
SBK-18	J-100T4H (2")	900	2300	3000	6500	5000	5100
SBK-40	J-130M (2")	900	2300	3000	6500	5000	5100
SBK-74	J-100T4 (1.75")	700	1800	3000	6500	5000	5100
SBB-02	J-130M (1.75")	700	1800	3000	6500	5000	5100
SBT-01	J-130M (2")	900	2300	3000	6500	5000	5100

From the table above, using the maximum pump pressure 3000 psi as the limitation, the software then calculates the best Nozzle-Throat Combination and power fluid rate for all the Sembakung HJP Wells using existing DP for best comparison.

Table 9. Best Combination of HJP Parameter for Each Well

Well	Pump Type	Gross Actual	Existing Parameters				Optimization Parameters				Low/Gain Power
			DP Actual	PF Actual	N/C	Power	DP Design	PF Design	N/C	Power	
		blpd	psi	blpd		HP	psi	blpd		HP	HP
SBK-08	J-130M (2")	168	2500	1381	D7	59	2500	1308	D7	56	-3
SBK-02	J-60M (1.75")	154	2800	1177	C+7	56	2800	815	B+4	39	-17
SBK-05	J-130M (2")	276	2800	1950	E9	93	2800	1364	D7	65	-28
SBK-09	J-130M (2")	278	2600	1980	E9	88	2600	1303	D7	58	-30
SBK-18	J-100T4H (2")	79	2500	1980	E9	84	2500	1790	E8	76	-8
SBK-40	J-130M (2")	259	2800	1502	D8	71	2800	1110	C+6	53	-19
SBK-74	J-100T4 (1.75")	61	2700	1410	D7	65	2700	1101	C+6	51	-14
SBB-02	J-130M (1.75")	55	2700	1353	C+6	62	2700	935	C5	43	-19
SBT-01	J-130M (2")	126	2600	1197	C+7	53	2600	787	B+4	35	-18
								Total Low/Gain			-156

From the table above, the new software shows the best combination of HJP parameter for each well. After optimization with new parameter from new software, the power consumption of HJP will be lower.

4 Conclusion

The following conclusions and observations are based on the data presented in this paper:

1. The general HJP software is not suitable for HJP in Sembakung Area
2. The problem of nozzle throat combination used in Sembakung can be solved by approximating nozzle throat ratio and nozzle area calculations.
3. Empirical equation has been made using multivariable regression could replace M.B Standings volumetric efficiency with lower error
4. New HJP Software is proven to be able to describe the existing conditions of Sembakung with an error of less than 10%
5. New HJP Software is proven to be able to provide recommendations for the most optimal combination of HJP parameters so that it can reduce power consumption in Sembakung

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