CHAPTER III

SOFTWARE DEVELOPMENT

3.1 Introduction

This chapter describes the concept used in the software development for optimizing artificial lift system and design support at Phitsanilok oil field under various geological conditions and petroleum engineering requirements. The software hereafter is called ALOP. The proposed system is based on the known analytical solutions and theories, but is not based on the heuristic knowledge, inference procedure and experience of artificial lift expert backed by the rationale and logic. The concepts include problem analysis, flowchart, programeming, testing, conclusion and discussion.

3.2 Problem analysis

Problem analysis is a primary step for software development which identifies statement of problem, solution, procedure and result. The problem analysis can be divided into 5 sub topics, which includes requirement, output, input, variable declaration and procedure.

3.2.1 Requirement

The primary requirement is software development using Microsoft visual basic version 6 for application of artificial lift system at Phitsanulok oil field, including electrical submersible pump, intermittent flow gas lift and sucker rod pump.

The software displays detail, step of design, basic facilities and necessary information that can be saved and print in terms of file and ducements.

3.2.2 Output

This topic describes display and characterictics of the software on monitor. The characteristics of the software include a main page and three modules which include module of electrical submersible pump, intermittent flow gas lift and sucker rod pump. The detail, step of design, basic facilities and necessary information for application of each artificial lift system at Phitsanulok oil field is output of the software to display on the moitor as follow as in Table 3.1–3.3. The main page includes 2 parts that are a help label (green color) and three modules (including, electrical submersible pump, gas lift and sucker rod pump) as follow as in Figure 3.1. Each module includes picture, form of software common button and hot keys as follow as in Table 3.4. Each module is developed and composed with four functions; each function is showed and displayed by different color as follow as in Table 3.5 and Figure 3.2.

Table 3.1 Output of electrical submersible pump software.

Output	**Range**	**Unit**
Pump displacement	1 - 1,500	bbl
Static live oil gradient	-	psi/ft
Bottom hole pressure drawdown for oil production	-	psi
Average flowing bottom hole pressure	-	psi
Static fluid head	-	ft
Static fluid level	-	ft
Dynamic fluid level	-	ft
Discharge head	-	ft
Friction losses	-	ft/1,000 ft
Friction head	-	ft
Total dynamic head	-	ft
Head/Stages	-	ft
Number of stage	-	-
Horsepower/Stage	-	-
Total horsepower	-	hp
Cable losses	-	v/1,000 ft
Voltage drop	-	volts
Surface current**:** Type 1/2	-	amps
Surface voltage: Type 1/2	-	volts
Cable size**:** Type 1 Cu/Al : Type 2 Cu/Al	-	-

Table 3.2 Output of intermittent flow gas lift software.

Output	Range	Unit
Static gradient	-	psi/ft
Bottom hole pressure drawdown	-	psi
Average flowing bottom hole pressure	-	psi
Static fluid head with tubing pressure	-	ft
Static fluid level with tubing pressure	-	ft
Hydrostatic head	-	ft
Working fluid level	-	ft
Number of cycle	-	cycles/day
Number of oil 's cycle	-	bbl/cycle
Volume of stating slug	-	bbl/cycle
Capacity of tubing	-	bbl/ft
Slug length	-	ft
Operating valve should be located below working fluid level	-	ft
Depth to operating valve	-	Ft
Pressure in tubing opposite valve with tubing pressure neglecting weight of gas column	-	psi
Valve opening pressure	-	psi
Surface operating pressure	-	psi

Table 3.2 Output of intermittent flow gas lift software (cont.).

Output	**Range**	**Unit**
Volume of oil tubing	-	bbl
Space occupied by gas just as starting slug reaches surface	-	bbl
Pressure under slug	-	psi
Average pressure	-	psi
Compressibility factor of gas injection	-	-
Minimum gas required	-	SCF/cycle
Minimum injection gas oil ratio	-	SCF/STB

Table 3.3 Output of sucker rod pump software.

Output	Range	Unit
Pump displacement (bbl/day)	1 – 1,500	bbl
Pump data		
API size	-	Unit
Stroke	-	in
Pump plunger data		
Diameter	-	in
Area	-	sq in
Pump constant	-	bbl/day/in/spm
Tubing data		
Nominal size	-	in
Outside diameter	-	in
Weight	-	lb/ft
Wall area	-	sq in
Sucker rod data		
Rod size	-	in
Area	-	sq in
Weight	-	lb/ft
Pumping speed	-	strokes/min
Section of rod string		
R1/L1	-	-/ft
R2/L2	-	-/ft
R3/L3	-	-/ft

Table 3.3 Output of sucker rod pump software (cont.).

Output	Range	Unit
Acceleration factor	-	-
Effective plunger stroke length	-	in
Probable production rate	-	bbl/day
Dead weight of rod string	-	lb
Fluid load	-	lb
Peak polished rod load/Allowable limit	-	lb/lb
Maximum stress at top of rod string	-	lb
Ideal Counterbalance Effect	-	lb
Peak torque on gear reducer	-	in-lb
Prime mover		
Hydraulic horsepower	-	hp
Friction horsepower	-	hp
Brake horsepower	-	hp
Synchronous Pumping Speed	-	-

Table 3.4 The hot key of module.

Hot key	Function
Alt + E	Electrical submersible pump
Alt + I	Intermittent Flow Gas lift
Alt + S	Sucker rod pump

Table 3.5 The color is related with function.

Color	Function
Orange	Input data: User must carefully input the parameters to white text box that is set in orange frame.
Green	Out put: The step of design, basic facilities and necessary information of each artificial lift is set to show in green frame.
Gray	Command button: This function is operating command button that compose check input, design, save&print, clear and back.
Pink	Help: User is suggested and guided by text in pink label. This text shows using step of the artificial lift's design software which is changed to next text within 4 seconds.

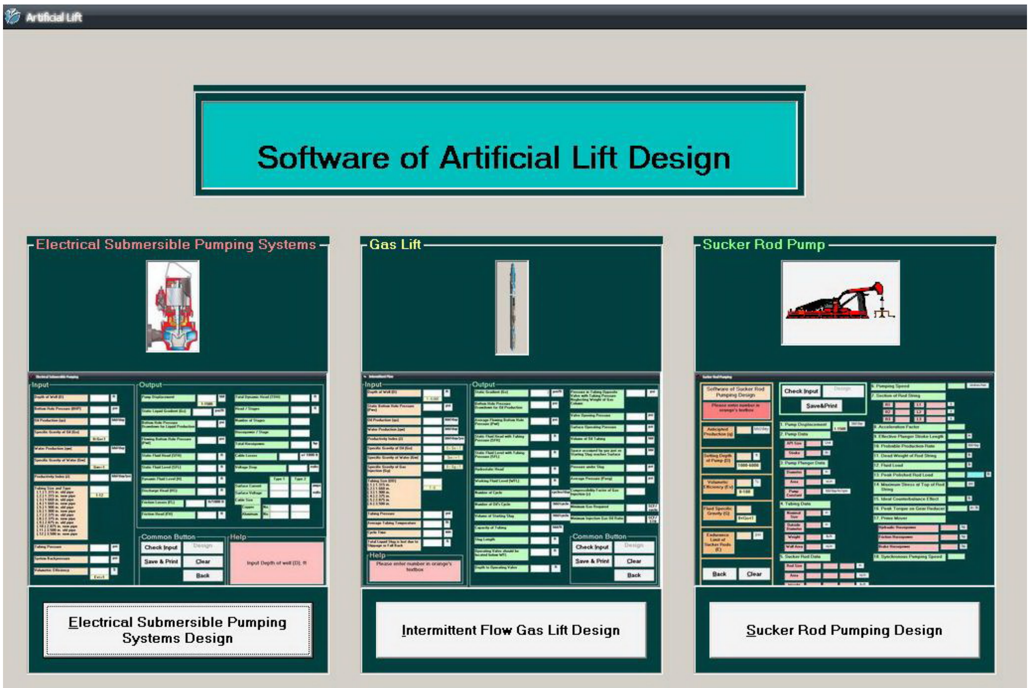

Figure 3.1 The main page of ALOP.

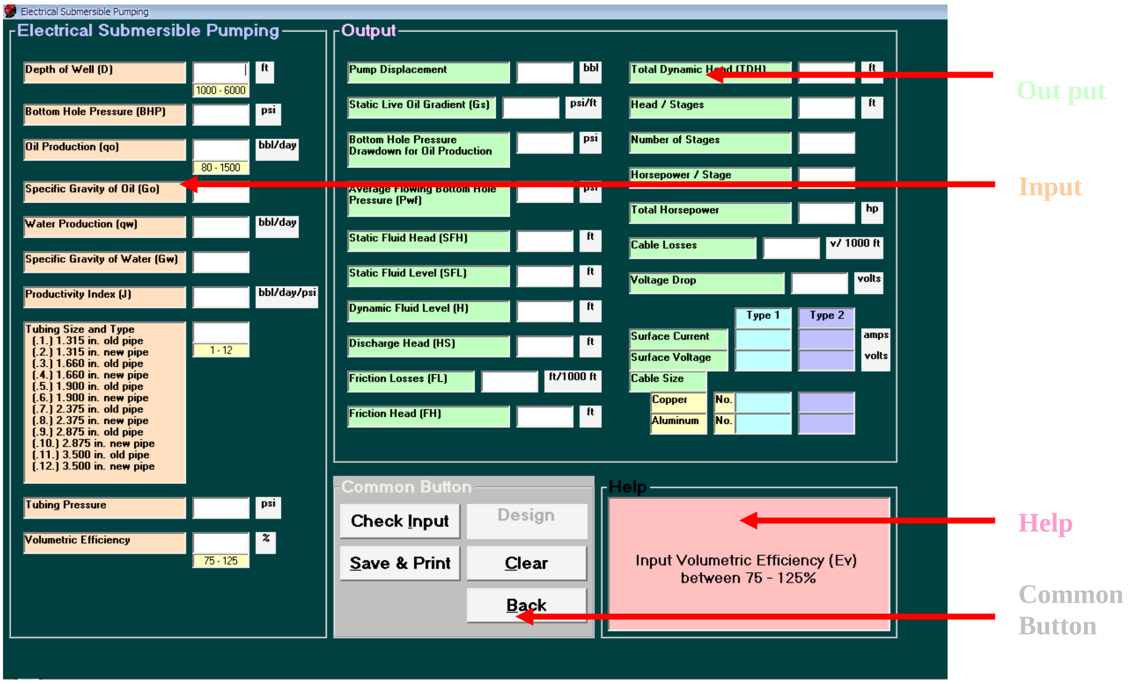

Figure 3.2 Module of ALOP.

3.2.3 Input

In software development, equation, data base and step of design are studied and analyzed for preparation minimum requirement information of each artificial lift system as follow as in Table 3.6.

Table 3.6 Minimum requirement information of each artificial lift system.

Conditions	Parameters	Artificial lift types		
		Eletrical submersible pump	**Intermittent flow gas lift**	**Sucker rod pump**
Production	Oil production (b/d)	/	/	/
	Productivity index	/	/	
	Water production (b/d)	/	/	/
Reservoir	Bottom hole pressure (psi)	/	/	
	Gas oil ratio (SCF/STB)	/	/	/
	Specific gravity of oil	/	/	/
	Specific gravity of water	/	/	/
Well	Depth of well (ft)	/	/	/
	Size, temperature, type and pressure of tubing	/	/	
Other	Cycle time (min)		/	
	Endurance limit (psi)			/
	Liquid slug (%)		/	
	Specific gravity of gas injection		/	
	System Backpressure	/		
	Volumetric efficiency (%)	/		/

3.2.4 Variable declaration

This topic explains variables in this programs that are set for software development. These variables are the input, output, calculation, process and compile. The variables and variable's meaning of software are shown in Appendix B.

3.3.5 Process

1) User must carefully input the parameters to white text box that is set in orange frame.
2) Press check input button, if the software shows massage box "clear and go to design" and then the design button is appeared.
3) Press design button and then the software will compile result of step of design, basic facilities and necessary information of artificial lift system.
4) Press save and print when user want to save and print information of input and output in terms of file or ducements.
5) Press clear button when user want to clear screen.

3.3 Flowchart

The topic shows and explains flowchart that is a step for software development which identifies, step, procedure and compile of software in terms of pictures and symbols as follow as in Appendix B. This process includes input, checking input, calculation, linking data base, checking input and output. These components sometimes work concurrently. The system uses forward chaining strategy. The data are compiled and subjected to rules and conditions to obtain specific answers. This approach is appropriate here because there are numerous different design recommendations at the end while a relative narrow path of input data is derived.

3.4 Programming

The topic shows and explains code of software that includes code of main menu and desings of electrical submersible pump, intermittent flow gas lift and sucker rod pump. In addition, each module includes sub codes that are command of checking input, design, save and print documents, clear screen and back to main menu. Finally, codes of help text in each module are presented in this topic. All codes of ALOP are shown in Appendix B.

3.5 Testing

This topic explains and compares between result of ALOP and manual design. The testing can be divided into 3 sub topic, which testing of electrical submersible pump, intermittent flow gas lift and sucker rod pump.

3.5.1 Testing of electrical submersible pump software

The Table 3.7 and 3.8 show input data and Result of design by using ALOP and manual design respectively.

Table 3.7 Input data of electrical submersible pump software.

Parameters	**Number**	**Unit**
Depth of well	3,715	ft
Bottom hole pressure	750	psi
Oil production	200	bbl/day
Specific gravity of oil	0.828	
Water production	0	bbl/day
Specific gravity of water	1	
Productivity index	2.07	bbl/day/psi
Tubing size & type	2.875	inch, old pipe
Tubing pressure	50	psi
Backpressure	400	psi
Volumetric efficiency	80	%

Table 3.8 Result of design by using ALOP and manual design for case of electrical submersible pump.

Output	**ALOP**	**Manual**
Pump displacement	250	250
Static live oil gradient	0.36	0.36
Bottom hole pressure drawdown for oil production	121	121
Average flowing bottom hole pressure	629	629
Static fluid head	1,944	1.944
Static fluid level	1,771	1.771
Dynamic fluid level	2,107	2,107
Discharge head	1,111	1,111
Friction losses	1.09	1.10
Friction head	4	4
Total dynamic head	3,221	3,221
Head/Stages	53	53
Number of stage	61	61
Horsepower/Stage	1.83	1.80
Total horsepower	111	110
Cable losses	28	28
Voltage drop	104	104
Surface current**:** Type 1/2	46/-	46/-
Surface voltage: Type 1/2	1,404/-	1,404/-
Cable size**:** Type 1 Cu/Al : Type 2 Cu/Al	6/4, -/-	6/4, -/-

3.5.2 Testing of intermittent flow gas lift software

The Table 3.9 and 3.10 show input data and result of design by using ALOP and manual design respectively.

Table 3.9 Input data of Intermittent flow gas lift software.

Parameters	**Number**	**Unit**
Depth of well	3,715	ft
Static bottom hole pressure	750	psi
Oil production	200	bbl/day
Water production	0	bbl/day
Productivity index	2.07	bbl/day/psi
Specific gravity of oil	0.828	-
Specific gravity of water	1	-
Specific gravity of gas injection	0.6	-
Tubing size	2.875	in
Tubing pressure	50	psi
Average tubing temperature	587	°R
Cycle time	15	min
Total liquid slug is lost due to slippage or fall back.	60	%

Table 3.10 Result of design by using ALOP and manual design for case of intermittent flow gas lift.

Output	ALOP	manual design
Static gradient (psi/ft)	0.36	0.36
Bottom hole pressure drawdown (psi)	97	97
Average flowing bottom hole pressure (psi)	653	653
Static fluid head with tubing pressure (ft)	1,944	1,944
Static fluid level with tubing pressure (ft)	1,771	1,771
Hydrostatic head (ft)	268	268
Working fluid level (ft)	2,039	2,039
Number of cycle (cycles/day)	96	96
Number of oil 's cycle (bbl/cycle)	2.08	2.08
Volume of stating slug (bbl/cycle)	3.47	3.47
Capacity of tubing (bbl/ft)	0.00579	0.00579
Slug length (ft)	599	599
Operating valve should be located below Working fluid level (ft)	300	300
Depth to operating valve (ft)	2,339	2,339
Pressure in tubing opposite valve with tubing pressure neglecting weight of gas column (psi)	266	266
Valve opening pressure (psi)	466	466
Surface operating pressure (psi)	442	440
Volume of oil tubing (bbl)	13.54	13.54

Table 3.10 Result of design by using ALOP and manual design for case of intermittent flow gas lift (cont.).

Output	**ALOP**	**manual design**
Space occupied by gas just as starting slug reaches surface (bbl)	10.07	10.07
Pressure under slug (psi)	179	179
Average pressure (psi)	323	323
Compressibility factor of gas injection	0.97	0.97
Minimum gas required (SCF/cycle)	202.79	202.79
Minimum injection gas oil ratio (SCF/STB)	97.50	97.50

3.5.3 Testing of sucker rod pump software

The Table 3.11 and 3.12 show input data and result of design by using ALOP and manual design respectively.

Table 3.11 Input data of suker rod pump software.

Parameters	**Number**	**Unit**
Anticipated production	500	bbl/day
Setting depth of pump	3,715	ft
Specific gravity of oil	0.828	-
Volumetic efficiency	80	%
Endurance limit of sucker rods	30000	psi

Table 3.12 Result of design by using ALOP and manual design for case of sucker rod pump.

Output	ALOP	Manual design
Pump displacement (bbl/day)	250	250
Pump data		
API size (unit)	114	114
Stoke (in)	54	54
Pump plunger data		
Diameter (in)	1 ¾	1 ¾
Area (sq in)	2.405	2.405
Pump constant (bbl/day/in/spm)	0.357	0.357
Tubing data		
Nominal size (in)	2 ½	2 ½
Outside diameter (in)	2.875	2.875
Weight (lb/ft)	6.50	6.50
Wall area (sq in)	1.812	1.812
Sucker rod data		
Rod size (in)	¾	¾
Area (sq in)	0.442	0.442
Weight (lb/ft)	1.63	1.63
Pumping speed (strokes/min)	18.54	18.54

Table 3.12 Result of design by using ALOP and manual design for case of sucker rod pump (cont.).

Output	**ALOP**	**Manual design**
Section of rod string		
R1/L1	1.00/3,715	1.00/3,715
R2/L2	-	-
R3/L3	-	-
Acceleration factor	0.26	0.26
Effective plunger stroke length (in)	45.47	45.47
Probable production rate (bbl/day)	241	241
Dead weight of rod string (lb)	6,055	6,055
Fluid load (lb)	2,565	2,565
Peak polished rod load/Allowable limit (lb/lb)	10,195/13,300	10,195/13,300
Maximum stress at top of rod string (lb)	23,065	23,065
Ideal Counterbalance Effect (lb)	7,020	7,020
Peak terque on gear reducer (in-lb)	95,209	95,209
Prime mover		
Hydraulic horsepower (hp)	5.45	5.45
Friction horsepower (hp)	3.83	3.83
Brake horsepower (hp)	13.92	13.92
Synchronous Pumping Speed	3.44	3.44

3.6 Conclusions

This topic explains how the program is developed. The program can be divided to into three phases, including (1) system shell, (2) system control and (3) data base system. The system shell is used as the program structure.The system control directs the paths and flows of the program. The data base stores the rules and conditions of the artificial lift.

3.6.1 System shell

The ALOP is developed on Microsoft Visual Basic version 6 software. The advantages of Microsoft Visual Basic version 6 are (1) equipped with GUI-Graphical User Interface, (2) ease of application, (3) quick construction, (4) supporting the management data base system and (5) compile of complex calculation.

3.6.2 System control

The main processes for control functions are the decision making, iteration, array and procedure. The main structures of program developments are as follows.

(1) Decision structures

- (i) Two-way decision making; “if…Then…Else”
- (ii) More than two-way decision making; “Select…Case”

(2) Iteration structures

- (i) Known number of interation; “For…Next”
- (ii) Unknown number of interation; “While…When”
- (iii) Unknown number of interation and go out from itration; “Do/While…Unit/Loop”

(3) Array and Dynamic. Array structures are parts of permanent and non-permanent storage data that are used for calculation.

(4) Procedure structure; include

(i) Sub program (sub routine)

(ii) Function (sub function)

3.6.3 Data base system

The data have been compiled and stored in form of Microsoft Access. They can be searched by Data Query Language (SQL) and data control constained Microsoft Visual Basic version 6 software.

3.7 Discussions

The researcher should know about Microsoft visual basic V.6 program because it is easy and convenient to use for software development. Reliability of software development depends on the accuracy of equation and data base of each artificial lift system. The digitized calculation by computer will provide more accurate values and less time of calculation than using the manual calculation. The repeating calculation manually often gives error. The ALOP is the method of compiling program to design the electrical submersible pump, intermittent flow gas lift and sucker rod pump that is similar to the actual by input the data in the software. The ALOP accuracy depends on the quantity and quality of input data. The complete data of Phitsanulok oil field should be collected and used in software so that the results are proximity of the actual performance. Finally, the results of testing between ALOP and manual dsign are satisfactory.

CHAPTER IV

TECHNICAL AND ECONOMIC ANALYSIS

4.1 Introduction

This chapter describes for technical consideration and economic consideration. The technical considerations include the probable applications of artificial lift for oil field in Phitsanulok basin. The economic considerations include basic assumptions, other assumptions, and cash flow table**.**

4.2 Technical considerations

4.2.1 The probable applications of artificial lift for oil field in Phitsanulok basin

The input artificial lift parameters are production, reservoir and well conditions, petroleum engineering requirements as follow as in Table 4.1-4.2. The predictive capability of the proposed system has been verified by comparing with 7 actual wells under Lankrabue oil field as follow as in Table 4.2. There are divided into 21 case studies that comprise 7 cases of electrical submersible pump, 7 cases of Intermittent flow gas lift and 7 cases sucker rod pump for study and analysis result of ALOP as follow as in Table 4.3. The probable applications of artificial lift for oil field in Phitsanulok basin most suitable ranking for intermittent flow gas lift ($q_{o,avg}$ = 181 STB/d), electrical submersible pump ($q_{o,avg}$ = 167 STB/d) and sucker rod pump ($q_{o,avg}$ = 131 STB/d) respectively. The detail, step of design, basic facilities and necessary information for application of each artificial lift system for oil field in Phitsanulok basin are output of the software. The table 4.4-4.6 concludes output of electrical submersible pump, intermittent flow gas lift and suckker rod pump respectively.

Table 4.1 Minimum requirement information of Lankrabue oil field.

Conditions	**Parameters**	**ESP**	**IFGL**	**SRP**
Production	Water production (b/d)	0		
Reservoir	Specific gravity of oil	0.828		
	Specific gravity of water	1.05		
Well	Depth (ft)	3,715		
	System backpressure (psi)	400		
	O.D of Tubing (in)	2.375		
	Tubing temperature (°R)	-	587	-
	Tubing type	New	-	-
	Tubing pressure (psi)	50		-
Other	Cycle Time (min)	-	15	-
	Endurance limit (psi)	-	-	30,000
	Liquid Slug (%)	-	60	-
	Specific gravity of gas injection	-	0.6	-
	Volumetric Efficiency	80	-	80

Table 4.2 Properties of Lankrabue oil field.

Well No.	P (psi)	Rs (SCF/STB)	B_o (bbl/STB)	B_g (cu ft/SCF)	J (b/d/psi)
1	700	251	1.22	0.025	2.07
2	630	235	1.21	0.028	1.70
3	570	221	1.20	0.031	1.38
4	490	172	1.20	0.036	0.27
5	490	171	1.20	0.036	0.24
6	470	167	1.19	0.037	0.16
7	470	167	1.19	0.037	0.15

Table 4.3 Relationship between the artificial lift and Lankrabue oil field.

Well No.	Oil production rate (STB/d)		
	Electrical submersible pump	Intermittent flow gas lift	Sucker rod pump
1	406	342	197
2	334	281	161
3	271	228	134
4	52	130	131
5	47	121	122
6	31	84	88
7	29	80	86
Average	167 (Medium)	181 (Good)	131 (Fair)

Table 4.4 Manufacturers of electrical submersible pump (q_o = 29-406 STB/d).

Output	Range	Unit
Pump displacement	101-507	bbl
Static live oil gradient	0.68	psi/ft
Bottom hole pressure drawdown for oil production	49-245	psi
Average flowing bottom hole pressure	455-651	psi
Static fluid head	956	ft
Static fluid level	2,759	ft
Dynamic fluid level	2,830-3,119	ft
Discharge head	588	ft
Friction losses	0.0001-0.21	ft/1,000 ft
Friction head	0.0004-0.78	ft
Total dynamic head	3,419-3,708	ft
Head/Stages	53.10-53.34	ft
Number of stage	64.09-69.84	-
Horsepower/Stage	1.81-1.86	-
Total horsepower	116-129.90	hp
Cable losses	28	v/1,000 ft
Voltage drop	104.02	volts
Surface current: Type 1/2	68/35	amps
Surface voltage: Type 1/2	1,229/2,374	volts
Cable size: Type 1 Cu/Al : Type 2 Cu/Al	4/2 : 6/4	-

Table 4.5 Manufacturers of intermittent flow gas lift (q_o = 80-342 STB/d).

Output	Range	Unit
Static gradient	0.67-0.85	psi/ft
Bottom hole pressure drawdown	119-322	psi
Average flowing bottom hole pressure	181-378	psi
Static fluid head with tubing pressure	294-970	ft
Static fluid level with tubing pressure	2,744-3,421	ft
Hydrostatic head	140-480	ft
Working fluid level	3,225-3,561	ft
Number of cycle	96	cycles/day
Number of oil 's cycle	0.5-2.9	bbl/cycle
Volume of stating slug	0.83-4.8	bbl/cycle
Capacity of tubing	0.00579	bbl/ft
Slug length	143-834	ft
Operating valve should be located below working fluid level	72-417	ft
Depth to operating valve	3,632-3,642	Ft
Pressure in tubing opposite valve with tubing pressure neglecting weight of gas column	172-609	psi
Valve opening pressure	372-913	psi
Surface operating pressure	341-837	psi

Table 4.5 Manufacturers of intermittent flow gas lift (q_o = 80-342 STB/d) (cont.).

Output	Range	Unit
Volume of oil tubing	21.03-21.09	bbl
Space occupied by gas just as starting slug reaches surface	16.26-20.20	bbl
Pressure under slug		psi
Average pressure	123-386	psi
Compressibility factor of gas injection	248-650	-
Minimum gas required	0.88-0.95	SCF/cycle
Minimum injection gas oil ratio	316-724	SCF/STB

Table 4.6 Manufacturers of sucker rod pump (q_o = 86-197 STB/d).

Output	Range	Unit
Pump displacement (bbl/day)	149-1,049	bbl
Pump data		
API size	57-640	Unit
Stoke	42-144	in
Pump plunger data		
Diameter	1 ¼-2 ½	in
Area	1.227-4.909	sq in
Pump constant	0.182-0.728	bbl/day/in/spm
Tubing data		
Nominal size	2.00-3.00	in

Table 4.6 Manufacturers of sucker rod pump (q_o = 86-197 STB/d) (cont.).

Output	Range	Unit
Outside diameter	2.375-3.50	in
Weight	4.70-9.30	lb/ft
Wall area	1.304-2.59	sq in
Sucker rod data		
Rod size	5/8-1.00	in
Area	0.307-0.785	sq in
Weight	1.16-2.88	lb/ft
Pumping speed	15.285-20.03	strokes/min
Section of rod string		
R1/L1	0.63-0.65/2,350-2,425	
R2/L2	0.35-0.37/1,300-1,375	-/ft
R3/L3	-	-/ft
Acceleration factor	0.24-0.48	-/ft
Effective plunger stroke length	37.76-134.88	-
Dead weight of rod string	4,921-9,014	in
Fluid load	1,091-5,467	lb
Peak polished rod load/Allowable limit	7,192-18,808/10,900-25,600	lb/lb
Maximum stress at top of rod string	16,273-23,959	lb
Ideal Counterbalance Effect	5,213-11,284	lb
Peak torque on gear reducer	47,047-582,334	in-lb

Table 4.6 Manufacturers of sucker rod pump (q_o = 86-197 STB/d) (cont.).

Output	Range	Unit
Prime mover		
Hydraulic horsepower	2.44-26.58	hp
Friction horsepower	2.61-12.52	hp
Brake horsepower	7.57-58.65	hp
Synchronous Pumping Speed	3.18-4.18	-

4.2.2 Relationship between artificial lift and controlling factor for oil field in Phitsanulok basin

This topic describes result of the ALOP under the controlling factor. These factors are bottom hole pressure and gas oil ratio, productivity index, size of tubing and variable rate. There are divided into 78 case studies that comprise a case of natural flow, 21 cases of bottom hole pressure and gas oil ratio, 21 cases of productivity index and 15 cases of size of tubing, and 21 cases of variable rate. The bottom hole pressure and gas liquid ratios, productivity index, size of tubing and variable rates are the controlling factors in the selection of the method of lift, which are divided into 2 cases (low and high) for study and analysis result of ALOP as follow as in Table 4.7. This topic includes 5 sub topics that are result of ALOP for case of natural flow, bottom hole pressure and gas oil ratio, productivity index, size of tubing, variable rate, and design of artificial lift system.

Table 4.7 Type of the controlling factors.

Controlling factors	Unit	Low/Small	High/Large
Gas liquid ratio	SCF/STB	< 150	> 150
Pressure	psi	< 250	> 250
Productivity index	b/d/psi	< 1	> 1
Out side diameter of tubing	inch	1.315, 1.660, 1.900 and 2.375	2.875 and 3.500
Variable rates	b/d	1–100	100–500

4.2.2.1 Technical consideration for case of natural flow

The exploration and production periods are divided into 4 years of exploration period and 21 years of production period. This study will be early production on the 5th year of investment as follow as in Table 4.8. The total production wells are 25. The original oil inplace of this study is 109 MMbbl.

Table 4.8 Production life of natural flow.

Year.	Production rate (b/d/well)	Year.	Production rate (b/d/well)
5	400	15	38
6	400	16	34
7	401	17	31
8	400	18	28
9	387	19	25
10	208	20	23
11	100	21	21
12	68	22	20
13	54	23	18
14	44	24	17
		25	16

4.2.2.2 Technical consideration in term of bottom hole pressure and gas oil ratio

The bottom hole pressure and gas oil ratio influences the selection of artificial lift equipment and the design of the lifting mechanism. There are divided into a 21 case for technical consideration in term of the bottom hole pressure and gas oil ratio. Figure 4.1 describes relationship between bottom hole pressure and gas oil ratio. Table 4.9 and Figure 4.2-4.3 describes relationship between the artificial lift (electrical submersible pump, intermittent flow gas lift and sucker rod pump) and controlling factors (bottom hole pressure and gas oil ratio) in term of oil production rate. In case of high gas oil ratio (> 150 SCF/STB) and high pressure (> 250 psi), the intermittent flow gas lift is capable of producing the most fluid from the well more than electrical submersible pump and sucker rod pump. In case of low gas oil ratio (< 150 SCF/STB) and low pressure (< 250 psi), the electrical submersible pump is capable of producing the most fluid from the well more than sucker rod pump and intermittent flow gas lift. Table 4.10 concludes selection of artificial lift's technique in term of bottom hole pressure and gas oil ratio.

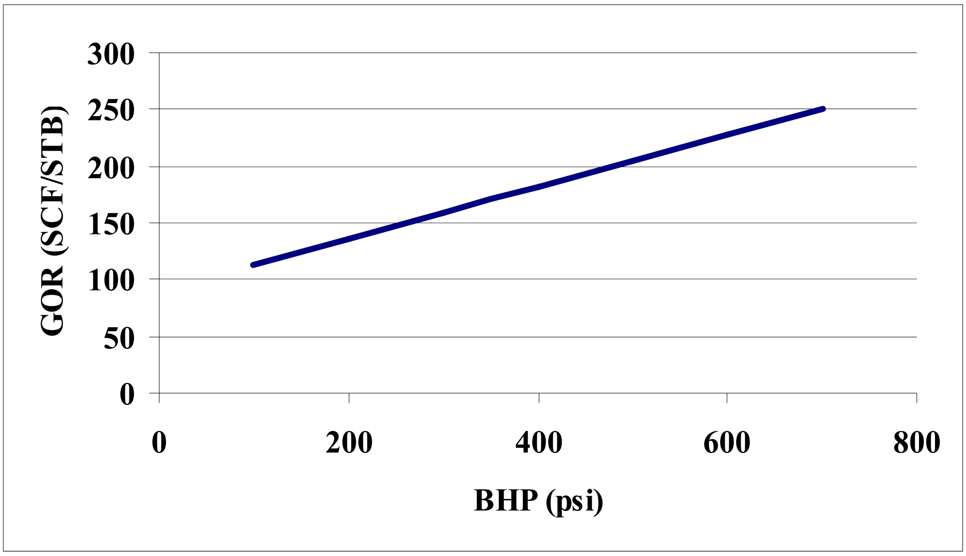

Figure 4.1 Relationship between bottom hole pressure and gas oil ratio.

Table 4.9 Relationship between the artificial lift and bottom hole pressure and gas oil ratio.

Bottom hole pressure (psi)	Gas oil ratio (SCF/STB)	Oil production rate (STB/d)		
		Electrical submersible pump	Intermittent flow gas lift	Sucker rod pump
700	251	246	300	56
600	228	191	219	49
500	205	139	146	42
400	182	93	85	34
300	159	53	39	26
200	136	24	10	18
100	113	1	-	10

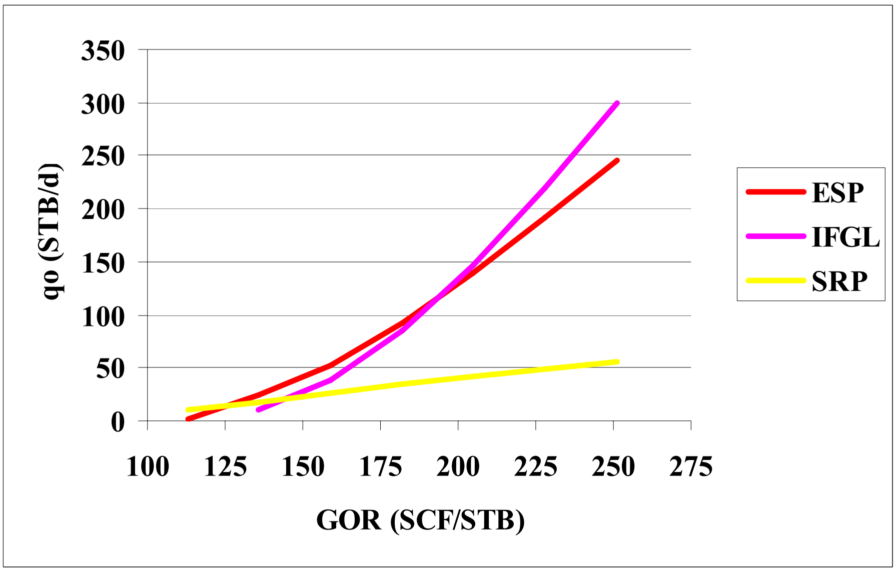

Figure 4.2 Relationship between gas oil ratio and artificial lift.

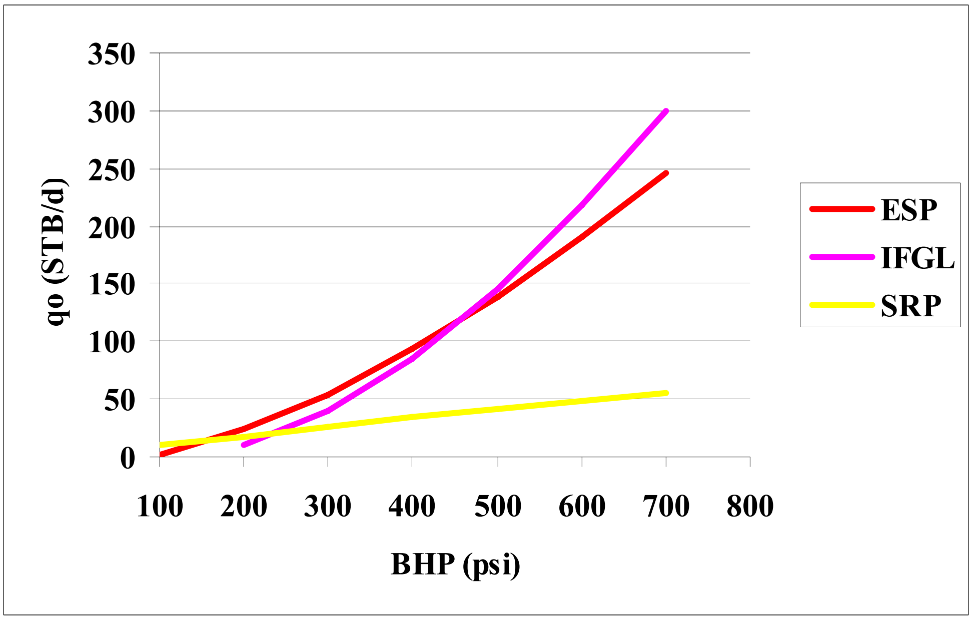

Figure 4.3 Relationship between bottom hole pressure and artificial lift.

Table 4.10 Selection of artificial lift's technique in term of bottom hole pressure and gas oil ratio.

Type	**Low gas oil ratio and low bottom hole pressure (<150 SCF/STB and < 250 psi)**	**High gas oil ratio and High bottom hole pressure (>150 SCF/STB and > 250 psi)**
Electrical submersible pump	Medium	Medium
Intermittent flow gas lift	Fair	Good
Sucker rod pump	Good	Fair

4.2.2.3 Technical consideration in term of productivity index

The productivity index influences the selection of artificial lift equipment and the design of the lifting mechanism. There are divided into a 21 case for technical consideration in term of the productivity index. The bottom hole pressure (100 psi), depth (3,715 ft), gas oil ratio (113 SCF/STB), and horsepower (159 hp) are controlling conditions under case of low productivity index (controlling factor). The bottom hole pressure (500 psi), depth (3,715 ft), gas oil ratio (205 SCF/STB), and horsepower (216 hp) are controlling conditions under case of high productivity index (controlling factor). Table 4.11 and Figure 4.4-4.5 describes relationship between the artificial lift (electrical submersible pump, intermittent flow gas lift and sucker rod pump) and controlling factors (productivity index) in term of oil production rate. In case of high productivity index (> 1 b/d/psi), the electrical submersible pump is capable of producing the most fluid from the well more than intermittent flow gas lift and sucker rod pump. In case of low productivity index (< 1 b/d/psi), the sucker rod pump is capable of producing the most fluid from the well more than intermittent flow gas lift and electrical submersible pump. Table 4.12 concludes selection of artificial lift's technique in term of productivity index.

Table 4.11 Relationship between the artificial lift and productivity index.

Productivity index (b/d/psi)	Oil production rate (STB/d)		
	Electrical submersible pump	Intermittent flow gas lift	Sucker rod pump
2.07	406	386	332
1.70	334	323	300
1.38	271	271	271
0.27	52	103	133
0.24	47	85	107
0.16	31	37	39
0.15	29	29	29

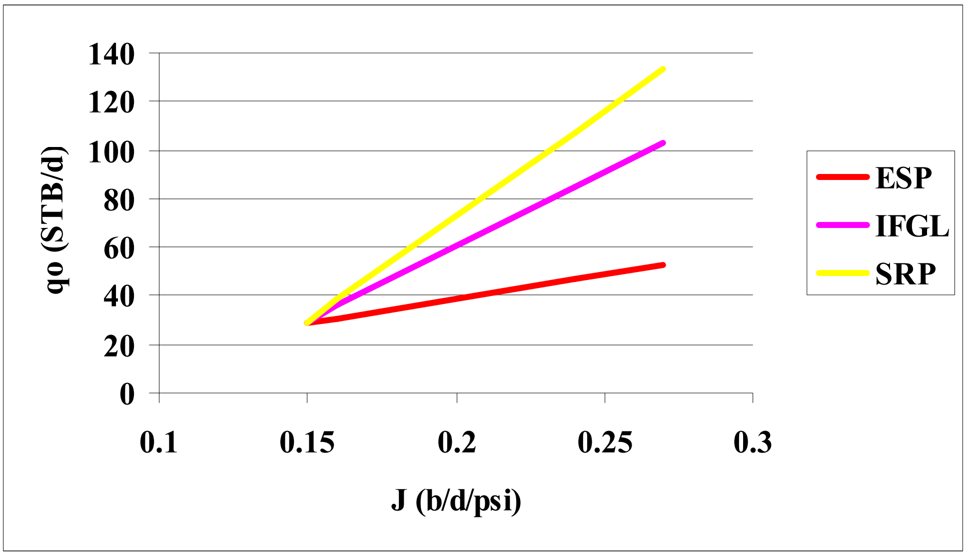

Figure 4.4 Relationship between low productivity index and artificial lift.

Figure 4.5 Relationship between high productivity index and artificial lift.

Table 4.12 Selection of artificial lift's technique in term of productivity index.

Type	**Productivity index**	
	Low (<1 b/d/psi)	**High (>1 b/d/psi)**
Electrical submersible pump	Fair	Good
Intermittent flow gas lift	Medium	Medium
Sucker rod pump	Good	Fair

4.2.2.4 Technical consideration in term of size of tubing

The size of tubing influences the selection of artificial lift equipment and the design of the lifting mechanism. There are divided into a 21 case for technical consideration in term of the size of tubing. Table 4.13 and Figure 4.6-4.7 describes relationship between the artificial lift (electrical submersible pump, intermittent flow gas lift and sucker rod pump) and controlling factors (size of tubing) in term of oil production rate. In case of large size of tubing (2.875–3.500 inch), the sucker rod pump is capable of producing the most fluid from the well more than intermittent flow gas lift and electrical submersible pump. In case of small size of tubing (1.315–2.375 inch), the electrical submersible pump is capable of producing the most fluid from the well more than intermittent flow gas lift and sucker rod pump Table 4.14 concludes selection of artificial lift's technique in term of size of tubing. The bottom hole pressure (100 psi), depth (3,715 ft), gas oil ratio (113 SCF/STB), and horsepower (159 hp) are controlling conditions under case of low productivity index (controlling factor). The bottom hole pressure (500 psi), depth (3,715 ft), gas oil ratio (205 SCF/STB), and horsepower (216 hp) are controlling conditions under case of high productivity index (controlling factor).

Table 4.13 Relationship between the artificial lift and size of tubing.

Size of tubing (inch)	**Oil production rate (STB/d)**		
	Electrical submersible pump	**Intermittent flow gas lift**	**Sucker rod pump**
1.315	17	5	-
1.660	23	12	-
1.900	26	16	-
2.375	28	23	17
2.875	29	29	29
3.500	29	44	51

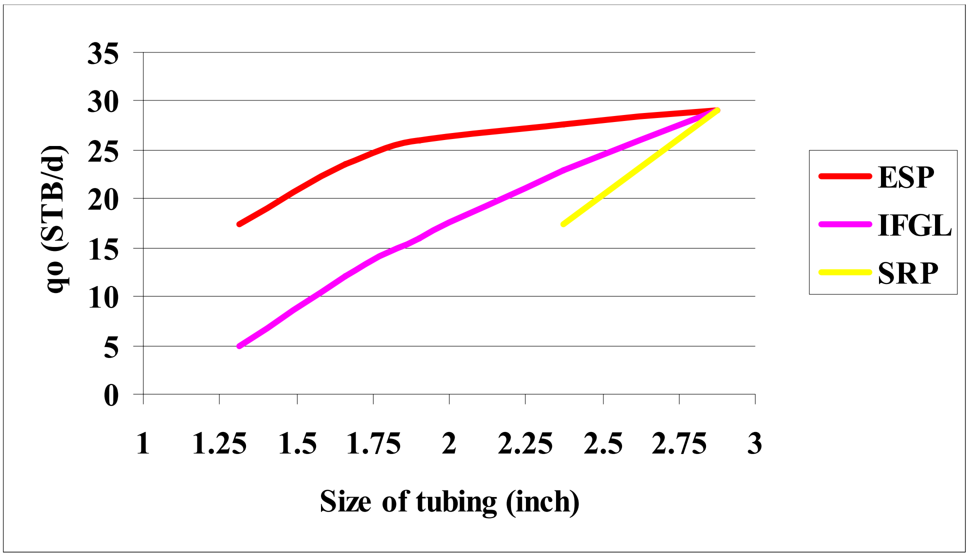

Figure 4.6 Relationship between small size of tubing and artificial lift.

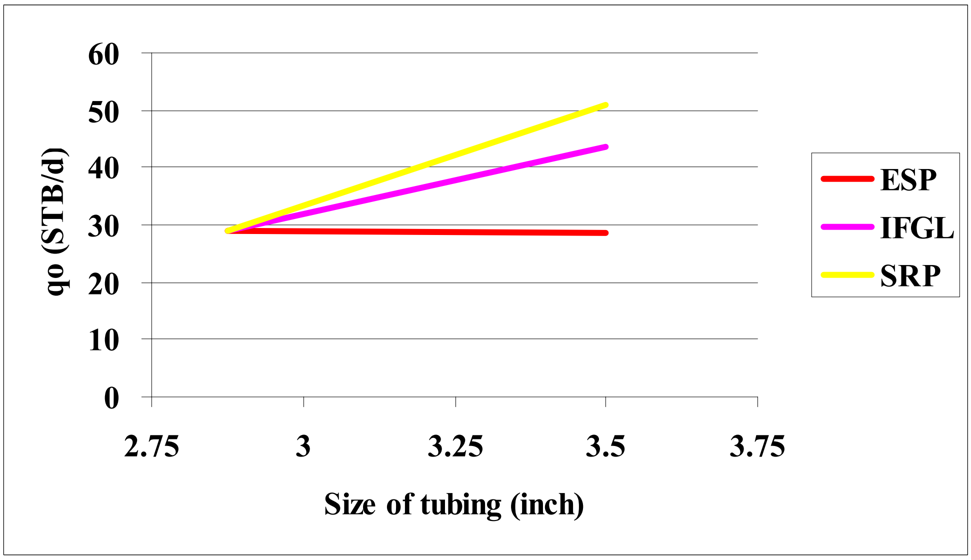

Figure 4.7 Relationship between large size of tubing and artificial lift.

Table 4.14 Selection of artificial lift's technique in term of size of tubing.

Type	**Size of tubing**	
	Small (1.315 – 2.375 inch)	**Large (2.875 – 3.500 inch)**
Electrical submersible pump	Good	Fair
Intermittent flow gas lift	Medium	Medium
Sucker rod pump	Fair	Good

4.2.5 Technical consideration in term of variable rate

The variable rate influences the selection of artificial lift equipment and the design of the lifting mechanism. There are divided into a 21 case for technical consideration in term of the variable rate. The horsepower (100±20 hp) are controlling conditions Figure 4.8 describes relationship between the artificial lift (electrical submersible pump, intermittent flow gas lift and sucker rod pump) and controlling factors (variable rate) in term of oil production rate. The intermittent flow gas lift is capable of producing the most fluid from the well more than sucker rod pump and electrical submersible pump. Table 4.15 concludes selection of artificial lift's technique in term of variable rates.

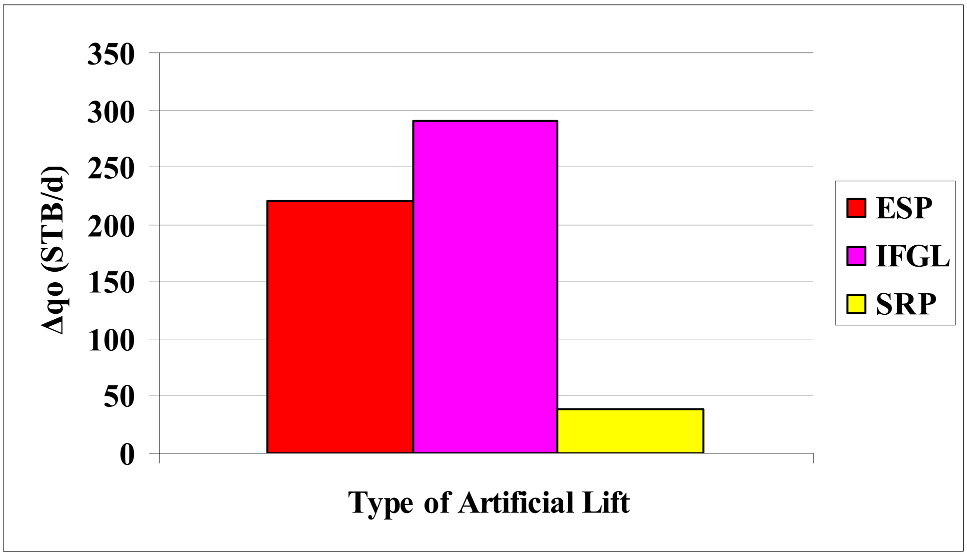

Figure 4.8 Relationship between variable rate and artificial lift.

Table 4.15 Selection of artificial lift's technique in term of variable rate.

Type	Variable rate (b/d)
Electrical submersible pump	Medium
Intermittent flow gas lift	Good
Sucker rod pump	Fair

4.3 Economic considerations

The objective is to determine the pay back period, net present value, profit investment ratio and internal rate of return for analyzing and estimating in all cases study. The exploration period and production region under the Petroleum Acts "Thailand III" statute are divided into 3 years of exploration period and 20 years of production period. This study will be early production on the 4th year of investment. The total exploration and production period is 23 years that are divided in this study into 3 years for exploration and 20 years for production. The work plan will be this following schedule.

1st year @ 2008: Petroleum concession

2nd year @ 2008: Geological and geophysical survey

3rd year @ 2008: Drill exploration, appraisal and production wells

4th year @ 2008: Production

The petroleum economic studies under the concession system and petroleum economics evaluation of Thailand III (Department of Mineral Resource, 1999) has assumptions and details that into basic assumptions add other assumption cost.

4.3.1 Basic assumptions

a.	Number of exploration, appraisal and production wells	25
b.	Oil in place (MMbbl)	109
c.	Exchange rate (Baht to US$)	33
d.	Income tax (%)	50
e.	Escalation factor (%)	2
f.	Discount rate (%)	10
g.	Tangible cost (%)	20
h.	Intangible cost (%)	80
i.	Depreciation of tangible cost (%)	20

j. Sliding scale royalty

Production level (b/d)	Rate (%)
0–2,000	5.00
2,000–5,000	6.25
5,000–10,000	10.00
10,000–20,000	12.50
>20,000	15.00

4.3.2 Other assumptions

a. The oil price is constant over the contact.

b. Increasing rate of capital expenditure comes from the price increasing of machinery and equipment used in oil industries, and given to two percent per year.

c. Discount rate of money is 10.00 percent (Siam Commercial Bank, January 2008).

d. Operating cost is escalated 2 percent each year forward.

e. The first production is conduct in the five years of work plan.

f. The expense used in cash flow analysis is estimated as follow:

1) Capital cost (MMMBaht) 17.18

- Geological and geophysical survey
- Well drilling and completion exploration wells
- Well drilling, completion appraisal well and well stimulation

- Well drilling, completion production well and well stimulation
- Pipeline
- Processing production facilities
- Special bonus

2) Operating cost (Baht/bbl) 840

3) Facilities and maintenances cost

(MMbaht/well and MMbaht/well/year)

- Electrical submersible pump 17.20 and 3.40
- Intermittent flow gas lift 12.25 and 2.94
- Sucker rod pump 6.30 and 2.66

4) Oil price (US$ / bbl) 80

4.3.3 Cash flow table

The economic considerations are determined and analyzed by using Microsoft Excels 2003. The predictive capability of the proposed system has been verified by comparing with 7 actual wells under Lankrabue oil field. There are divided into 115 case studies that comprise a case of natural flow, 21 cases of bottom hole pressure and gas oil ratio, 21 cases of productivity index and 15 cases of size of tubing, and 57 cases of variable rate as follow as in Table 4.5, 4.7 and 4.9. There are presented into 4 cases in this topic as follow as in Table 4.16-4.19 that include a case of natural flow, electrical submersible pump, intermittent flow gas lift and sucker rod pump. The table 4.20 shows economic evaluation in all cases study.

Table 4.16 Economic analysis for natural flow.

No. of Year	Year	Oil production total (bbl/year)	Income (Baht)	Royalty sliding scale (Baht)	2% Escal Factor	Investment cost: Concession (Baht)	Geological and geophysical surveys (Baht)	Exploration and apprisal wells (Baht)	No. of production wells	Production wells (Baht) INTANG	Production wells (Baht) TANG	Pipelines and processing production facilities (Baht)
0	2006											
1	2007				1.0000	210,000,000						
2	2008				1.0200		280,000,000					
3	2009				1.0404			588,000,000	25	1,680,000,000	420,000,000	14,000,000,000
4	2010	3,650,000	9,636,000,000	963,600,000	1.0612				0	0	0	0
5	2011	3,650,000	9,636,000,000	963,600,000	1.0824				0	0	0	0
6	2012	3,660,000	9,662,400,000	1,207,800,000	1.1041				0	0	0	0
7	2013	3,650,000	9,636,000,000	963,600,000	1.1262				0	0	0	0
8	2014	3,528,544	9,315,356,160	931,535,616	1.1487				0	0	0	0
9	2015	1,900,990	5,018,613,600	501,861,360	1.1717				0	0	0	0
10	2016	916,148	2,418,630,720	151,164,420	1.1951				0	0	0	0
11	2017	623,042	1,644,830,880	82,241,544	1.2190				0	0	0	0
12	2018	490,992	1,296,218,880	64,810,944	1.2434				0	0	0	0
13	2019	404,050	1,066,692,000	53,334,600	1.2682				0	0	0	0
14	2020	350,086	924,227,040	46,211,352	1.2936				0	0	0	0
15	2021	312,034	823,769,760	41,188,488	1.3195				0	0	0	0
16	2022	281,090	742,077,600	37,103,880	1.3459				0	0	0	0
17	2023	253,770	669,952,800	33,497,640	1.3728				0	0	0	0
18	2024	230,668	608,963,520	30,448,176	1.4002				0	0	0	0
19	2025	210,088	554,632,320	27,731,616	1.4282				0	0	0	0
20	2026	193,104	509,794,560	25,489,728	1.4568				0	0	0	0
21	2027	178,236	470,543,040	23,527,152	1.4859				0	0	0	0
22	2028	165,608	437,205,120	21,860,256	1.5157				0	0	0	0
23	2029	153,684	405,725,760	20,286,288	1.5460				0	0	0	0
		20,039,534	52,904,369,760	5,531,996,976		210,000,000	280,000,000	588,000,000		0	0	0

Table 4.16 Economic analysis for natural flow (cont.).

No. of Year	Year	Oil production total (bbl/year)	Income (Baht)	Depreciation (20%) Tangible Expense (Baht)		Investment cost		Taxable income (Baht)	Income tax (Baht)	Annual cash flow (Baht)	Discounted cash flow (Baht)
						Operation cost (840 Baht/bbl)	Total allow expense (Baht)				
0	2006			2011	2015						
1	2007						210,000,000	-210,000,000	0	-210,000,000	-210,000,000
2	2008						280,000,000	-280,000,000	0	-280,000,000	-280,000,000
3	2009			2,884,000,000			5,152,000,000	-5,152,000,000	0	-5,152,000,000	-5,152,000,000
4	2010	3,650,000	9,636,000,000			3,253,663,728	7,101,263,728	2,534,736,272	0	2,534,736,272	1,731,258,980
5	2011	3,650,000	9,636,000,000			3,318,737,003	7,166,337,003	2,469,662,997	0	2,469,662,997	1,533,466,416
6	2012	3,660,000	9,662,400,000			3,394,386,021	7,486,186,021	2,176,213,979	769,306,624	1,406,907,355	794,162,524
7	2013	3,650,000	9,636,000,000		2,884,000,000	3,452,813,977	7,300,413,977	2,335,586,023	1,167,793,011	1,167,793,011	599,262,464
8	2014	3,528,544	9,315,356,160			3,404,677,853	4,336,213,469	4,979,142,691	2,489,571,345	2,489,571,345	1,161,403,406
9	2015	1,900,990	5,018,613,600			1,870,942,724	2,372,804,084	2,645,809,516	1,322,904,758	1,322,904,758	561,040,757
10	2016	916,148	2,418,630,720			919,700,600	1,070,865,020	1,347,765,700	673,882,850	673,882,850	259,811,011
11	2017	623,042	1,644,830,880			637,967,166	720,208,710	924,622,170	462,311,085	462,311,085	162,037,215
12	2018	490,992	1,296,218,880			512,808,944	577,619,888	718,598,992	359,299,496	359,299,496	114,483,892
13	2019	404,050	1,066,692,000			430,443,802	483,778,402	582,913,598	291,456,799	291,456,799	84,424,653
14	2020	350,086	924,227,040			380,413,799	426,625,151	497,601,889	248,800,944	248,800,944	65,517,065
15	2021	312,034	823,769,760			345,846,679	387,035,167	436,734,593	218,367,297	218,367,297	52,275,395
16	2022	281,090	742,077,600			317,780,510	354,884,390	387,193,210	193,596,605	193,596,605	42,132,262
17	2023	253,770	669,952,800			292,632,336	326,129,976	343,822,824	171,911,412	171,911,412	34,011,756
18	2024	230,668	608,963,520			271,312,346	301,760,522	307,202,998	153,601,499	153,601,499	27,626,580
19	2025	210,088	554,632,320			252,048,214	279,779,830	274,852,490	137,426,245	137,426,245	22,470,289
20	2026	193,104	509,794,560			236,305,494	261,795,222	247,999,338	123,999,669	123,999,669	18,431,761
21	2027	178,236	470,543,040			222,473,429	246,000,581	224,542,459	112,271,230	112,271,230	15,171,275
22	2028	165,608	437,205,120			210,845,436	232,705,692	204,499,428	102,249,714	102,249,714	12,560,966
23	2029	153,684	405,725,760			199,577,565	219,863,853	185,861,907	92,930,953	92,930,953	10,378,358
		20,039,534	52,904,369,760			18,695,221,307	41,405,218,283	11,499,151,477	5,749,575,739	5,749,575,739	738,594,547

Table 4.17 Economic analysis for electrical submersible.

No. of Year	Year	Oil production total (bbl/year)	Income (Baht)	Royalty sliding scale (Baht)	2% Escal Factor	Investment cost					
						Concession (Baht)	Geological and geophysical surveys (Baht)	Exploration and apprisal wells (Baht)	No. of production wells	Production wells (Baht)	
										INTANG	TANG
0	2006										
1	2007				1.0000	210,000,000					
2	2008				1.0200		280,000,000				
3	2009				1.0404			588,000,000	25	1,680,000,000	420,000,000
4	2010	3,650,000	9,636,000,000	963,600,000	1.0612				0	0	0
5	2011	3,650,000	9,636,000,000	963,600,000	1.0824				0	0	0
6	2012	3,660,000	9,662,400,000	1,207,800,000	1.1041				0	0	0
7	2013	3,650,000	9,636,000,000	963,600,000	1.1262				0	0	0
8	2014	3,528,544	9,315,356,160	931,535,616	1.1487				0	0	0
9	2015	2,472,875	6,528,390,000	652,839,000	1.1717				25	0	0
10	2016	2,472,875	6,528,390,000	652,839,000	1.1951				0	0	0
11	2017	2,472,875	6,528,390,000	652,839,000	1.2190				0	0	0
12	2018	2,472,875	6,528,390,000	652,839,000	1.2434				0	0	0
13	2019	2,472,875	6,528,390,000	652,839,000	1.2682				0	0	0
14	2020	2,472,875	6,528,390,000	652,839,000	1.2936				0	0	0
15	2021	2,472,875	6,528,390,000	652,839,000	1.3195				0	0	0
16	2022	2,472,875	6,528,390,000	652,839,000	1.3459				0	0	0
17	2023	2,472,875	6,528,390,000	652,839,000	1.3728				0	0	0
18	2024	2,472,875	6,528,390,000	652,839,000	1.4002				0	0	0
19	2025	2,472,875	6,528,390,000	652,839,000	1.4282				0	0	0
20	2026	2,472,875	6,528,390,000	652,839,000	1.4568				0	0	0
21	2027	2,472,875	6,528,390,000	652,839,000	1.4859				0	0	0
22	2028	2,472,875	6,528,390,000	652,839,000	1.5157				0	0	0
23	2029	2,472,875	6,528,390,000	652,839,000	1.5460				0	0	0
		55,231,669	145,811,606,160	14,169,881,616		0	0	0	25	1,680,000,000	420,000,000

Table 4.17 Economic analysis for electrical submersible pump (cont.).

	Depreciation (20%) Tangible Expense (Baht)		Investment cost						
Pipelines and processing production facilities (Baht)	2009	2019	Operation cost (840 Baht/bbl)	Maintanence cost of electrical submersible pump (3.40 MMBaht/well/year)	Total allow expense (Baht)	Taxable income (Baht)	Income tax (Baht)	Annual cash flow (Baht)	Discounted cash flow (Baht)
					210,000,000	-210,000,000	0	-210,000,000	-190,909,091
					280,000,000	-280,000,000	0	-280,000,000	-231,404,959
14,000,000,000	2,884,000,000				5,152,000,000	-5,152,000,000	0	-5,152,000,000	-3,870,773,854
0			4,067,079,660	0	7,914,679,660	1,721,320,340	0	1,721,320,340	1,175,684,953
0			4,148,421,253	0	7,996,021,253	1,639,978,747	0	1,639,978,747	1,018,297,773
0			4,242,982,527	0	8,334,782,527	1,327,617,473	0	1,327,617,473	749,405,453
0			4,316,017,472	0	8,163,617,472	1,472,382,528	259,649,544	1,212,732,984	622,323,776
0			4,255,847,316	0	5,187,382,932	4,127,973,228	2,063,986,614	2,063,986,614	962,864,988
0			3,042,235,551	99,591,047	3,880,665,599	2,647,724,401	1,323,862,201	1,323,862,201	561,446,806
0			3,103,080,262	101,582,868	3,943,502,131	2,584,887,869	1,292,443,935	1,292,443,935	498,293,086
0			3,165,141,868	103,614,526	4,007,595,393	2,520,794,607	1,260,397,303	1,260,397,303	441,761,566
0			3,228,444,705	105,686,816	4,072,970,521	2,455,419,479	1,227,709,739	1,227,709,739	391,186,158
0		86,000,000	3,293,013,599	107,800,553	4,139,653,152	2,388,736,848	1,194,368,424	1,194,368,424	345,965,989
0			3,358,873,871	109,956,564	4,121,669,435	2,406,720,565	1,203,360,283	1,203,360,283	316,882,373
0			3,426,051,349	112,155,695	4,191,046,043	2,337,343,957	1,168,671,978	1,168,671,978	279,770,780
0			3,494,572,375	114,398,809	4,261,810,184	2,266,579,816	1,133,289,908	1,133,289,908	246,636,903
0			3,564,463,823	116,686,785	4,333,989,608	2,194,400,392	1,097,200,196	1,097,200,196	217,075,210
0			3,635,753,099	119,020,521	4,407,612,620	2,120,777,380	1,060,388,690	1,060,388,690	190,720,227
0			3,708,468,161	121,400,931	4,482,708,092	2,045,681,908	1,022,840,954	1,022,840,954	167,242,669
0			3,782,637,525	123,828,950	4,559,305,474	1,969,084,526	984,542,263	984,542,263	146,345,934
0			3,858,290,275	126,305,529	4,637,434,804	1,890,955,196	945,477,598	945,477,598	127,762,928
0			3,935,456,081	128,831,639	4,717,126,720	1,811,263,280	905,631,640	905,631,640	111,253,201
0			4,014,165,202	131,408,272	4,798,412,474	1,729,977,526	864,988,763	864,988,763	96,600,352
14,000,000,000			73,640,995,976	1,722,269,504	102,151,986,095	38,017,620,065	19,008,810,032	19,008,810,032	4,374,433,219

Table 4.18 Economic analysis for electrical intermittent flow gas lift.

No. of Year	Year	Oil production total (bbl/year)	Income (Baht)	Royalty sliding scale (Baht)	2% Escal Factor	Investment cost				Production wells (Baht)		
						Concession (Baht)	Geological and geophysical surveys (Baht)	Exploration and apprisal wells (Baht)	No. of production wells	INTANG	TANG	Pipelines and processing production facilities (Baht)
0	2006											
1	2007				1.0000	210,000,000						
2	2008				1.0200		280,000,000					
3	2009				1.0404			588,000,000	25	1,680,000,000	420,000,000	14,000,000,000
4	2010	3,650,000	9,636,000,000	963,600,000	1.0612				0	0	0	0
5	2011	3,650,000	9,636,000,000	963,600,000	1.0824				0	0	0	0
6	2012	3,660,000	9,662,400,000	1,207,800,000	1.1041				0	0	0	0
7	2013	3,650,000	9,636,000,000	963,600,000	1.1262				0	0	0	0
8	2014	3,528,544	9,315,356,160	931,535,616	1.1487				0	0	0	0
9	2015	2,080,500	5,492,520,000	549,252,000	1.1717				25	0	0	0
10	2016	2,080,500	5,492,520,000	549,252,000	1.1951				0	0	0	0
11	2017	2,080,500	5,492,520,000	549,252,000	1.2190				0	0	0	0
12	2018	2,080,500	5,492,520,000	549,252,000	1.2434				0	0	0	0
13	2019	2,080,500	5,492,520,000	549,252,000	1.2682				0	0	0	0
14	2020	2,080,500	5,492,520,000	549,252,000	1.2936				0	0	0	0
15	2021	2,080,500	5,492,520,000	549,252,000	1.3195				0	0	0	0
16	2022	2,080,500	5,492,520,000	549,252,000	1.3459				0	0	0	0
17	2023	2,080,500	5,492,520,000	549,252,000	1.3728				0	0	0	0
18	2024	2,080,500	5,492,520,000	549,252,000	1.4002				0	0	0	0
19	2025	2,080,500	5,492,520,000	549,252,000	1.4282				0	0	0	0
20	2026	2,080,500	5,492,520,000	549,252,000	1.4568				0	0	0	0
21	2027	2,080,500	5,492,520,000	549,252,000	1.4859				0	0	0	0
22	2028	2,080,500	5,492,520,000	549,252,000	1.5157				0	0	0	0
23	2029	2,080,500	5,492,520,000	549,252,000	1.5460				0	0	0	0
		49,346,044	130,273,556,160	12,719,663,616		0	0	0	25	1,680,000,000	420,000,000	14,000,000,000

Table 4.18 Economic analysis for electrical intermittent flow gas lift (cont.).

IFGL	Depreciation (20%) Tangible Expense (Baht)		Investment cost						
Facilities (12.25 MMBaht/well)	2009	2019	Operation cost (840 Baht/bbl)	Maintanence cost of intermittent flow gas lift (2.66 MMBaht/well/ year)	Total allow expense (Baht)	Taxable income (Baht)	Income tax (Baht)	Annual cash flow (Baht)	Discounted cash flow (Baht)
					210,000,000	-210,000,000	0	-210,000,000	-190,909,091
					280,000,000	-280,000,000	0	-280,000,000	-231,404,959
0	2,884,000,000				5,152,000,000	-5,152,000,000	0	-5,152,000,000	-3,870,773,854
0			4,067,079,660	0	7,914,679,660	1,721,320,340	0	1,721,320,340	1,175,684,953
0			4,148,421,253	0	7,996,021,253	1,639,978,747	0	1,639,978,747	1,018,297,773
0			4,242,982,527	0	8,334,782,527	1,327,617,473	0	1,327,617,473	749,405,453
0			4,316,017,472	0	8,163,617,472	1,472,382,528	259,649,544	1,212,732,984	622,323,776
0			4,255,847,316	0	5,187,382,932	4,127,973,228	2,063,986,614	2,063,986,614	962,864,988
306,250,000			2,559,519,209	77,915,349	3,247,936,558	2,244,583,442	1,122,291,721	1,122,291,721	475,961,246
0			2,610,709,593	79,473,656	3,300,685,249	2,191,834,751	1,095,917,375	1,095,917,375	422,523,590
0			2,662,923,785	81,063,129	3,354,488,914	2,138,031,086	1,069,015,543	1,069,015,543	374,683,426
0			2,716,182,261	82,684,392	3,409,368,653	2,083,151,347	1,041,575,674	1,041,575,674	331,878,109
0		61,250,000	2,770,505,906	84,338,079	3,465,345,986	2,027,174,014	1,013,587,007	1,013,587,007	293,600,052
0			2,825,916,024	86,024,841	3,461,192,865	2,031,327,135	1,015,663,567	1,015,663,567	267,455,961
0			2,882,434,345	87,745,338	3,519,431,683	1,973,088,317	986,544,159	986,544,159	236,170,828
0			2,940,083,032	89,500,244	3,578,835,276	1,913,684,724	956,842,362	956,842,362	208,236,776
0			2,998,884,692	91,290,249	3,639,426,942	1,853,093,058	926,546,529	926,546,529	183,312,291
0			3,058,862,386	93,116,054	3,701,230,441	1,791,289,559	895,644,780	895,644,780	161,089,586
0			3,120,039,634	94,978,375	3,764,270,009	1,728,249,991	864,124,995	864,124,995	141,291,342
0			3,182,440,427	96,877,943	3,828,570,370	1,663,949,630	831,974,815	831,974,815	123,667,755
0			3,246,089,235	98,815,502	3,894,156,737	1,598,363,263	799,181,631	799,181,631	107,993,870
0			3,311,011,020	100,791,812	3,961,054,832	1,531,465,168	765,732,584	765,732,584	94,067,165
0			3,377,231,240	102,807,648	4,029,290,888	1,463,229,112	731,614,556	731,614,556	81,705,366
306,250,000			65,293,181,019	1,347,422,612	91,751,769,247	32,879,786,913	16,439,893,456	16,439,893,456	3,739,126,402

Table 4.19 Economic analysis for sucker rod pump.

No. of Year	Year	Oil production total (bbl/year)	Income (Baht)	Royalty sliding scale (Baht)	2% Escal Factor	Investment cost						
						Concession (Baht)	Geological and geophysical surveys (Baht)	Exploration and apprisal wells (Baht)	No. of production wells	Production wells (Baht)		Pipelines and processing production facilities (Baht)
										INTANG	TANG	
0	2006											
1	2007				1.0000	210,000,000						
2	2008				1.0200		280,000,000					
3	2009				1.0404			588,000,000	25	1,680,000,000	420,000,000	14,000,000,000
4	2010	3,650,000	9,636,000,000	963,600,000	1.0612				0	0	0	0
5	2011	3,650,000	9,636,000,000	963,600,000	1.0824				0	0	0	0
6	2012	3,660,000	9,662,400,000	1,207,800,000	1.1041				0	0	0	0
7	2013	3,650,000	9,636,000,000	963,600,000	1.1262				0	0	0	0
8	2014	3,528,544	9,315,356,160	931,535,616	1.1487				0	0	0	0
9	2015	1,900,990	5,018,613,600	501,861,360	1.1717				0	0	0	0
10	2016	1,195,375	3,155,790,000	197,236,875	1.1951				25	0	0	0
11	2017	1,195,375	3,155,790,000	197,236,875	1.2190				0	0	0	0
12	2018	1,195,375	3,155,790,000	197,236,875	1.2434				0	0	0	0
13	2019	1,195,375	3,155,790,000	197,236,875	1.2682				0	0	0	0
14	2020	1,195,375	3,155,790,000	197,236,875	1.2936				0	0	0	0
15	2021	1,195,375	3,155,790,000	197,236,875	1.3195				0	0	0	0
16	2022	1,195,375	3,155,790,000	197,236,875	1.3459				0	0	0	0
17	2023	1,195,375	3,155,790,000	197,236,875	1.3728				0	0	0	0
18	2024	1,195,375	3,155,790,000	197,236,875	1.4002				0	0	0	0
19	2025	1,195,375	3,155,790,000	197,236,875	1.4282				0	0	0	0
20	2026	1,195,375	3,155,790,000	197,236,875	1.4568				0	0	0	0
21	2027	1,195,375	3,155,790,000	197,236,875	1.4859				0	0	0	0
22	2028	1,195,375	3,155,790,000	197,236,875	1.5157				0	0	0	0
23	2029	1,195,375	3,155,790,000	197,236,875	1.5460				0	0	0	0
		36,774,784	97,085,429,760	8,096,076,351		0	0	0	25	1,680,000,000	420,000,000	14,000,000,000

Table 4.19 Economic analysis for sucker rod pump (cont.).

SRP	Depreciation (20%) Tangible Expense (Baht)		Investment cost						
Facilities (6.30 MMBaht/well)	2009	2020	Operation cost (840 Baht/bbl)	Maintanence cost of sucker rod pump (2.94 MMBaht/well/year)	Total allow expense (Baht)	Taxable income (Baht)	Income tax (Baht)	Annual cash flow (Baht)	Discounted cash flow (Baht)
					210,000,000	-210,000,000	0	-210,000,000	-190,909,091
					280,000,000	-280,000,000	0	-280,000,000	-231,404,959
0	2,884,000,000				5,152,000,000	-5,152,000,000	0	-5,152,000,000	-3,870,773,854
0			4,067,079,660	0	7,914,679,660	1,721,320,340	0	1,721,320,340	1,175,684,953
0			4,148,421,253	0	7,996,021,253	1,639,978,747	0	1,639,978,747	1,018,297,773
0			4,242,982,527	0	8,334,782,527	1,327,617,473	0	1,327,617,473	749,405,453
0			4,316,017,472	0	8,163,617,472	1,472,382,528	259,649,544	1,212,732,984	622,323,776
0			4,255,847,316	0	5,187,382,932	4,127,973,228	2,063,986,614	2,063,986,614	962,864,988
0			2,338,678,405	0	2,840,539,765	2,178,073,835	1,089,036,917	1,089,036,917	461,857,963
157,500,000			1,500,012,968	87,839,304	1,816,589,147	1,339,200,853	669,600,427	669,600,427	258,159,951
0			1,530,013,228	89,596,090	1,848,346,192	1,307,443,808	653,721,904	653,721,904	229,125,539
0			1,560,613,492	91,388,012	1,880,738,379	1,275,051,621	637,525,811	637,525,811	203,135,370
0			1,591,825,762	93,215,772	1,913,778,409	1,242,011,591	621,005,796	621,005,796	179,883,259
0		31,500,000	1,623,662,277	95,080,087	1,947,479,240	1,208,310,760	604,155,380	604,155,380	159,092,994
0			1,656,135,523	96,981,689	1,950,354,087	1,205,435,913	602,717,957	602,717,957	144,285,887
0			1,689,258,233	98,921,323	1,985,416,431	1,170,373,569	585,186,784	585,186,784	127,353,694
0			1,723,043,398	100,899,749	2,021,180,022	1,134,609,978	567,304,989	567,304,989	112,238,268
0			1,757,504,266	102,917,744	2,057,658,885	1,098,131,115	549,065,557	549,065,557	98,754,267
0			1,792,654,351	104,976,099	2,094,867,325	1,060,922,675	530,461,337	530,461,337	86,734,667
0			1,828,507,438	107,075,621	2,132,819,934	1,022,970,066	511,485,033	511,485,033	76,028,991
0			1,865,077,587	109,217,134	2,171,531,595	984,258,405	492,129,202	492,129,202	66,501,700
0			1,902,379,139	111,401,476	2,211,017,490	944,772,510	472,386,255	472,386,255	58,030,749
0			1,940,426,721	113,629,506	2,251,293,102	904,496,898	452,248,449	452,248,449	50,506,274
157,500,000			47,330,141,016	1,403,139,606	68,720,093,848	22,723,335,912	11,361,667,956	11,361,667,956	2,547,178,613

Table 4.20 Economic evaluations.

Type of production	**Oil Rate (b/d)**	**Recovery Factor (%)**	**Total allow expense and Income tax (MMMBaht)**	**Discounted cash flow (MMMBaht)**	**IRR (%)**	**PIR**
Natural Flow	136	22.74	47.16	0.74	15.25	0.33
Electrical Submersible Pump	406	67.95	164.36	5.71	25.40	1.45
	334	58.56	139.80	5.40	26.69	1.31
	271	50.65	121.16	4.37	24.97	1.08
	52	25.03	59.92	1.49	18.68	0.37
	47	24.57	58.86	1.44	18.55	0.35
	31	23.28	55.64	1.39	18.48	0.33
	29	23.17	55.39	1.38	18.46	0.32
Intermittent Flow Gas Lift	342	59.56	141.91	5.60	27.00	1.37
	281	51.90	123.87	4.60	25.38	1.14
	228	45.25	108.19	3.74	23.78	0.94
	130	34.08	80.90	2.58	21.26	0.65
	121	32.55	77.39	2.38	20.93	0.61
	84	28.35	67.63	1.87	19.66	0.48
	80	27.92	66.47	1.85	19.60	0.47

Table 4.20 Economic evaluations (cont.).

Type of production	Oil Rate (b/d)	Recovery Factor (%)	Total allow expense and Income tax (MMMBaht)	Discounted cash flow, 10% (MMMBaht)	IRR (%)	PIR
Sucker Rod Pump	197	40.75	96.32	3.48	23.27	0.89
	161	37.24	88.20	3.01	22.35	0.77
	134	34.08	80.89	2.59	21.44	0.67
	131	33.71	80.08	2.55	21.34	0.66
	122	32.67	77.64	2.41	21.01	0.62
	88	28.79	68.63	1.93	19.83	0.50
	86	28.57	68.13	1.90	19.76	0.49

4.4 Conclusions

The probable applications of artificial lift for Lan Kra Bu oil field are most suitable ranking for intermittent flow gas lift, electrical submersible pump and sucker rod pump respectively. The best return on investment of artificial lift for Lankrabue oil field intermittent flow gas lift (IRR 22.52% and PIR 0.81), electrical submersible pump (IRR 21.60% and PIR 0.74) and sucker rod pump (IRR 21.29% and PIR 0.66) respectively. The table 4.20 concludes optimizing artificial lift system selection for oil field in Phitsanulok basin. In technical analysis, the bottom hole pressure and gas liquid ratios, productivity index, size of tubing and variable rates are the controlling factors in the selection of the method of lift. The table 4.21 concludes selection of artificial lift's technique.

Table 4.21 Summary of optimizing artificial lift system selection for oil field in Phitsanulok basin.

Type of production	**$q_{o,avg}$ (b/d)**	**RF_{avg} (%)**	**Total $expense_{avg}$ (MMM Baht)**	**NPV_{avg} @ 10% (MMM Baht)**	**IRR_{avg} (%)**	**PIR_{avg}**
Natural Flow	136	22.74	47.16	0.74	15.25	0.33
Electrical Submersible Pump	167	39.03	93.59	3.03	21.60	0.74
Intermittent Flow Gas Lift	181	39.95	95.19	3.23	22.52	0.81
Sucker Rod Pump	131	33.69	79.98	2.55	21.29	0.66

Table 4.22 Selection of artificial lift's technique.

Controlling Factor	**Number**	**ESP**	**IFGL**	**SRP**
Low GOR and BHP High GOR and BHP	<150 SCF/STB and < 250 psi >150 SCF/STB and > 250 psi	Medium Medium	Fair Good	Good Fair
Low J High J	<1 b/d/psi >1 b/d/psi	Fair Good	Medium Medium	Good Fair
Small tubing Large tubing	1.315–2.375 inch 2.875–3.500 inch	Good Fair	Medium Medium	Fair Good
Variable rate	1–500 b/d	Medium	Good	Fair

CHAPTER V

CONCLUSIONS AND DISCUSSIONS

5.1 Introduction

This chapter concludes software development, the probable application and economic evaluation of artificial lift for oil field in Phitsanulok basin, and discussion.

5.2 Software development

The software has been developed for optimizing artificial lift system selection for oil field in Phitsanulok basin and design support of artificial lift system under various petroleum engineering requirements, including electrical submersible pump, intermittent flow gas lift and sucker rod pump. The software hereafter is called ALOP. The proposed system is based on the known analytical solutions and theories, but is not based on the heuristic knowledge, inference procedure and experience of artificial lift expert backed by the rationale and logic. The input artificial lift parameters are hierarchically characterized into several groups using various criteria, e.g., production, reservoir and well conditions, engineering requirements, design constraints and project goals, etc. Manufacturer's motor and data base of electrical submersible pump, intermittent flow gas lift and sucker rod pump are Adam Person Associates Engineering Production Manual and Byron Jackson pump division, Kirkpatrick and Lufkin Pump Division respectively.

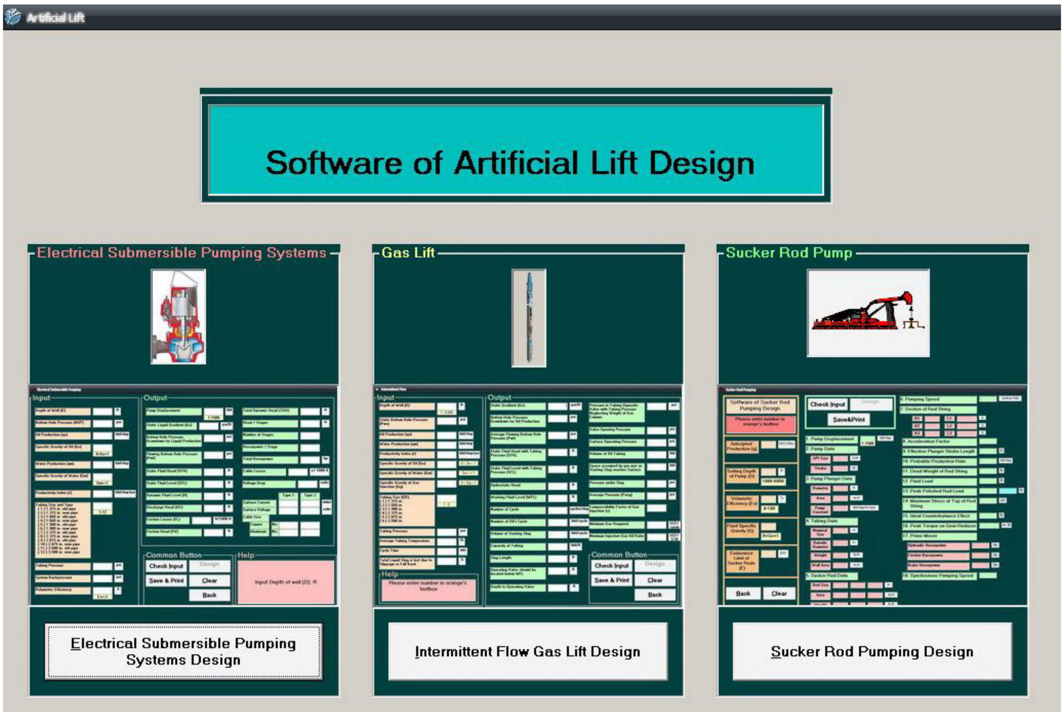

Figure 5.1 The main page of ALOP.

5.3 The probable applications and economic evaluation of artificial lift for oil field Phitsanulok basin.

The probable applications of artificial lift for Lankrabue oil field is most suitable ranking for intermittent flow gas lift, electrical submersible pump and sucker rod pump respectively. The best return on investment of artificial lift for Lankrabue oil field are intermittent flow gas lift (IRR 22.52% and PIR 0.81), electrical submersible pump (IRR 21.60% and PIR 0.74) and sucker rod pump (IRR 21.29% and PIR 0.66) respectively. The table 4.20 concludes optimizing artificial lift system selection for oil field in Phitsanulok basin. In technical analysis, the bottom hole pressure and gas liquid ratios, productivity index, size of tubing and variable rates are the controlling factors in the selection of the method of lift. The table 4.21 concludes selection of artificial lift's technique.

Table 5.1 Summary of optimizing artificial lift system selection for oil field in Phitsanulok basin**.**

Type of production	**$q_{o,avg}$ (b/d)**	**RF_{avg} (%)**	**Total $expense_{avg}$ (MMM Baht)**	**NPV_{avg} @ 10% (MMM Baht)**	**IRR_{avg} (%)**	**PIR_{avg}**
Natural Flow	136	22.74	47.16	0.74	15.25	0.33
ESP	167	39.03	93.59	3.03	21.60	0.74
IFGL	181	39.95	95.19	3.23	22.52	0.81
SRP	131	33.69	79.98	2.55	21.29	0.66

Table 5.2 Selection of artificial lift's technique.

Controlling Factor	**Number**	**ESP**	**IFGL**	**SRP**
Low GOR and BHP	<150 SCF/STB and < 250 psi	Medium	Fair	Good
High GOR and BHP	>150 SCF/STB and > 250 psi	Medium	Good	Fair
Low J	<1 b/d/psi	Fair	Medium	Good
High J	>1 b/d/psi	Good	Medium	Fair
Small tubing	1.315–2.375 inch	Good	Medium	Fair
Large tubing	2.875–3.500 inch	Fair	Medium	Good
Variable rate	1–500 b/d	Medium	Good	Fair

5.4 Discussions

5.4.1 The artificial lift can improve the petroleum production rates on the wells. They should be installed at Phitsanulok oil field because it is a big filed that has importance for exploration and production under high present of consumption rates.

5.4.2 The researcher should study and learn to understand equations, step and design of electrical submersible pump, intermittent flow gas lift and sucker rod pump.

5.4.3 The researcher should know about Microsoft visual basic V.6 program because it is easy and convenient to use for software development.

5.4.4 Manufacturer's motor and data base of electrical submersible pump, intermittent flow gas lift and sucker rod pump are studied and determined with the actual wells at Phitsanulok oil field.

5.4.5 Reliability of software development depends on the accuracy of equation and data base of each artificial lift system.

5.4.6 Simulation result is case study data of natural flow which can be used for decision making in the installation of artificial lift in the nearby petroleum potential area.

5.4.7 Reliability of simulation result depends on the accuracy of the input data and the simulation model.

5.4.8 The digitized calculation by computer will provide more accurate values and less time of calculation than using the manual calculation. The repeating calculation manually often gives error.

5.4.9 The design about electrical submersible pump, intermittent flow gas lift and sucker rod pump are very difficult and complex because limitation of some input data is not distinct and clearly explained. The complete data of Phitsanulok oil field should be collected and used in software so that the results are proximity of the actual performance.

5.4.10 The ALOP is advantage valuable data to use for decision-making in the investment of petroleum exploration and production in the other petroleum prospects at Phitsanulok oil field. The ALOP is the method of compiling program to design the electrical submersible pump, intermittent flow gas lift and sucker rod pump that is similar to the actual by input the data in the software. The ALOP accuracy depends on the quantity and quality of input data.

5.4.11 The thesis is useful in the prediction of the future petroleum business at Phitsanulok oil field.

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APPENDIX A

ARTIFICIA LIFT SYSTEMS FOR THESIS STUDY

A.1 Electrical submersible pump system

Electrical submersible pumps have their greatest application in moving large volumes of low GLR fluid. They are particularly attractive for water supply wells, high water cut producer and high deliverability undersaturated oils. Modified design procedure and improved gas oil separators/compressors are allowing effective operation at up to 1,000 SCF/bbl. High rate units are best suited to a total head of around 4,000–5,000 ft (Hallan N. Marsh, 1931). The other critical limitation indicated in Table A.1 is that the casing size will determine the available horsepower and capacity.

Table A.1 Approximate pump limitation by casing size.

Casing size (inch)	Maximum HP (hp)	Maximum rate (b/d)
4 1/2	120	1,750
5 1/2	200-300	4,000
7	400-650	8,000
9 5/8	750	25,000

Given below are the steps to be taken in designing an electrical submersible pump installation.

A.1.1 Determine the production target.

A.1.2 Review the casing size and weight in Table A.1 for implications available pump size.

A.1.3 Select a suitable pump from the manufacturers' design curves. Note the operating range 75–125 % of the peak pump efficiency, the Head/Stage and BHP/Stage at the design conditions in Figure A.1.

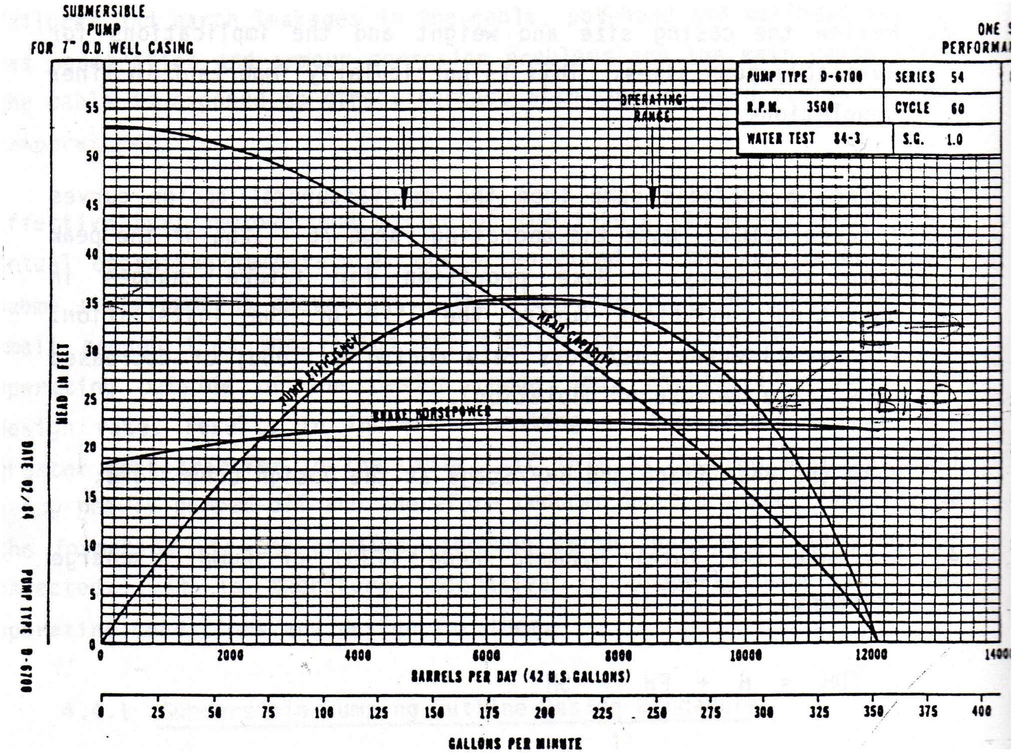

Figure A.1 Manufacturers' design curve (Hallan N. Marsh, 1931).

A.1.4 Estimate the Total Dynamic Head (TDH) or Pump Discharge Pressure.

$$TDH = H + FH \text{ (Figure A.2)} + SH1 \quad (A.1)$$

$$H = \frac{\text{Drawdown}}{\text{Live Gradient}} + \text{Static Fluid Level }) \quad (A.2)$$

A.1.5 Determine the number of stages required:

$$\text{Stages} = \frac{\text{TDH}}{\text{Head/Stage}} \tag{A.3}$$

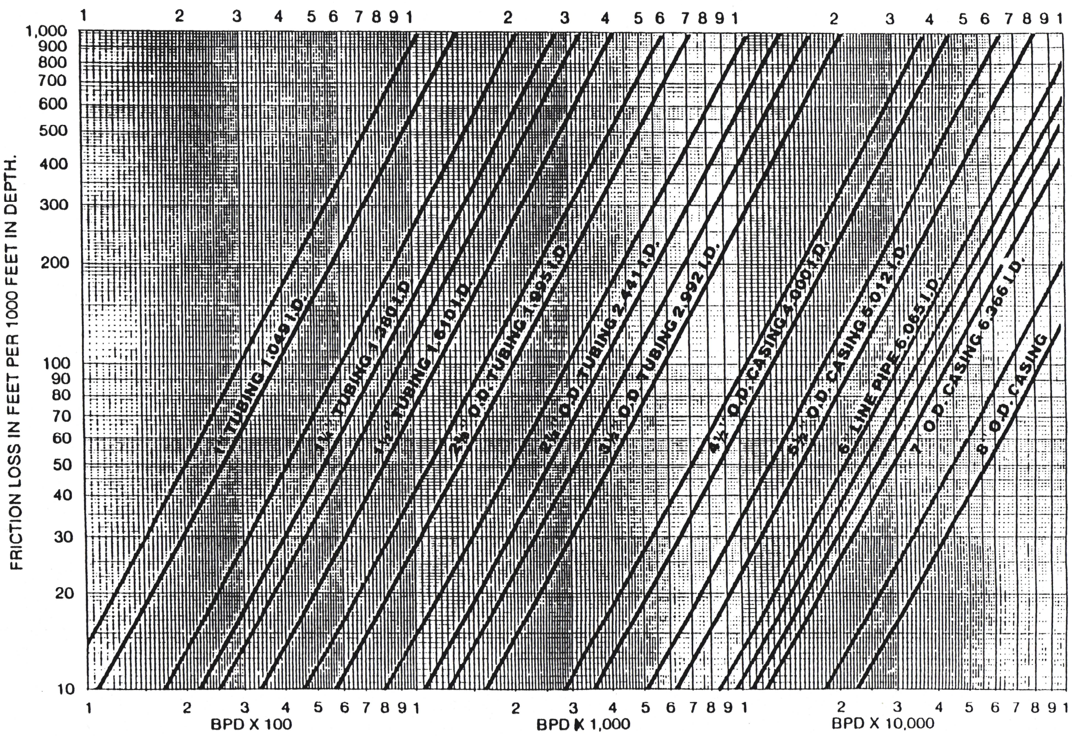

Figure A.2 Head due to friction in the tubing (Hallan N. Marsh, 1931)

A.1.6 Determine total brake horsepower required:

$$\text{BHP} = \text{Stages} \times \frac{\text{BHP}}{\text{Stage}} \times \text{SG} \tag{A.4}$$

A.1.7 Select the pump type and motor requirements from the manufacturers' specifications in Table A.2.

Table A.2 The manufacturers' specifications of electrical submersible pump.

HP	Type I			
	Cable Size		Surface	
	Cu	Al	Current (amps)	Voltage (volts)
≤ 24	8	6	28	440+vd
25-35	6	4	40	440+vd
36-45	4	2	60	440+vd
46-55	2	1/0	72	430+vd
56-72.5	6	4	34	1010+vd
73.5-80	6	4	35	1350+vd
81-97.5	6	4	42	1270+vd
98.5-112.5	6	4	46	1300+vd
113.5-137.5	4	2	68	1125+vd
138.5-165	4	2	70	1300+vd
166-190	2	1/0	92	1180+vd
191-212.5	1	2/0	105	1130+vd
213.5-237.5	1	2/0	110	1210+vd
238.5-262.5	1	2/0	105	1405+vd
263.5-287.5	1	2/0	105	1565+vd
288.5-325	1	2/0	105	1675+vd
326-362.5	1	2/0	105	1950+vd
363.5-387.5	1	2/0	105	2150+vd
≥ 388.5	1	2/0	105	2225+vd

Table A.2 The manufacturers' specifications of electrical submersible pump (cont.).

HP	Type II			
	Cable Size		Surface	
	Cu	Al	Current (amps)	Voltage (volts)
≤ 24	10	8	17	760+vd
25-35	8	6	23	760+vd
36-45	6	4	35	740+vd
46-55	6	4	42	745+vd
56-72.5	0	0	0	0
73.5-80	0	0	0	0
81-97.5	0	0	0	0
98.5-112.5	0	0	0	0
113.5-137.5	6	4	35	2270+vd
138.5-165	6	4	46	1950+vd
166-190	4	2	53	2040+vd
191-212.5	4	2	53	2270+vd
213.5-237.5	4	2	63	2100+vd
238.5-262.5	0	0	0	0
263.5-287.5	0	0	0	0
288.5-325	0	0	0	0
326-362.5	0	0	0	0
363.5-387.5	0	0	0	0
≥ 388.5	0	0	0	0

A.1.8 Select a cable that will give a voltage loss of less than 30v/1,000 ft and determine the corresponding wellhead voltage (Figure A.3).

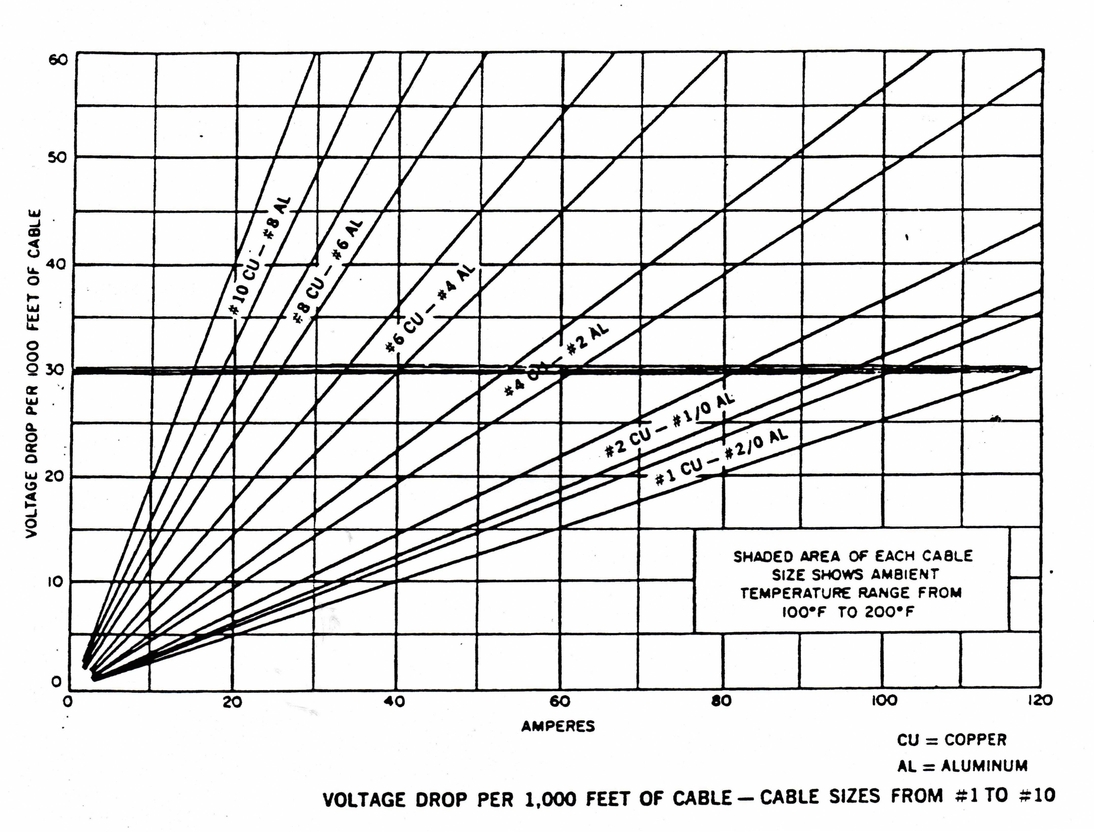

Figure A.3 The corresponding wellhead voltage (Hallan N. Marsh, 1931).

A.2 Intermittent Flow Gas lift

Gas lift is mechanical process of lifting fluid from a well where gas relatively high pressure (≥ 250 psi) is used as the lifting medium. The gas lift is installed either during completion or in later workover operations. In addition, these installations may be applied to wells of any depth, any reservoir pressure and any rate of flow up to tens of thousands of barrels of fluid per day. The factors limits to impair the efficiency of gas lift are the presence of sour gas or crudes of high viscosity. In intermittent flow, as is injected at a pressure great than the pressure exerted by the column of fluid in the tubing above the operating valve, lifting the fluid by expansion and displacement (Gilbert, W.E., 1954).

Given below are the steps to be taken in designing intermittent flow.

A.2.1 The static gradient is calculated from (psi/ft).

$$G_s = 0.433\gamma_o \tag{A.5}$$

A.2.2 The bottom hole pressure drawdown is calculated from (psi).

$$\Delta p = \frac{q_o}{J} \tag{A.6}$$

A.2.3 The average flowing bottom hole pressure is calculated from (psi).

$$p_{wf} = p_{bh} - \Delta p \tag{A.7}$$

A.2.4 The depth to the static fluid level with surface tubing pressure is calculated from (ft).

$$D_s = D - \left(\frac{p_{bh} - p_t}{G_s}\right) \tag{A.8}$$

A.2.5 The hydrostatic head is calculated from (ft).

$$H = \frac{\Delta p}{G_s} \tag{A.9}$$

A.2.6 The working fluid level is calculated from (ft).

$$D_w = D_s + H \tag{A.10}$$

A.2.7 The number of cycles required per day is calculated from $\frac{1440}{\text{cycle time}}$ (cycles per day). (A.11)

A.2.8 The number of barrels per cycle is calculated from

$$\frac{q_o}{\text{cycles per day}} \text{ (bbl per cycle).} \tag{A.12}$$

A.2.9 The volume of the starting slug is calculated from

$$\frac{\text{bbl per cycle}}{0.60} \text{ (bbl).} \tag{A.13}$$

A.2.10 The slug length is calculated from

$$\frac{\text{The volume of the starting slug}}{\text{The capacity of tubing}} \text{ (ft).} \tag{A.14}$$

A.2.11 The operating valve should be located below the working fluid level is calculated from

$$\frac{\text{The slug length}}{2} \text{ (ft).} \tag{A.15}$$

A.2.12 The depth to the operating valve is calculated from the working fluid + the operating valve (ft) (A.16)

A.2.13 The pressure in the tubing opposite the valve with surface tubing pressure, neglecting the weight of the gas column is calculated from

$$p_t = \text{Surface tubing pressure} + \left(\text{Slug length} \times G_s\right) \qquad \text{(A.17)}$$

A.2.14 The valve opens the minimum casing pressure is calculated from (psig)

$$p_{v,\min} = p_t + \frac{p_t}{2} \qquad \text{(A.18)}$$

$$\text{If } \frac{p_t}{2} \leq 200 \text{ then } p_{v,\min} = p_t + 200 \qquad \text{(A.19)}$$

A.2.15 Surface operating pressure is taken from Table A.3.

Table A.3 Surface operating pressure.

Depth (ft)	Surface operating pressure
1,000-1,499	$P_{so} = 0.957P_{v,\min}$
1,500-1,999	$P_{so} = 0.953P_{v,\min}$
2,000-2,499	$P_{so} = 0.948P_{v,\min}$
2,500-2,999	$P_{so} = 0.93P_{v,\min}$
3,000-3,499	$P_{so} = 0.923P_{v,\min}$
3,500-3,999	$P_{so} = 0.916P_{v,\min}$
4,000-4,499	$P_{so} = 0.913P_{v,\min}$
4,500-4,999	$P_{so} = 0.901P_{v,\min}$
5,000-5,499	$P_{so} = 0.874P_{v,\min}$
5,500-6,000	$P_{so} = 0.847P_{v,\min}$

A.3 Sucker rod pump

This parts are prime mover, the surface pumping equipment, the sucker rod string and the subsurface pump.

Given below are the steps to be taken in designing a pumping installation.

A.3.1 From maximum anticipated fluid production and estimated volumetric efficiency, calculate the pump displacement.

$$V = \frac{q}{E_v} \tag{A.20}$$

A.3.2 From Figure A.4 determine the stroke length and API rating of the pumping unit to be used. From manufacturers' literature, select a unit which has the desired stroke length and API rating.

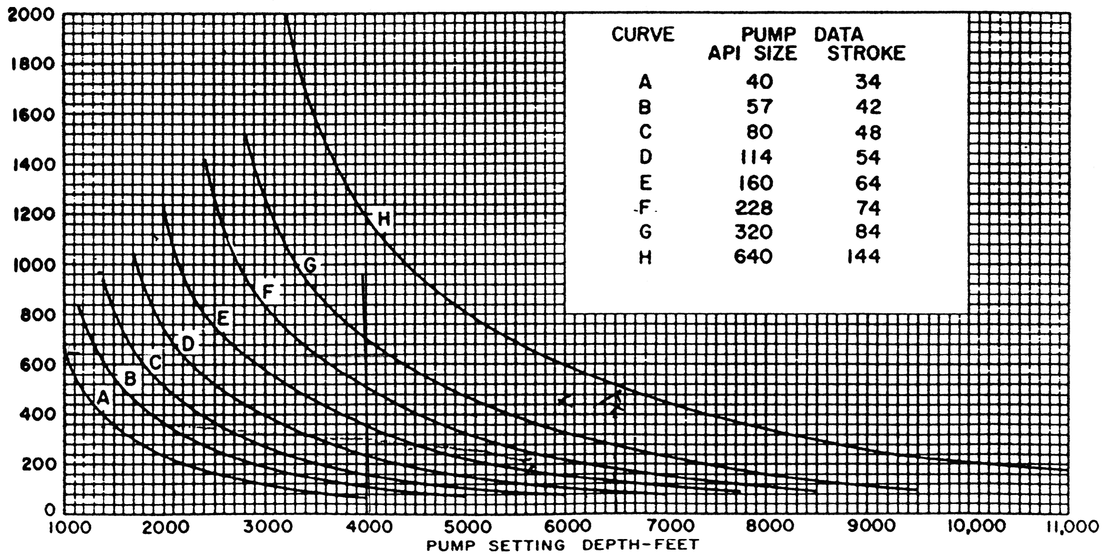

Figure A.4 Pump unit and stroke length selection chart (Howard L. Kelley and Roy M. Willis, 1954).

A.3.3 From the appropriate chart of Table A.5 through A.12, select tubing size, plunger size, rod size and pumping speed corresponding to the pump setting depth.

Table A.4 Design data for API size 40 unit with 34 inch.

Pump depth (ft)	Plunger size (inch)	Tubing size (inch)	Rod size (inch)	Pumping speed (strokes/min)
1,000 – 1,100	2 3/4	3	7/8	24-19
1,100 – 1,250	2 1/2	3	7/8	24-19
1,250 – 1,650	2 1/4	2 1/2	3/4	24-19
1,650 – 1,900	2	2 1/2	3/4	24-19
1,900 – 2,150	1 3/4	2 1/2	3/4	24-19
2,150 – 3,000	1 1/2	2	5/8-3/4	24-19
3,000 – 3,700	1 1/4	2	5/8-3/4	22-18
3,700 – 4,000	1	2	5/8-3/4	21-18

Table A.5 Design data for API size 57 unit with 42 inch.

Pump depth (ft)	Plunger size (inch)	Tubing size (inch)	Rod size (inch)	Pumping speed (strokes/min)
1,150 – 1,300	2 3/4	3	7/8	24-19
1,300 – 1,450	2 1/2	3	7/8	24-19
1,450 – 1,850	2 1/4	2 1/2	3/4	24-19
1,850 – 2,200	2	2 1/2	3/4	24-19
2,200 – 2,500	1 3/4	2 1/2	3/4	24-19
2,500 – 3,400	1 1/2	2	5/8-3/4	23-18
3,400 – 4,200	1 1/4	2	5/8-3/4	22-17
4,200 – 5,000	1	2	5/8-3/4	21-17

Table A.6 Design data for API size 80 unit with 48 inch.

Pump depth (ft)	**Plunger size (inch)**	**Tubing size (inch)**	**Rod size (inch)**	**Pumping speed (strokes/min)**
1,400 – 1,550	2 3/4	3	7/8	24-19
1,550 – 1,700	2 1/2	3	7/8	24-19
1,700 – 2,200	2 1/4	2 1/2	3/4	24-19
2,200 – 2,600	2	2 1/2	3/4	24-19
2,600 – 3,000	1 3/4	2 1/2	3/4	23-18
3,000 – 4,100	1 1/2	2	5/8-3/4	23-18
4,100 – 5,000	1 1/4	2	5/8-3/4	21-17
5,000 – 6,000	1	2	5/8-3/4	19-17

Table A.7 Design data for API size 114 unit with 54 inch.

Pump depth (ft)	**Plunger size (inch)**	**Tubing size (inch)**	**Rod size (inch)**	**Pumping speed (strokes/min)**
1,700 – 1,900	2 3/4	3	7/8	24-19
1,900 – 2,100	2 1/2	3	7/8	24-19
2,100 – 2,700	2 1/4	2 1/2	3/4	24-19
2,700 – 3,300	2	2 1/2	3/4	23-18
3,300 – 3,900	1 3/4	2 1/2	3/4	22-17
3,900 – 5,100	1 1/2	2	5/8-3/4	21-17
5,100 – 6,300	1 1/4	2	5/8-3/4	19-16

Table A.8 Design data for API size 160 unit with 64 inch.

Pump depth (ft)	**Plunger size (inch)**	**Tubing size (inch)**	**Rod size (inch)**	**Pumping speed (strokes/min)**
2,000 – 2,200	2 3/4	3	7/8	24-19
2,200 – 2,400	2 1/2	3	7/8	23-19
2,400 – 3,000	2 1/4	2 1/2	3/4-7/8	23-19
3,000 – 3,600	2	2 1/2	3/4-7/8	23-18
3,600 – 4,200	1 3/4	2 1/2	3/4-7/8	22-17
4,200 – 5,400	1 1/2	2	5/8-3/4-7/8	21-17
5,400 – 6,700	1 1/4	2	5/8-3/4-7/8	19-15

Table A.9 Design data for API size 228 unit with 74 inch.

Pump depth (ft)	**Plunger size (inch)**	**Tubing size (inch)**	**Rod size (inch)**	**Pumping speed (strokes/min)**
2,400 – 2,600	2 3/4	3	7/8	24-20
2,600 – 3,000	2 1/2	3	7/8	23-18
3,000 – 3,700	2 1/4	2 1/2	3/4-7/8	22-17
3,700 – 4,500	2	2 1/2	3/4-7/8	21-16
4,500 – 5,200	1 3/4	2 1/2	3/4-7/8	19-15
5,200 – 6,800	1 1/2	2	5/8-3/4-7/8	18-14

Table A.10 Design data for API size 320 unit with 84 inch.

Pump depth (ft)	**Plunger size (inch)**	**Tubing size (inch)**	**Rod size (inch)**	**Pumping speed (strokes/min)**
2,800 – 3,200	2 3/4	3	7/8	23-18
3,200 – 3,600	2 1/2	3	7/8	21-17
3,600 – 4,100	2 1/4	2 1/2	3/4-7/8-1	21-17
4,100 – 4,800	2	2 1/2	3/4-7/8-1	20-16
4,800 – 5,600	1 3/4	2 1/2	3/4-7/8-1	19-16
5,600 – 6,700	1 1/2	2 1/2	3/4-7/8-1	18-15

Table A.11 Design data for API size 640 unit with 114 inch.

Pump depth (ft)	**Plunger size (inch)**	**Tubing size (inch)**	**Rod size (inch)**	**Pumping speed (strokes/min)**
3,200 – 3,500	2 3/4	3	7/8	18-14
3,500 – 4,000	2 1/2	3	7/8	17-13
4,000 – 4,700	2 1/4	2 1/2	3/4-7/8-1	16-13
4,700 – 5,700	2	2 1/2	3/4-7/8-1	15-12
5,700 – 6,600	1 3/4	2 1/2	3/4-7/8- 1	14-12

A.3.4 Calculate the fractional length of each section of the rod string, using the data of Table A.13 and A.15.

Table A.12 Pump plunger data.

Diameter (inch)	Area (sq in)	Pump constant (bbl/day/in/spm)
1	0.785	0.116
1 1/16	0.886	0.131
1 1/4	1.227	0.182
1 1/2	1.767	0.262
1 3/4	2.405	0.357
1 25/32	2.448	0.369
2	3.142	0.466
2 1/4	3.976	0.59
2 1/2	4.909	0.728
2 3/4	5.940	0.881
3 3/4	11.045	1.639
4 3/4	17.721	2.63

Table A.13 Tubing data.

Nominal size (inch)	Outside diameter (inch)	Weight (lb/ft)	Well area (sq in)
1 1/2	1.900	2.90	0.800
2	2.375	4.70	1.304
2 1/2	2.875	6.50	1.812
3	3.500	9.30	2.590
3 1/2	4.000	11.00	3.077
4	4.500	12.75	3.601

Table A.14 Data for design of tapered sucker rod string.

Rod size in string (inch)	**Valve of R_a**
5/8 - 3/4	$R_1 = 0.759 - 0.0896A_p$ $R_2 = 0.241 - 0.0896A_p$
3/4 - 7/8	$R_1 = 0.786 - 0.0566A_p$ $R_2 = 0.214 - 0.0566A_p$
7/8 - 1	$R_1 = 0.814 - 0.0375A_p$ $R_2 = 0.186 - 0.0375A_p$
5/8 - 3/4 -7/8	$R_1 = 0.627 - 0.1393A_p$ $R_2 = 0.199 - 0.0737A_p$ $R_3 = 0.175 - 0.0655A_p$
3/4 - 7/8 -1	$R_1 = 0.664 - 0.0894A_p$ $R_2 = 0.181 - 0.0478A_p$ $R_3 = 0.155 - 0.0416A_p$

A.3.5 Calculation the length of each section of the rod string to the nearest 25 ft.

$$L_1 = LR_1 \tag{A.27}$$

$$L_2 = LR_2 \tag{A.28}$$

$$L_3 = LR_3 \tag{A.29}$$

A.3.6 Calculate the acceleration factor.

$$\alpha = \frac{SN^2}{70{,}500} \tag{A.24}$$

A.3.7 Determine the effective plunger stroke length.

$$S_p = S + \frac{40.8L^2\alpha}{E} - \frac{5.2GDA_p}{E}\left[\frac{L}{A_t} + \frac{L}{A_1} + \frac{L}{A_2} + \frac{L}{A_3}\right] \tag{A.25}$$

A.3.8 Using the estimated volumetric efficiency, determine the probable production rate and check it against the desired production rate.

$$q = 0.466 S_p N E_v \tag{A.26}$$

A.3.9 Calculate the dead weight of the rod string.

$$W_r = M_1 L_1 + M_2 L_2 + M_3 L_3 \tag{A.27}$$

A.3.10 Calculate the fluid load.

$$W_f = 0.433G\left(LA_p - 0.294W_r\right) \tag{A.28}$$

A.3.11 Determine peak polished rod load and check it against maximum beam load for the unit selected.

$$W_{\max} = W_f + W_r\left(1 + \alpha\right) \tag{A.29}$$

A.3.12 Calculate the maximum stress at the top of the rod string and check it against the maximum permissible working stress for the rods to be used.

$$\frac{W_p}{A_3} \tag{A.30}$$

A.3.13 Calculate the ideal counterbalance effect and check it against the counterbalance available for the unit selected.

$$C_i = 0.5W_f + W_r(1 - 0.127G) \tag{A.31}$$

A.3.14 On the assumption that the unit will be no more than five percent out of counterbalance, calculate the peak torque on the gear reducer and check it against the API rating of the unit selected.

$$T_p = \frac{(W_{nax} - 0.95C_i)S}{2} \tag{A.32}$$

A.3.15 Calculate hydraulic horsepower, friction horsepower, and brake horsepower of the prime mover. Select the prime mover.

$$H_h = 7.36 \times 10^{-6} qGL_N \tag{A.33}$$

$$H_f = 6.31 \times 10^{-7} W_r SN \tag{A.34}$$

$$H_b = 1.5(H_h + H_f) \tag{A.35}$$

A.3.16 Check synchronous.

$$n = \frac{237{,}000}{NL} \tag{A.42}$$

APPENDIX B

VARIABLE DECLARATION, FLOWCHART AND PROGRAMMING

B.1 Variable declaration

This topic explains variables in this programs that are set for software development. This variable is agent of the input, output, calculation, process and compile. The variables and variable's meaning of each module as follow as in Table B.1.

B.1.1 Variables and variable's meaning of electrical submersible pump's input data.

a. Resrevoir's input data

bhp = Bottom hole pressure

go = Specific gravity of oil

gw = Specific gravity of water

j = Productivity index

bo = Oil formation volume factor

bg = Gas formation volume factor

bw = Water formation volume factor

gori = Initial gas oil ratio

gord = Dissolved gas oil ratio

b. Production's input data

qo = Oil Production

qw = WaterProduction

c. Well's input data

d = Depth

ts = Tubing Size

tt = Tubing Type

ptev = Average Tubing Pressure

d. Other's input data

ev = Volumetric Efficiency of Pump

B.1.2 Variables and variable's meaning of electrical submersible pump's output data

pd = Pump Displacement

gs = Static Live oil Gradient

dd = Bottom Hole Pressure Drawdown for liquid production

pwf = Average Flowing Bottom Hole Pressure for liquid production

sfh = Static Fluid Head

sfl = Static Fluid Level

h = Dynamic Fluid Level

hs = Discharge Head

fl = Friction Losses

fh = Friction Head for

tdh = Total Dynamic Head

hes = Head/Stages

ns = Number of Stage

hps = Horsepower/Stage

thp = Total Horsepower

cl = Cable Losses

vd = Vottage Drop

sc1 = Surface current of Type1

sc2 = Surface current of Type 2

sv1 = Surfave voltage of type 1

sv2 = Surfave voltage of type 2

cu1 = Copper's cable size of Type1

cu2 = Copper's cable size of Type 2

al1 = Aluminum's cable size of Type 1

al2 = Aluminum's cable size of Type 2

B.2.1 Variables and variable's meaning of intermittent flow gas lift's input data

a. Resrevoir's input data

bhp = Bottom hole pressure

go = Specific gravity of oil

gg = Specific Gravity of Gas

gw = Specific gravity of water

j = Productivity index

bo = Oil formation volume factor

bg = Gas formation volume factor

bw = Water formation volume factor

gori = Initial gas oil ratio

gord = Dissolved gas oil ratio

gord = Dissolved gas oil ratio

b. Production's input data

qo = Oil Production

qw = Water Production

c. Well's input data

d	=	Depth
ts	=	Tubing Size
pt	=	Tubing Pressure
tavg	=	Average Tubing Temperature

d. Other's input data

ev	=	Volumetric Efficiency of Pump
ct	=	Cycle Time
fb	=	Total Liquid Slug is lost due to Slippage or Fall Back

B.2.2 Variables and variable's meaning of intermittent flow gas lift's output data

gs	=	Static Gradient
dd	=	Bottom Hole Pressure Drawdown for oil Production
pwf	=	Flowing Bottom Hole Pressure for oil Production
sfh	=	Static Fluid Head with Tubing Pressure
sfl	=	Static Fluid Level with Tubing Pressure
hh	=	Hydrostatic Head
wfl	=	Working Fluid Level for oil Production
nc	=	Number of Cycle
noc	=	Number of Oil's Cycle
vss	=	Volume of Starting Slug
ct	=	Capacity of Tubing
sl	=	Slug Length

bwfl	=	Operating Valve should be located below Working Fluid Level
dov	=	Depth to Operating Valve
ptov	=	Pressure in Tubing Opposite Valve with Tubing Pressure Neglecting Weight of Gas Column
vop	=	Valve Opening Pressure
ss	=	Surface Operating Pressure
vot	=	Volume of Oil Tubing
spa	=	Space occupied by gas just as Starting Slug reaches Surface
pus	=	Pressure under Slug of Gas Injection
pgi	=	Average Pressure of Gas Injection
z	=	Compressibility Factor of Gas Injection
gr	=	Minimum Gas Required
gior	=	Minimum Injection Gas Oil Ratio

B.2.3 Variables and variable's meaning of intermittent flow gas lift's other data

min_dif	=	Minimum Differential of pressure
ppc	=	Critical Psedu Pressure
tpc	=	Critical Psedu Temperature
denpr	=	Reduce Psedu Density
ppr	=	Reduce Psedu Pressure
tpr	=	Reduce Psedu Temperature
z1	=	1^{st} Compressibility Factor

z2	=	2nd Compressibility Factor
z3	=	3rt Compressibility Factor
z4	=	4th Compressibility Factor
z5	=	5th Compressibility Factor
z6	=	6th Compressibility Factor
z7	=	7th Compressibility Factor
z8	=	8th Compressibility Factor
z9	=	9th Compressibility Factor

B.3.1 Variables and variable's meaning of sucker rod pump's input data

a. Resrevoir's input data

go	=	Specific gravity of oil
gw	=	Specific gravity of water
bo	=	Oil formation volume factor
bg	=	Gas formation volume factor
bw	=	Water formation volume factor
gori	=	Initial gas oil ratio
gord	=	Dissolved gas oil ratio

b. Production’s input data

qo = Oil Production

qw = Water Production

c. Well’s input data

d = Depth

d. Other’s input data

e = Endurance Limit of Sucker Rods

ev = Volumetric Efficiency of Pump

B.3.2 Variables and variable’s meaning of sucker rod pump’s output data

pud = Pump Data

pai = API Size

str = Stroke

pg = Pump Plunger Data

dpg = Diameter of Plunger

apg = Area of Plunger

pc = Pump Constant

td = Tubing Data

nst	=	Nominal Size of Tubing
ot	=	Outside Diameter of Tubing
wt	=	Weight of Tubing
wat	=	Well Area of Tubing
srd	=	Sucker Rod Data
rs1	=	1^{st} Rod Size
rs2	=	2^{nd} Rod Size
rs3	=	3^{rt} Rod Size
ars1	=	1^{st} area of sucker rod
ars2	=	2^{nd} area of sucker rod
ars3	=	3^{rt} area of sucker rod
wrs1	=	1^{st} weight of sucker rod
wrs2	=	2^{nd} weight of sucker rod
wrs3	=	3^{rd} weight of sucker rod
ps	=	Pumping Speed for oil Production
srs	=	Section of Rod String
af	=	Acceleration Factor for pump
ep	=	Effective Plunger Stroke Length
pqo	=	Probable Production Rate
dwr	=	Dead Weight of Rod Load
fl	=	Fluid Load
ppr	=	Peak Polished Rod Load
ms	=	Maximum Stress at Top of Rod String
ice	=	Ideal Counterbalance Effect

pt = Peak Torque on Gear Reducer

pm = Prime Mover for pump

hh = Hydraulic Horsepower

fh = Friction Horsepower

bh = Brake Horsepower

sp = Synchronous Pumping speed for pump

B.4.1 Variables and variable's meaning of general commands

"" = No display

"massages" = Diplay massages

&HFF& = Red color

&H8000& = Green color

&H80C0FF = Orange color

Artificial_Lift.Show = Back to main page

Electrical_Submersible_Pump.Show = Back to electrical submersible pump's page

Gas_Lift.Show = Back to gas lifr's page

Sucker_Rod_Pump.Show = Back to sucker rod pump's page

Beep = Bell

Printer.Print = Printer

IIf(xxx.Text = "", "No Data", xxx.Text = If no data then no display
Else xxx.Text

vbCritical + vbOKOnly = Critical's Massage

vbInformation + vbOKOnly = Information's Massage

Response = Massage box

Again = Massage box

Timer = Clock

Private = Main program

Private Sub = Module

Static number = Zero

Case = If..Then..Else

End Select = End case

End Sub = End Module

Artifical_Lift_Click = Main page

Electrical_Submersible_Pump _Click = Electrical submersible pump's page

Gas_Lift _Click = Gas lift's page

Sucker_Rod_Pump _Click = Sucker rod pump's page

Check_Input_Click = Check Input

Design_Click = Design artificial lift

Save_Print_Click = Save or print files

Clear_Click = Clear screen

Back_Click = Main page

lbl = Label

MsgBox = Massage box

B.2 Flowchart

The topic shows and explains flowchart that is developed for description compiling process of ALOP. This process includes input, checking input, calculation, linking data base, checking output and output. The flowchart includes many flowchart symbols that are used to present the compiling process of ALOP. This flowchart symbol is shown in Figure B.1.

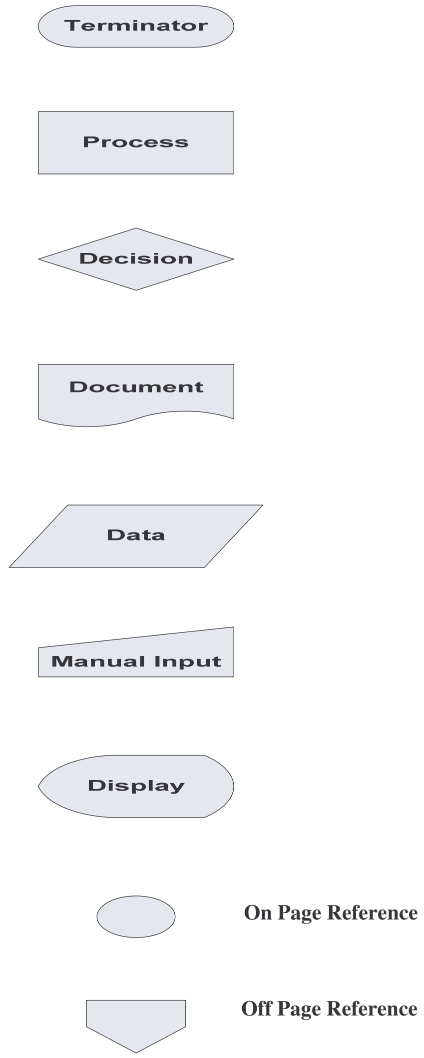

Figure B.1 Flowchart symbol

B.2.1 Flowchart of electrical submersible pump module

The flowchart of electrical submersible pump module includes parameters of input and output, equation and data base as follow as in Table B.2.

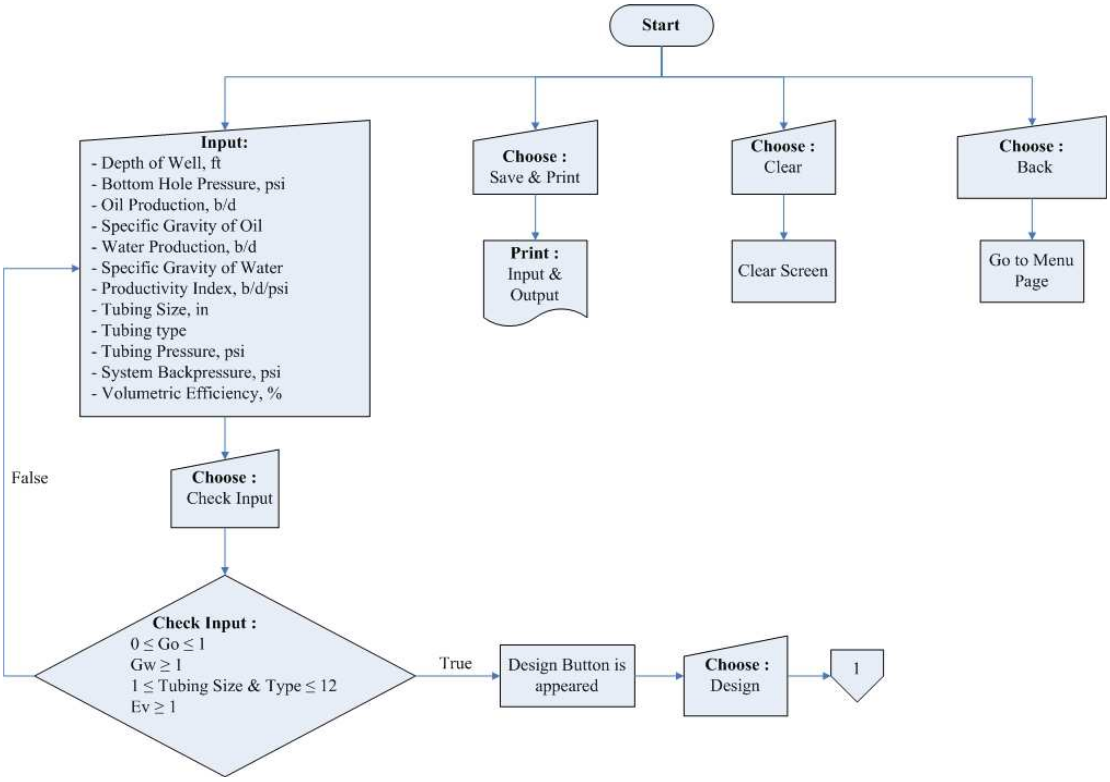

Figure B.2 Electrical submersible pump process

1

Calculate :

$$G_s = 0.433 \times \left(\left(\frac{q_w}{q_o} \times \gamma_w \right) + \gamma_o \right)$$

$$\Delta p = \frac{q_o}{J}$$

$$p_{wf} = p_w - \Delta p$$

$$SFH = \frac{P_{wf}}{G_s}$$

$$SFL = D - SFH$$

$$H = SFL + \frac{\Delta p}{G_s}$$

$$HS = \frac{THP}{G_s}$$

Friction Losses from Data Base

$$\text{Friction Head} = \text{Friction Losses from Data Base} \times \text{D}$$

$$TDH = H + HS + FH$$

$\frac{\text{Head}}{\text{Stage}}$ from Data base

$$\text{No. of Stage} = \text{TDH} \times \frac{\text{Head}}{\text{Stage}}$$

$\frac{\text{Horsepower}}{\text{Stage}}$ from Data base

$$\text{Total Horsepower} = \text{No. of Stage} \times \frac{\text{Horsepower}}{\text{Stage}}$$

Manufacturers' Motor from Data base

Cable Size from Data base

Cable Losses from Data base

Surface Voltage from Data base

2

Figure B.2 Electrical submersible pump process (cont.)

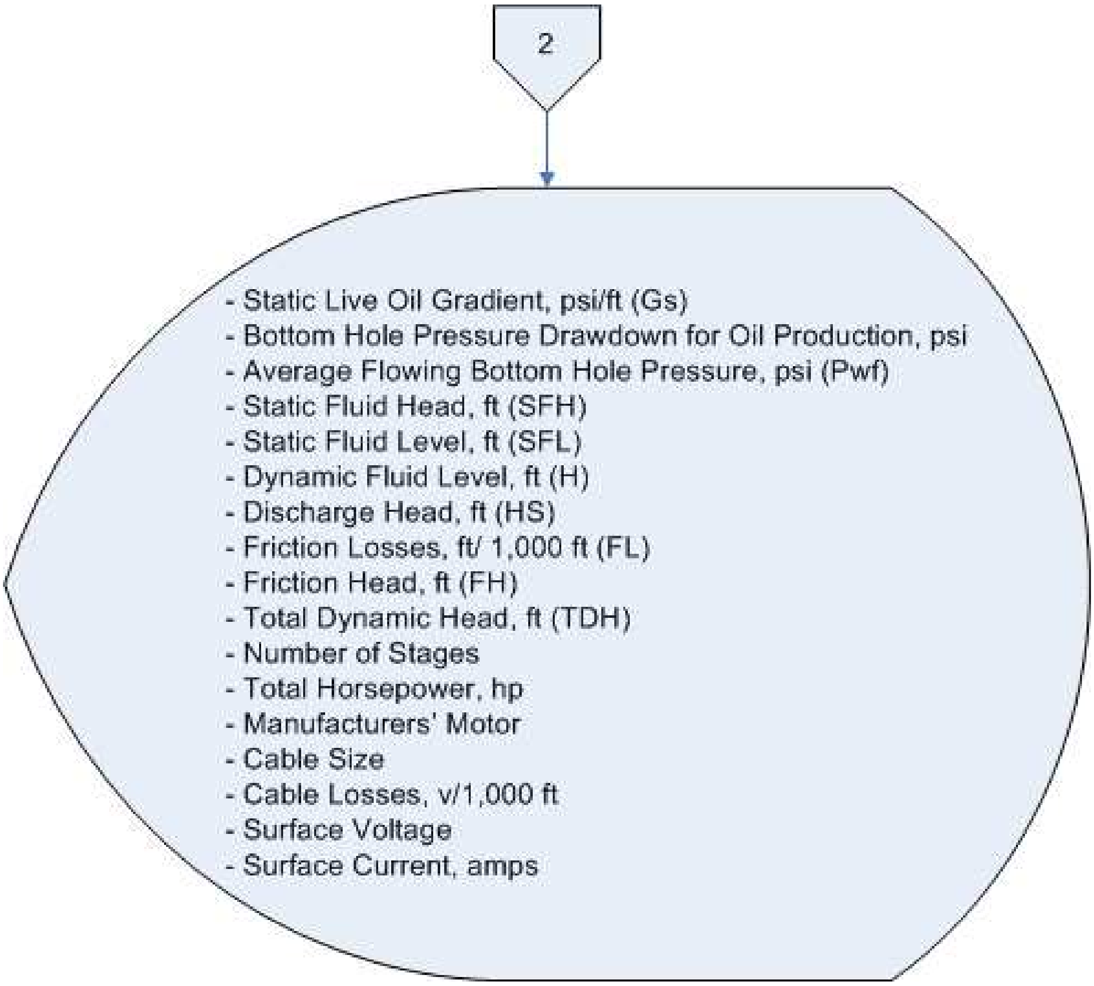

Figure B.2 Electrical submersible pump process (cont.)

B.2.2 Flowchart of intermittent flow gas lift module

The flowchart of intermittent flow gas lift module includes parameters of input and output, equation and data base as follow as in Table B.3.

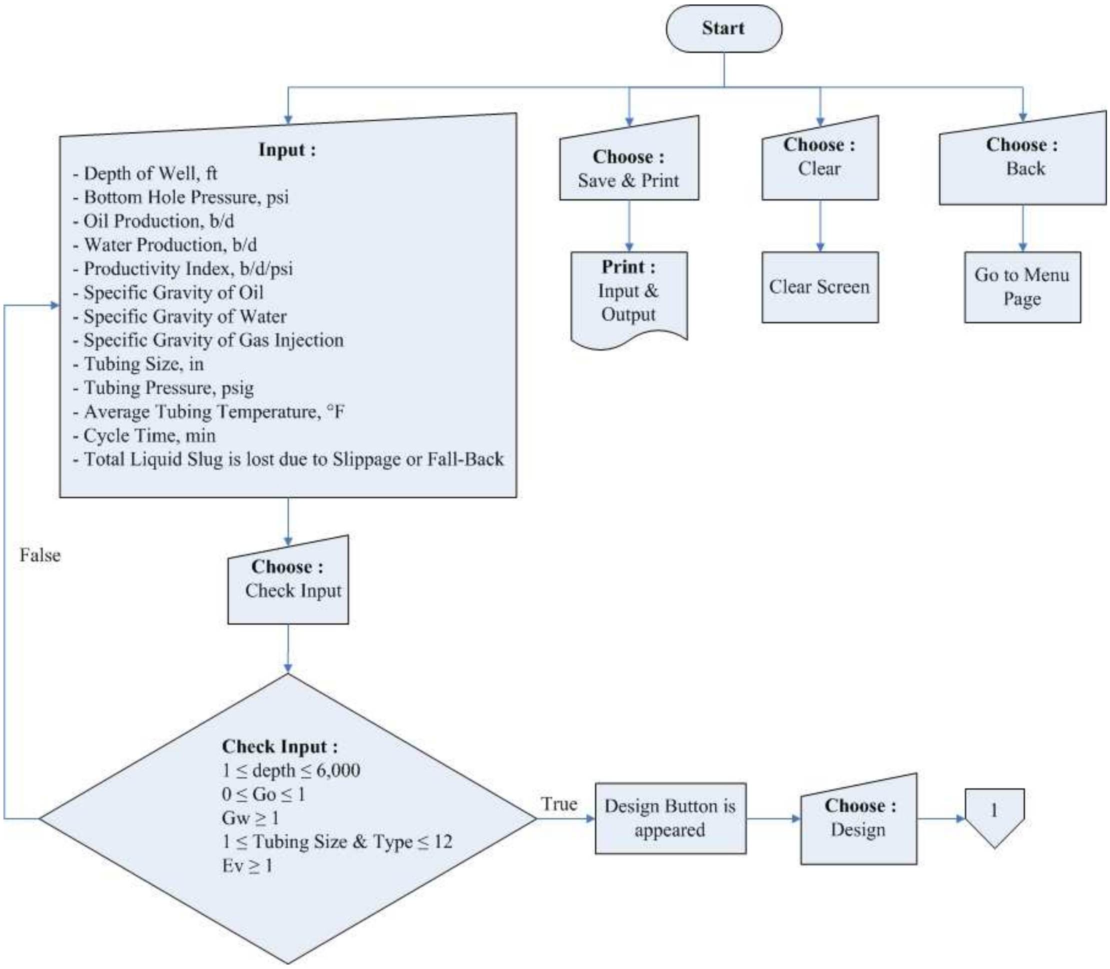

Figure B.3 Intermittent flow Gas lift process

1

Calculate :

$$G_s = \gamma_o \times 0.433$$

$$\Delta p = \frac{q_o}{J}$$

$$p_{wf} = p_w - \Delta p$$

$$D_s = D - \left(\frac{P_w - P_t}{G_s} \right)$$

$$\text{Hydrostatic Head} = \frac{\Delta p}{G_s}$$

$$\text{Working Fluid Level} = D_s + \text{Hydrodtatic Head}$$

$$\frac{Cycle}{Day} = \frac{Cycle}{\min} \times \frac{1440 \min}{Day}$$

$$\frac{bbl}{Cycle} = q_o \times \frac{Day}{Cycle}$$

$$\text{Volume of Starting Slug} = \frac{\frac{bbl}{Cycle}}{\text{\% of Starting Slug is produced}}$$

$$\text{Slug Length} = \frac{\text{Volume of Starting Slug}}{\text{Capacity of Tubing}\left(\frac{bbl}{ft}\right)}$$

$$\text{Opearting Valve Should be located below Working Fluid Level} = \frac{\text{Slug Length}}{2}$$

$$\text{Depth Operating Valve} = \text{Working Fluid Level} + \frac{\text{Slug Length}}{2}$$

$$p_t = \text{Tubing Pressure} + (\text{Slug Length} \times G_s)$$

2

Figure B.3 Intermittent flow Gas lift process (cont.)

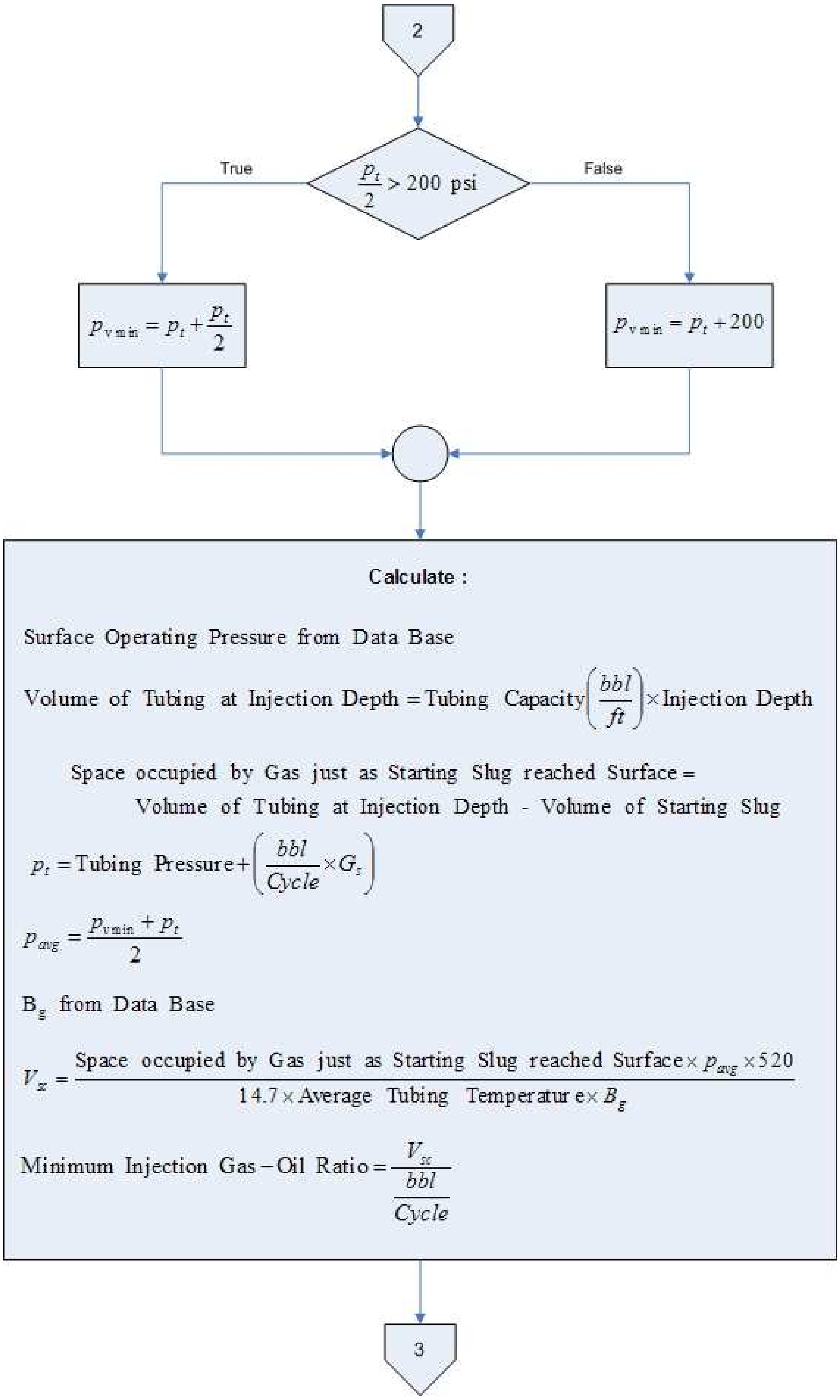

Figure B.3 Intermittent flow Gas lift process (cont.)

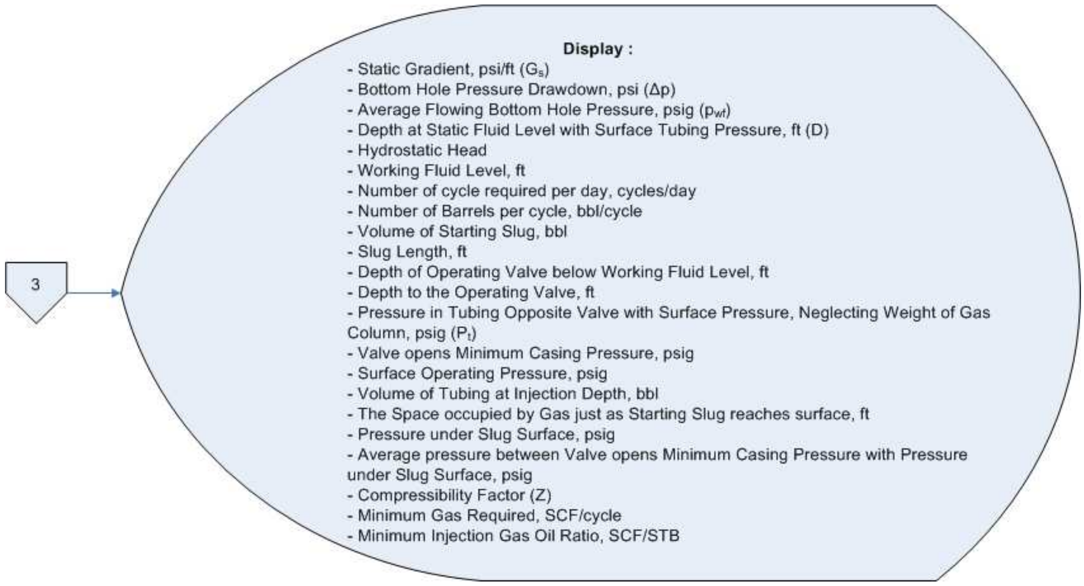

Figure B.3 Intermittent flow Gas lift process (cont.)

B.2.3 Sucker rod pump flowchart

The flowchart of sucker rod pump's design software includes parameters of input and output, equation and data base as follow as in Table B.4.

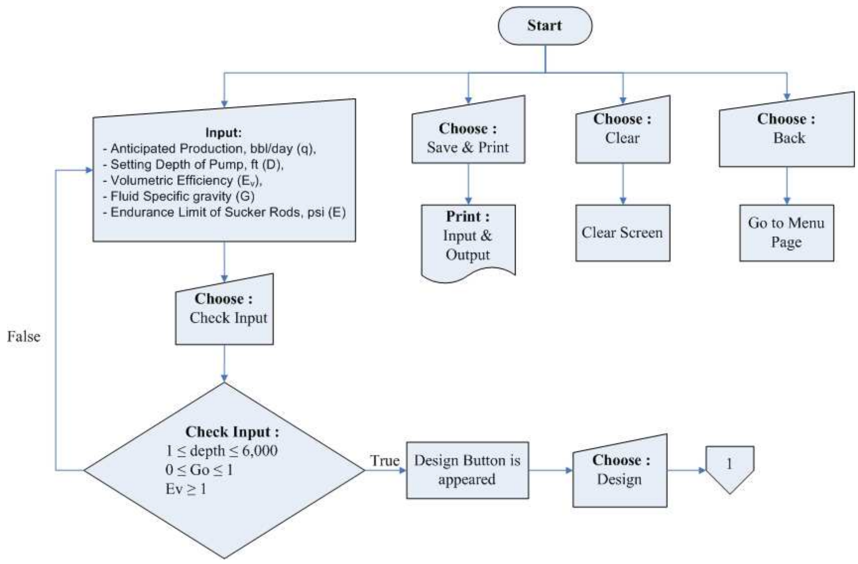

Figure B.4 Sucker rod pump process

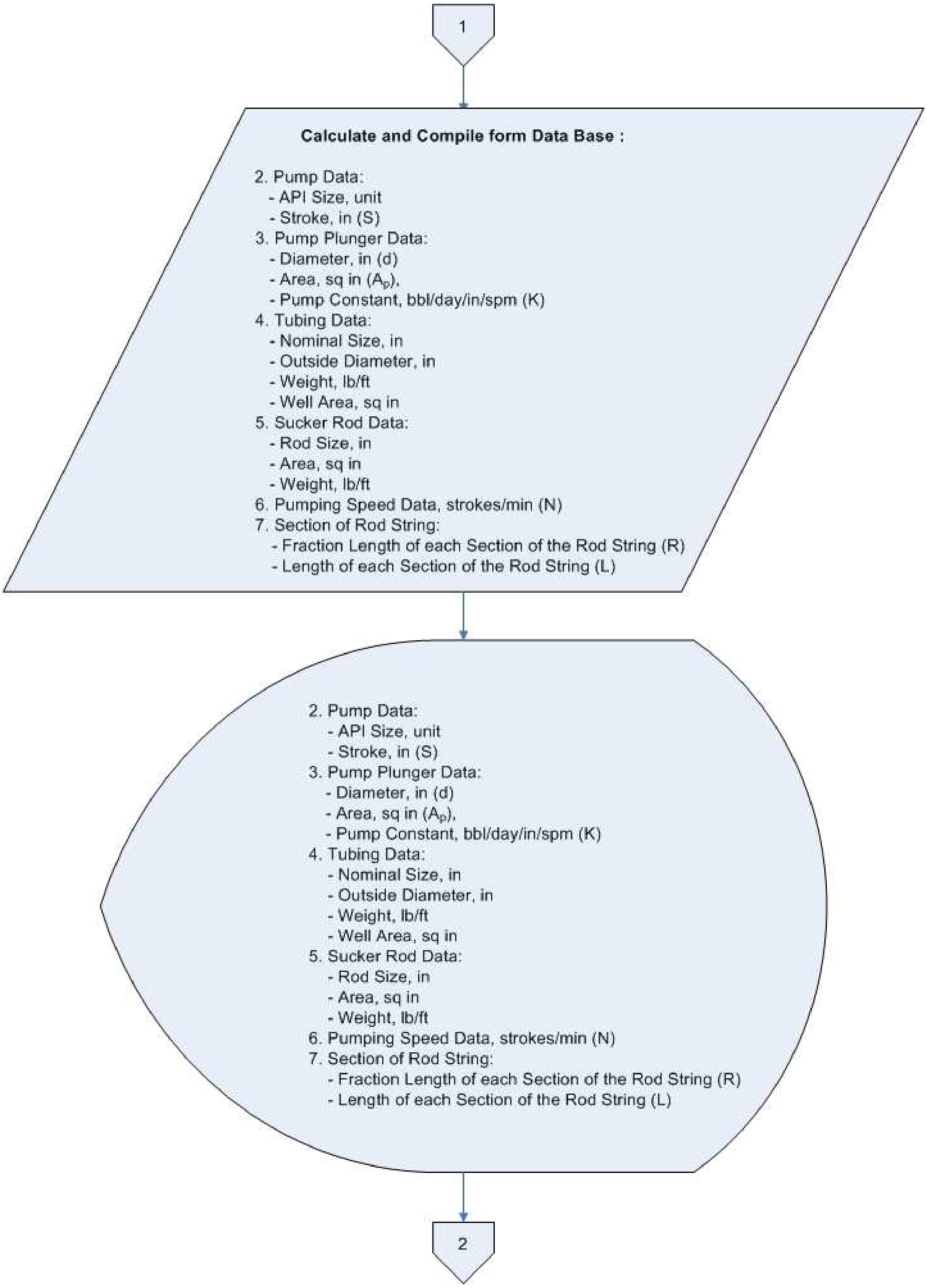

Figure B.4 Sucker rod pump process (cont.).

2

Calculate :

8. $\alpha = \dfrac{SN^2}{70{,}500}$

9. $S_p = S + \dfrac{40.8D^2\alpha}{30\times10^6} - \dfrac{5.2GDA_p}{30\times10^6}\left[\dfrac{L}{A_t} + \dfrac{L_1}{A_1} + \dfrac{L_2}{A_2} + \dots\right]$

10. $q = KA_pNE_v$

11. $W_r = M_1L_1 + M_2L_2 + \dots$

12. $W_f = 0.433G(LA_p - 0.294W_f)$

13. $W_{max} = W_f + W_r(1+\alpha)$

14. $\sigma_R = \dfrac{W_{max}}{A_{TopRod}}$

15. $C_i = 0.5W_f + W_r(1 - 0.0635G)$

16. $d = \dfrac{S(C_i - C_s)}{2W_c}$

17. Position of Counter Weight = Crank Length - Center of gravity from outer edge of Counter Weight - d

18. $T_p = \dfrac{(W_{max} - 0.95C_i)S}{2}$

19. $H_h = 7.36\times10^{-6}qgL_N$

20. $H_f = 6.31\times10^{-7}W_rSN$

21. $H_b = 1.5(H_h + H_f)$

22. $d_e = Zd_u\dfrac{N}{N_e}$

23. $n = \dfrac{237{,}000}{NL}$

3

.

Figure B.4 Sucker rod pump process (cont.).

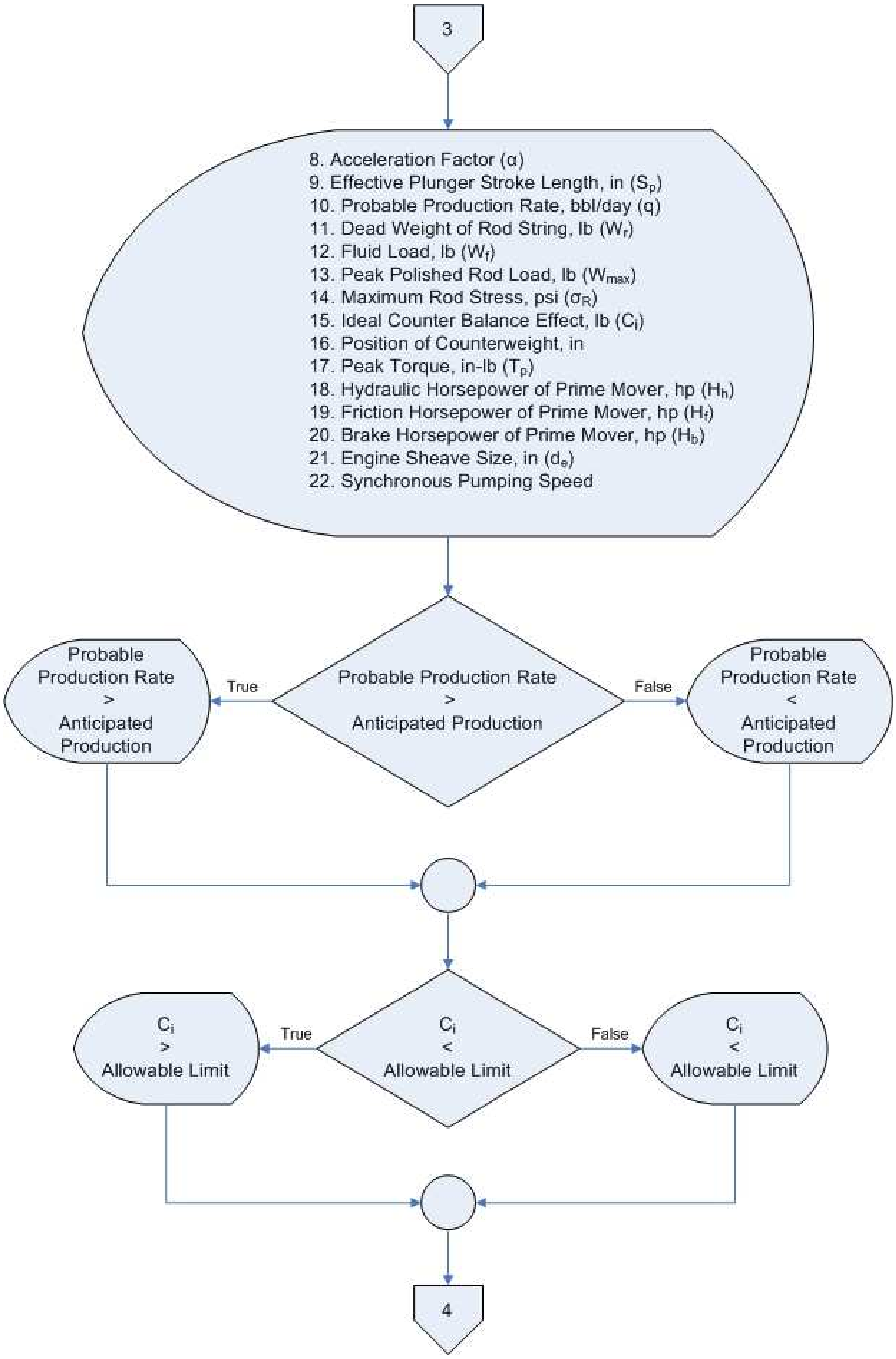

Figure B.4 Sucker rod pump process (cont.).

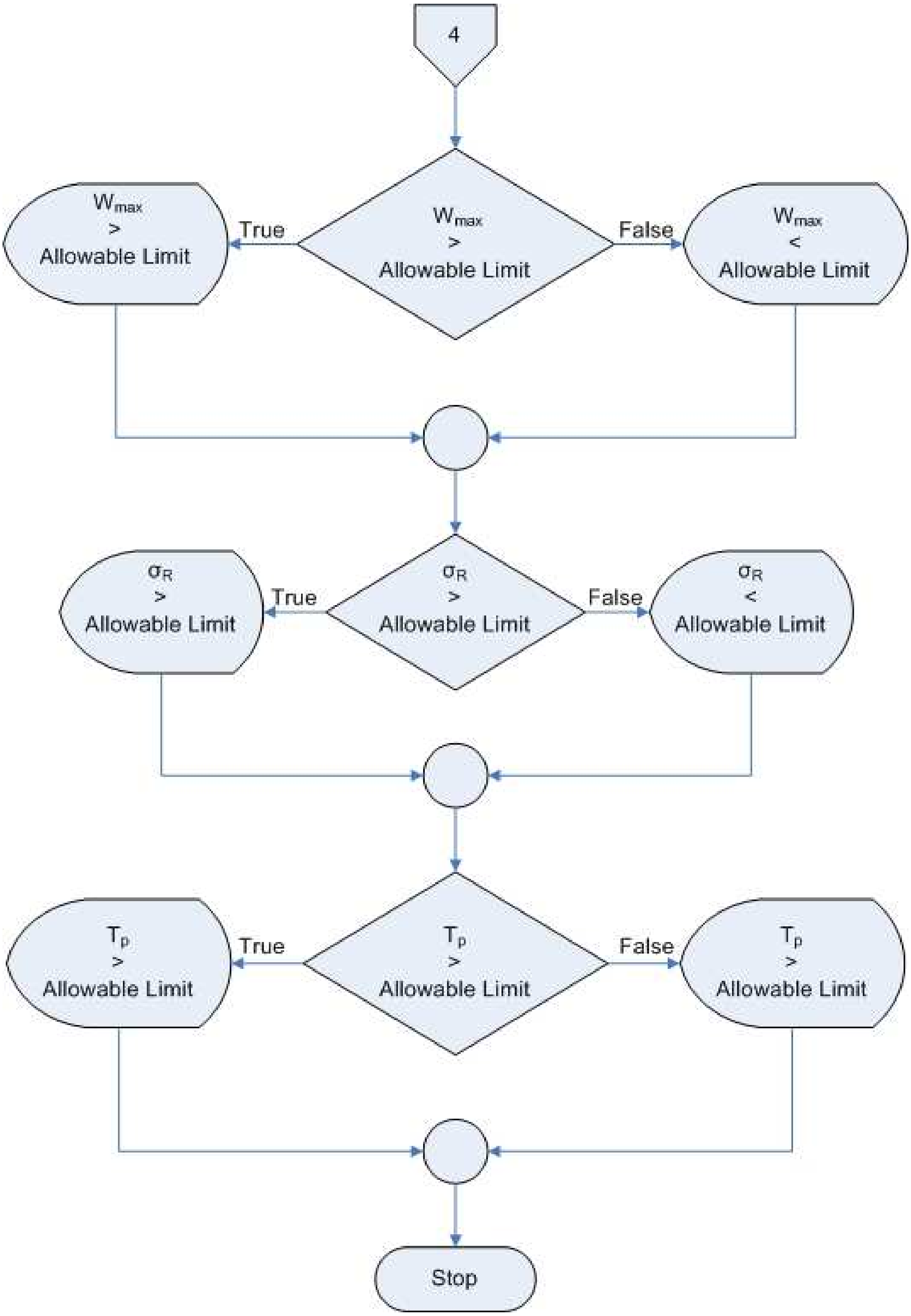

Figure B.4 Sucker rod pump process (cont.).

B.3 Programming

The topic shows and explains source codes of each module that includes source codes of main menu, electrical submersible pump, intermittent flow gas lift and sucker rod pump. Each module of artificial lift includes sub codes that are command of checking input, design, save and print documents, clear screen and back to main menu. Finally, source codes of text help in each module are presented in this topic B.

B.3.1 Main menu

The menu page of ALOP includes 2 functions that are a help label (green color) and three modules (electrical submersible pump, intermittent flow gas lift and sucker rod pump) as follow as in Figure B.5.

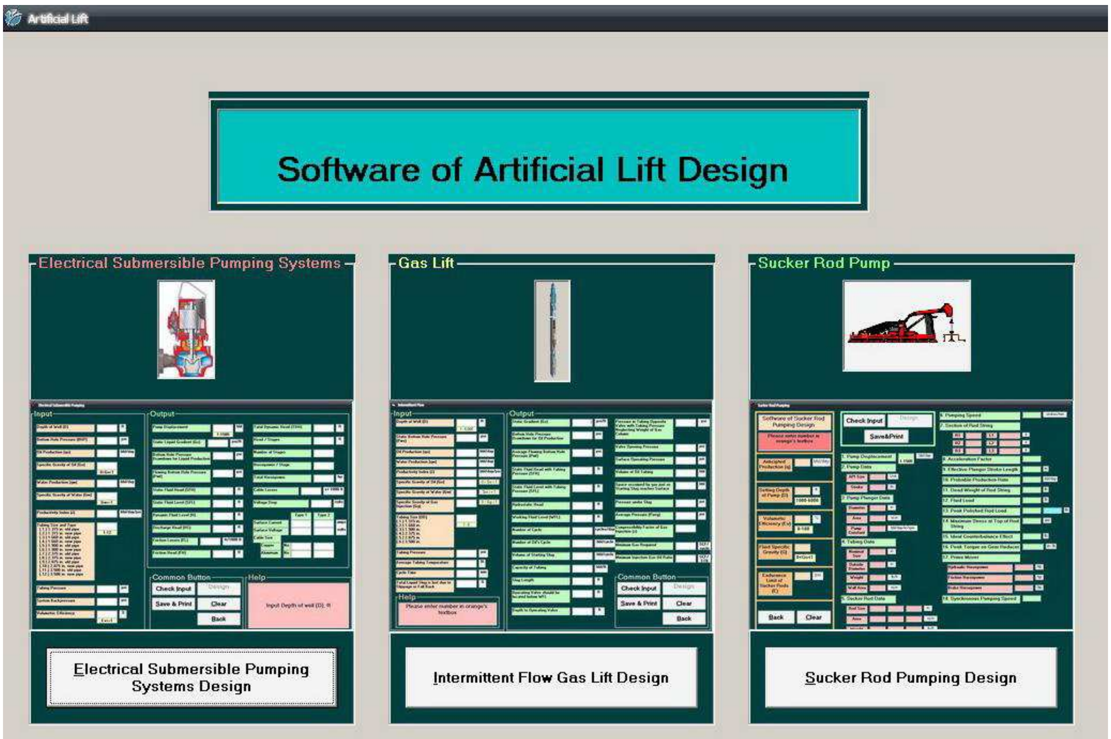

Figure B.5 The main page.

B.3.1.1 Source code of help label (green color)

```
Private Sub Timer1_Timer()
Static number
  number = number + 1
  Select Case number
  Case 1
    Label15.Caption = "User can choose type of artificial lift design"
  Case 2
    Label15.Caption = "Such as"
  Case 3
    Label15.Caption = "Electrical Submersible Pumping Design (Alt+E)"
  Case 4
    Label15.Caption = "Gas Lift Design (Alt+G)"
  Case 5
    Label15.Caption = "Sucker Rod Pumping Design (Alt+S)"
  Case 6
    Label15.Caption = "and All Programes use Orange Color that is agent of 'Input'"
  Case 7
    Label15.Caption = "and All Programes use Green Color that is agent 'Output'"
  Case 8
    Label15.Caption = "Software of Artificial Lift Design"
    number = 0
  End Select
End Sub
```

B.3.1.2 Source code of three modules (electrical submersible pump, gas lift and sucker rod pump)

```
Private Sub Command1_Click()
  Electrical_Submersible_Pumping.Show
End Sub
Private Sub Command2_Click()
  Gas_Lift.Show
End Sub
Private Sub Command3_Click()
  Sucker_Rod_Pumping.Show
```

End Sub

B.3.2 Electrical submersible pump module

The electrical submersible pump module includes 5 command buttons (gray color) that are checking input, design, save and print documents, clear screen and back to main menu as follow as in Figure B.6.

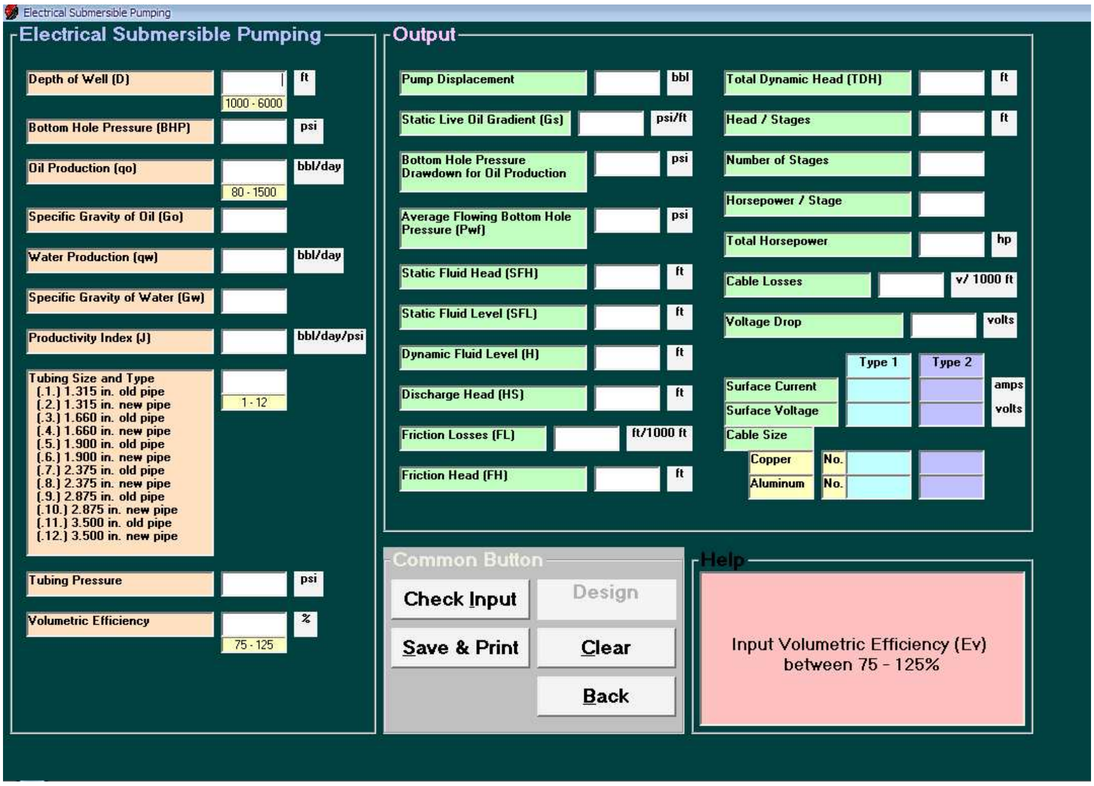

Figure B.6 Electrical submersible pump’s design page.

B.3.2.1 Source code of checking input button of electrical submersible pump module

```
Private Sub check_Click()
    Dim Response As Variant
    Dim Again As Variant
    d.BackColor = &HC0E0FF
    qo.BackColor = &HC0E0FF
    tst.BackColor = &HC0E0FF
```

```
ev.BackColor = &HC0E0FF
tst.BackColor = &HC0E0FF
ev.BackColor = &HC0E0FF
pd.Text = ""
gs.Text = ""
dd.Text = ""
pwf.Text = ""
sfh.Text = ""
sfl.Text = ""
h.Text = ""
hs.Text = ""
fl.Text = ""
fh.Text = ""
tdh.Text = ""
hes.Text = ""
ns.Text = ""
hps.Text = ""
thp.Text = ""
cu1.Text = ""
cu2.Text = ""
al1.Text = ""
al2.Text = ""
cl.Text = ""
vd.Text = ""
sc1.Text = ""
sc2.Text = ""
sv1.Text = ""
sv2.Text = ""
If d.Text = "" Or bhp.Text = "" Or qo.Text = "" Or go.Text = "" Or qw.Text = "" Or gw.Text = "" Or j.Text = "" Or tst.Text =
"" Or pt.Text = "" Or ev.Text = "" Then
    Response = MsgBox("Please enter number in orange's text box", vbCritical + vbOKOnly, "Error !!")
    Exit Sub
End If
If d > 6000 Or d < 1000 Then
    d.BackColor = &HFF&
    Response = MsgBox("Depth of well should be between 1,000 to 6,000 ft", vbCritical + vbOKOnly, "Error !!")
```

```
        Again = MsgBox("Please enter new depth of well", vbInformation + vbOKOnly, "New number !!")
    End If
    If qo > 1500 Or qo < 80 Then
        qo.BackColor = &HFF&
        Response = MsgBox("Oil production should be between 80 to 1,500 bbl/day", vbCritical + vbOKOnly, "Error !!")
        Again = MsgBox("Please enter new oil production", vbInformation + vbOKOnly, "New number !!")
    End If
    If tst > 12 Or tst < 1 Then
        tst.BackColor = &HFF&
        Response = MsgBox("Choose tubing size and type with No.1 to 12", vbCritical + vbOKOnly, "Error !!")
        Again = MsgBox("Please choose new tubing size and type", vbInformation + vbOKOnly, "New number !!")
    End If
    If ev > 125 Or ev < 75 Then
        ev.BackColor = &HFF&
        Response = MsgBox("Volumetric efficiency should be between 75 to 125%", vbCritical + vbOKOnly, "Error !!")
        Again = MsgBox("Please enter new volumetric efficiency", vbInformation + vbOKOnly, "New number !!")
    End If
    pd = Round((Val(qo) + Val(qw)) / Val(ev) * 100, 2)
    If pd > 1500 Or pd < 80 Then
        qo.BackColor = &HFF&
        qw.BackColor = &HFF&
        ev.BackColor = &HFF&
        Response = MsgBox("Pump displacement should be between 80 to 1,500 bbl/day", vbCritical + vbOKOnly, "Error !!")
        Again = MsgBox("Please enter new oil production or water production or volumetric efficiency", vbInformation +
vbOKOnly, "New number !!")
    End If
    If d <= 6000 And d >= 1000 And qo <= 1500 And qo >= 80 And tst <= 12 And tst >= 1 And ev <= 125 And ev >= 75 And
pu_d <= 1500 And pu_d >= 80 Then
        d.BackColor = &HC0E0FF
        qo.BackColor = &HC0E0FF
        qw.BackColor = &HC0E0FF
        tst.BackColor = &HC0E0FF
        ev.BackColor = &HC0E0FF
        MsgBox "Clear and go to design of a pumping installation"
        Timer2.Enabled = False
        cmdcal.Visible = True
```

```
      d.Enabled = False
      bhp.Enabled = False
      qo.Enabled = False
      go.Enabled = False
      qw.Enabled = False
      gw.Enabled = False
      j.Enabled = False
      tst.Enabled = False
      pt.Enabled = False
      ev.Enabled = False
   End If
End Sub
```

B.3.2.2 Source code of design button of electrical submersible pump module

```
Private Sub cmdcal_Click()
              Dim Response As Variant
              cmdcal.Visible = False
                            gs = Round(0.433 * (go + (qw / qo * gw)), 2)
                            dd = Round(pd / j, 2)
                            pwf = Round(bhp - pd, 2)
                            sfh = Round((bhp - pt) / gs, 2)
                            sfl = Round(d - sfh, 2)
                            h = Round(sfl + (pd / gs), 2)
                            hs = Round(pt / gs, 2)
                            If tst = 1 Then
                               fl = Round(0.003 * (pd ^ 1.8205), 2)
                            End If
                            If tst = 2 Then
                               fl = Round(0.002 * (pd ^ 1.808), 2)
                            End If
                            If tst = 3 Then
                               fl = Round(0.001 * (pd ^ 1.797), 2)
                            End If
                            If tst = 4 Then
                               fl = Round(0.00058 * (pd ^ 1.803), 2)
```

```
End If
If tst = 5 Then
    fl = Round(0.000475 * (pd ^ 1.792), 2)
End If
If tst = 6 Then
    fl = Round(0.000325 * (pd ^ 1.775), 2)
End If
If tst = 7 Then
    fl = Round(0.000205 * (pd ^ 1.763), 2)
End If
If tst = 8 Then
    fl = Round(0.000141 * (pd ^ 1.763), 2)
End If
If tst = 9 Then
    fl = Round(0.000031 * (pd ^ 1.895), 2)
End If
If tst = 10 Then
    fl = Round(2 * 10 ^ -14 * (pd ^ 4.814), 2)
End If
If tst = 11 Then
    fl = Round(7 * 10 ^ -7 * (pd ^ 2.31), 2)
End If
If tst = 12 Then
    fl = Round(0.0127 * (pd ^ 0.911), 2)
End If    p
fh = Round(fl * d / 1000, 2)
tdh = Round(Val(h) + hs + fh, 2)
hes = Round((-3 * 10 ^ -7 * pd ^ 2) - (0.0004 * pd) + 53.383, 2)
ns = Round(tdh / hes, 2)
hps = Round((0.00012 * pd) + 1.799, 2)
thp = Round(hps * ns, 2)
cl = 28
vd = 28 * d / 1000
If thp <= 24 Then
    sc1 = 28
    sc2 = 17
```

```
    sv1 = 440 + vd
    sv2 = 760 + vd
    cu1 = 8
    al1 = 6
    cu2 = 10
    al2 = 8
End If
If thp > 24 And thp <= 35 Then
    sc1 = 40
    sc2 = 23
    sv1 = 440 + vd
    sv2 = 760 + vd
    cu1 = 6
    al1 = 4
    cu2 = 8
    al2 = 6
End If
If thp > 35 And thp <= 45 Then
    sc1 = 60
    sc2 = 35
    sv1 = 440 + vd
    sv2 = 740 + vd
    cu1 = 4
    al1 = 2
    cu2 = 6
    al2 = 4
End If
If thp > 45 And thp <= 55 Then
    sc1 = 72
    sc2 = 42
    sv1 = 430 + vd
    sv2 = 745 + vd
    cu1 = 2
    al1 = "1/0"
    cu2 = 6
    al2 = 4
```

```
End If
If thp > 55 And thp <= 72.5 Then
    sc1 = 34
    sc2 = 0
    sv1 = 1010 + vd
    sv2 = 0
    cu1 = 6
    al1 = 4
    cu2 = 0
    al2 = 0
End If
If thp > 72.5 And thp <= 80 Then
    sc1 = 35
    sc2 = 0
    sv1 = 1350 + vd
    sv2 = 0
    cu1 = 6
    al1 = 4
    cu2 = 0
    al2 = 0
End If
If thp > 80 And thp <= 97.5 Then
    sc1 = 42
    sc2 = 0
    sv1 = 1270 + vd
    sv2 = 0
    cu1 = 6
    al1 = 4
    cu2 = 0
    al2 = 0
End If
If thp > 97.5 And thp <= 112.5 Then
    sc1 = 46
    sc2 = 0
    sv1 = 1300 + vd
    sv2 = 0
```

```
    cu1 = 6
    al1 = 4
    cu2 = 0
    al2 = 0
End If
If thp > 112.5 And thp <= 137.5 Then
    sc1 = 68
    sc2 = 35
    sv1 = 1125 + vd
    sv2 = 2270 + vd
    cu1 = 4
    al1 = 2
    cu2 = 6
    al2 = 4
End If
If thp > 137.5 And thp <= 165 Then
    sc1 = 70
    sc2 = 46
    sv1 = 1300 + vd
    sv2 = 1950 + vd
    cu1 = 4
    al1 = 2
    cu2 = 6
    al2 = 4
End If
If thp > 165 And thp <= 190 Then
    sc1 = 92
    sc2 = 53
    sv1 = 1180 + vd
    sv2 = 2040 + vd
    cu1 = 2
    al1 = "1/0"
    cu2 = 4
    al2 = 2
End If
If thp > 190 And thp <= 212.5 Then
```

```
    sc1 = 105
    sc2 = 53
    sv1 = 1130 + vd
    sv2 = 2270 + vd
    cu1 = 1
    al1 = "2/0"
    cu2 = 4
    al2 = 2
End If
If thp > 212.5 And thp <= 237.5 Then
    sc1 = 110
    sc2 = 63
    sv1 = 1210 + vd
    sv2 = 2100 + vd
    cu1 = 1
    al1 = "2/0"
    cu2 = 4
    al2 = 2
End If
If thp > 237.5 And thp <= 262.5 Then
    sc1 = 105
    sc2 = 0
    sv1 = 1405 + vd
    sv2 = 0
    cu1 = 1
    al1 = "2/0"
    cu2 = 0
    al2 = 0
End If
If thp > 262.5 And thp <= 287.5 Then
    sc1 = 105
    sc2 = 0
    sv1 = 1565 + vd
    sv2 = 0
    cu1 = 1
    al1 = "2/0"
```

```
    cu2 = 0
    al2 = 0
End If
If thp > 287.5 And thp <= 325 Then
    sc1 = 105
    sc2 = 82
    sv1 = 1675 + vd
    sv2 = 2265 + vd
    cu1 = 1
    al1 = "2/0"
    cu2 = 0
    al2 = 0
End If
If thp > 325 And thp <= 362.5 Then
    sc1 = 105
    sc2 = 0
    sv1 = 1950 + vd
    sv2 = 0
    cu1 = 1
    al1 = "2/0"
    cu2 = 0
    al2 = 0
End If
If thp > 362.5 And thp <= 387.5 Then
    sc1 = 105
    sc2 = 0
    sv1 = 2150 + vd
    sv2 = 0
    cu1 = 1
    al1 = "2/0"
    cu2 = 0
    al2 = 0
End If
If thp > 387.5 Then
    sc1 = 105
    sc2 = 0
```

```
        sv1 = 2225 + vd
        sv2 = 0
        cu1 = 1
        al1 = "2/0"
        cu2 = 0
        al2 = 0
      End If
        d.Enabled = True
        bhp.Enabled = True
        qo.Enabled = True
        go.Enabled = True
        qw.Enabled = True
        gw.Enabled = True
        j.Enabled = True
        tst.Enabled = True
        pt.Enabled = True
        ev.Enabled = True
      Response = MsgBox("*****Succesfully Design*****", vbOKOnly, "Finished !!")
End Sub
```

B.3.2.3 Source code of save and print button of electrical submersible pump module

```
Private Sub Command1_Click()
dlg.ShowPrinter
  Printer.Print "     Electrical Submersible Pumping"
  Printer.Print "=================================================================="
  Printer.Print "     Input"
  Printer.Print "Depth of Well, ft (D) = "; IIf(d.Text = "", "No Data", d.Text)
  Printer.Print "Static Bottom Hole Pressure, psi (BHP) = "; IIf(bhp.Text = "", "No Data", bhp.Text)
  Printer.Print "Oil Production, bbl/day (qo) = "; IIf(qo.Text = "", "No Data", qo.Text)
  Printer.Print "Water Production, bbl/day (qw) = "; IIf(qw.Text = "", "No Data", qw.Text)
  Printer.Print "Productivity Index, bbl/day/psi (J) = "; IIf(j.Text = "", "No Data", j.Text)
  Printer.Print "Specific Gravity of Oil (Go) = "; IIf(go.Text = "", "No Data", go.Text)
  Printer.Print "Specific Gravity of Water (Gw) = "; IIf(gw.Text = "", "No Data", gw.Text)
  Printer.Print "Productivity Index, bbl/day/psi (J) = "; IIf(j.Text = "", "No Data", j.Text)
```

```
    Printer.Print "Tubing Size and Type = "; IIf(tst.Text = "", "No Data", IIf(tst.Text = "1", "1.315 in. old pipe", IIf(tst.Text = "2", "1.315 in. new pipe", IIf(tst.Text = "3", "1.660 in. old pipe", IIf(tst.Text = "4", "1.660 in. new pipe", IIf(tst.Text = "5", "1.900 in. old pipe", IIf(tst.Text = "6", "1.900 in. new pipe", IIf(tst.Text = "7", "2.375 in. old pipe", IIf(tst.Text = "8", "2.375 in. new pipe", IIf(tst.Text = "9", "2.875 in. old pipe", IIf(tst.Text = "10", "2.875 in. new pipe", IIf(tst.Text = "11", "3.500 in. old pipe", "3.500 in. new pipe"))))))))))))
    Printer.Print "Tubing Pressure, psi = "; IIf(pt.Text = "", "No Data", pt.Text)
    Printer.Print "Volemetric Efficiency, % = "; IIf(ev.Text = "", "No Data", ev.Text)
    Printer.Print "=================================================================="
    Printer.Print "     Output"
    Printer.Print "Static Live Oil Gradient, psi/ft (Gs) = "; IIf(gs.Text = "", "No Data", gs.Text)
    Printer.Print "Bottom Hole Pressure Drawdown for Oil Production ,psi = "; IIf(dd.Text = "", "No Data", dd.Text)
    Printer.Print "Average Flowing Bottom Hole Pressure, psi (Pwf) = "; IIf(pwf.Text = "", "No Data", pwf.Text)
    Printer.Print "Static Fluid Head, ft (SGH)= "; IIf(sfh.Text = "", "No Data", sfh.Text)
    Printer.Print "Static Fluid Level, ft (SFL) = "; IIf(sfl.Text = "", "No Data", sfl.Text)
    Printer.Print "Dynamic Fluid Level, ft (H) = "; IIf(h.Text = "", "No Data", h.Text)
    Printer.Print "Discharge Head, ft (HS) = "; IIf(hs.Text = "", "No Data", hs.Text)
    Printer.Print "Friction Losses, ft/1000 ft (FL) = "; IIf(fl.Text = "", "No Data", fl.Text)
    Printer.Print "Friction Head, ft (FH)) = "; IIf(fh.Text = "", "No Data", fh.Text)
    Printer.Print "Total Dynamic Head, ft (TDH) = "; IIf(tdh.Text = "", "No Data", tdh.Text)
    Printer.Print "Head / Stages = "; IIf(hes.Text = "", "No Data", hes.Text)
    Printer.Print "Number of Stages = "; IIf(ns.Text = "", "No Data", ns.Text)
    Printer.Print "Horsepower / Stages = "; IIf(hps.Text = "", "No Data", hps.Text)
    Printer.Print "Total Horsepower, hp = "; IIf(thp.Text = "", "No Data", thp.Text)
    Printer.Print "Cable Losses, v/1000 ft = "; IIf(cl.Text = "", "No Data", cl.Text)
    Printer.Print "Voltage Drop, volts = "; IIf(vd.Text = "", "No Data", vd.Text)
    Printer.Print "Type 1 of Cable Size : Copper No."; IIf(cu1.Text = "", "No Data", cu1.Text)
    Printer.Print "Type 1 of Cable Size : Aluminum No."; IIf(al1.Text = "", "No Data", al1.Text)
    Printer.Print "Type 1 of Surface Current, amps = "; IIf(sc1.Text = "", "No Data", sc1.Text)
    Printer.Print "Type 1 of Surface Voltage, volts = "; IIf(sv1.Text = "", "No Data", sv1.Text)
    Printer.Print "Type 2 of Cable Size : Copper No."; IIf(cu2.Text = "", "No Data", cu2.Text)
    Printer.Print "Type 2 of Cable Size : Aluminum No."; IIf(al2.Text = "", "No Data", al2.Text)
    Printer.Print "Type 2 of Surface Current, amps = "; IIf(sc2.Text = "", "No Data", sc2.Text)
    Printer.Print "Type 2 of Surface Voltage, volts = "; IIf(sv2.Text = "", "No Data", sv2.Text)
    Printer.EndDoc
End Sub
```

B.3.2.4 Source code of clear screen button of of electrical submersible pump module

```
Private Sub Command2_Click()
    d.Text = ""
    bhp.Text = ""
    qo.Text = ""
    qw.Text = ""
    j.Text = ""
    go.Text = ""
    gw.Text = ""
    j.Text = ""
    tst.Text = ""
    pt.Text = ""
    ev.Text = ""
    pd.Text = ""
    gs.Text = ""
    dd.Text = ""
    pwf.Text = ""
    sfh.Text = ""
    sfl.Text = ""
    h.Text = ""
    hs.Text = ""
    fl.Text = ""
    fh.Text = ""
    tdh.Text = ""
    hes.Text = ""
    ns.Text = ""
    hps.Text = ""
    thp.Text = ""
    cl.Text = ""
    vd.Text = ""
    sc1.Text = ""
    sc2.Text = ""
    sv1.Text = ""
    sv2.Text = ""
```

```
    cu1.Text = ""
    al1.Text = ""
    cu2.Text = ""
    al2.Text = ""
End Sub
```

B.3.2.5 Source code of back button of electrical submersible pump module

```
Private Sub Command3_Click()
    Artificial_Lift.Show
End Sub
```

B.3.3 Intermittent flow gas lift module

The intermittent flow gas lift module includes 5 command buttons (gray color) that are checking input, design, save and print documents, clear screen and back to main menu as follow as in Figure B.7.

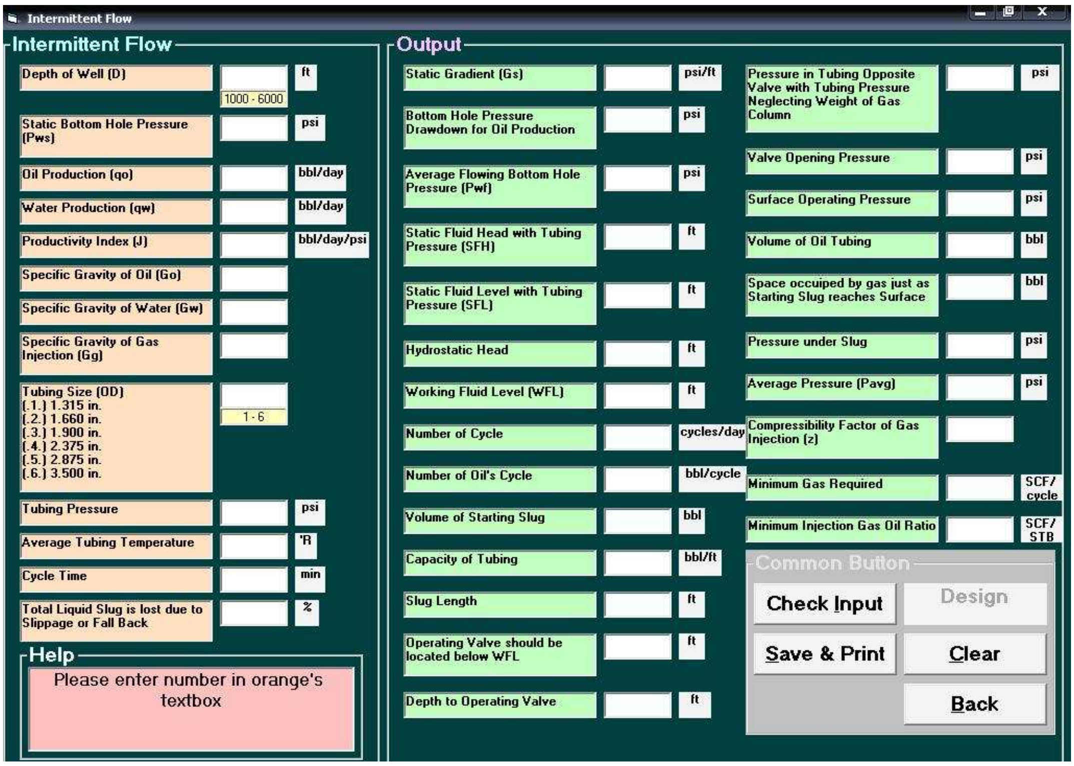

Figure B.7 Intermittent flow gas lift design.

B.3.3.1 Source code of checking input button of intermittent flow gas lift module

```
Private Sub check_Click()
    Dim Response As Variant
    Dim Again As Variant
    Timer2.Enabled = False
    cmdcal.Visible = False
    d.BackColor = &HC0E0FF
    gs.Text = ""
    dd.Text = ""
    pwf.Text = ""
    sfh.Text = ""
    sfl.Text = ""
    hh.Text = ""
    wfl.Text = ""
    nB.Text = ""
    noB.Text = ""
    vss.Text = ""
    ct.Text = ""
    sl.Text = ""
    bwfl.Text = ""
    dov.Text = ""
    ptov.Text = ""
    vop.Text = ""
    sop.Text = ""
    vot.Text = ""
    s.Text = ""
    pus.Text = ""
    pavg.Text = ""
    z.Text = ""
    vsB.Text = ""
    migor.Text = ""
```

```
    If d.Text = "" Or pws.Text = "" Or qo.Text = "" Or qw.Text = "" Or j.Text = "" Or go.Text = "" Or gw.Text = "" Or gg.Text =
"" Or ts.Text = "" Or pt.Text = "" Or ttavg.Text = "" Or ct.Text = "" Or fb.Text = "" Then
        Response = MsgBox("Please enter number in orange's text box", vbCritical + vbOKOnly, "Error !!")
        Exit Sub
    End If
    If d < 1000 Or d > 6000 Then
        d.BackColor = &HFF&
        Response = MsgBox("Depth of Well should be between 1,000 to 6,000 ft", vbCritical + vbOKOnly, "Error !!")
        Again = MsgBox("Please enter new Depth of Well", vbInformation + vbOKOnly, "New number !!")
    End If
    If ts > 6 Or ts < 1 Then
        ts.BackColor = &HFF&
        Response = MsgBox("Choose tubing size with No.1 to 6", vbCritical + vbOKOnly, "Error !!")
        Again = MsgBox("Please choose new tubing size", vbInformation + vbOKOnly, "New number !!")
    End If
    If d >= 1000 And d <= 6000 And ts < 6 And ts > 1 Then
        d.BackColor = &HC0E0FF
        ts.BackColor = &HC0E0FF
        MsgBox "Clear and go to design Intermittent Flow"
        Timer2.Enabled = False
        cmdcal.Visible = True
        d.Enabled = False
        pws.Enabled = False
        qo.Enabled = False
        qw.Enabled = False
        j.Enabled = False
        go.Enabled = False
        gw.Enabled = False
        gg.Enabled = False
        ts.Enabled = False
        pt.Enabled = False
        ttavg.Enabled = False
        ct.Enabled = False
        fb.Enabled = False
    End If
End Sub
```

B.3.3.2 Source code of design button of intermittent flow gas lift module

```
Private Sub cmdcal_Click()
    Dim min_dif As Currency
    Dim ppc As Currency
    Dim tpc As Currency
    Dim denpr As Currency
    Dim ppr As Currency
    Dim tpr As Currency
    Dim z1 As Currency
    Dim z2 As Currency
    Dim z3 As Currency
    Dim z4 As Currency
    Dim z5 As Currency
    Dim z6 As Currency
    Dim z7 As Currency
    Dim z8 As Currency
    Dim z9 As Currency
    Dim z10 As Currency
    gs = Round(0.433 * (go + (qw / qo * gw)), 2)
    pd = Round(qo / j, 2)
    pwf = Round(pws - pd, 2)
    sfh = Round((pws - pt) / gs, 2)
    sfl = Round(d - sfh, 2)
    hh = Round(pd / gs, 2)
    wfl = Round(Val(sfl) + Val(hh), 2)
    noc = Round(1440 / ct, 2)
    nooc = Round(qo / noc, 2)
    vss = Round(nooc / fb * 100, 2)
        If ts = 1 Then
            cot = 0.00107
        End If
```

```
    If ts = 2 Then
        cot = 0.00185
    End If
    If ts = 3 Then
        cot = 0.00252
    End If
    If ts = 4 Then
        cot = 0.00387
    End If
    If ts = 5 Then
        cot = 0.00579
    End If
    If ts = 6 Then
        cot = 0.0087
    End If
sl = Round(vss / cot, 2)
bwfl = Round(sl / 2, 2)
dov = Round(Val(wfl) + Val(bwfl), 2)
ptov = Round(pt + (sl * gs), 2)
min_dif = Round(ptov / 2, 2)
If min_dif > 200 Then
    vop = ptov + min_dif
Else
    vop = ptov + 200
End If
    If (dov >= 1000 And dov < 1500) Then
        sop = Round(0.957 * vop, 2)
    End If
    If (dov >= 1500 And dov < 2000) Then
        sop = Round(0.953 * vop, 2)
    End If
    If (dov >= 2000 And dov < 2500) Then
        sop = Round(0.948 * vop, 2)
    End If
    If (dov >= 2500 And dov < 3000) Then
        sop = Round(0.93 * vop, 2)
```

```
        End If
        If (dov >= 3000 And dov < 3500) Then
            sop = Round(0.923 * vop, 2)
        End If
        If (dov >= 3500 And dov < 4000) Then
            sop = Round(0.916 * vop, 2)
        End If
        If (dov >= 4000 And dov < 4500) Then
            sop = Round(0.913 * vop, 2)
        End If
        If (dov >= 4500 And dov < 5000) Then
            sop = Round(0.901 * vop, 2)
        End If
        If (dov >= 5000 And dov < 5500) Then
            sop = Round(0.874 * vop, 2)
        End If
        If (dov >= 5500 And dov < 6000) Then
            sop = Round(0.847 * vop, 2)
        End If
        If dov > 6000 Then
            sop = Round(0.873 * vop, 2)
        End If
    vot = Round(cot * dov, 2)
    s = Round(vot - vss, 2)
    pus = Round(pt + (nooc / cot * gs), 2)
    pavg = Round((Val(vop) + Val(pus)) / 2, 2)
    ppc = 702.5 - (50 * gg)
    tpc = 167 + (316.67 * gg)
    denpr = (0.27 * pavg / (702.5 - (50 * gg)) / 0.99 * (167 + (316.67 * gg)) / ttavg)
    ppr = pavg / ppc
    tpr = ttavg / tpc
    z1 = 1 + (denpr * (0.31506237 + (-1.0467099 / tpr) + (-0.57832729 / tpr ^ 3))) + (denpr ^ 2 * (0.53530771 + (-0.61232032 /
tpr))) + (0.06422513 * denpr ^ 5 / tpr) + (0.68157001 * denpr ^ 2 / tpr ^ 3 * (1 + (0.68446549 * denpr ^ 2)) * 10 ^ (-0.68446549 *
denpr ^ 2))
    denpr = (0.27 * pavg / (702.5 - (50 * gg)) / z1 * (167 + (316.67 * gg)) / ttavg)
```

z2 = 1 + (denpr * (0.31506237 + (-1.0467099 / tpr) + (-0.57832729 / tpr ^ 3))) + (denpr ^ 2 * (0.53530771 + (-0.61232032 / tpr))) + (0.06422513 * denpr ^ 5 / tpr) + (0.68157001 * denpr ^ 2 / tpr ^ 3 * (1 + (0.68446549 * denpr ^ 2)) * 10 ^ (-0.68446549 * denpr ^ 2))

denpr = (0.27 * pavg / (702.5 - (50 * gg)) / z2 * (167 + (316.67 * gg)) / ttavg)

z3 = 1 + (denpr * (0.31506237 + (-1.0467099 / tpr) + (-0.57832729 / tpr ^ 3))) + (denpr ^ 2 * (0.53530771 + (-0.61232032 / tpr))) + (0.06422513 * denpr ^ 5 / tpr) + (0.68157001 * denpr ^ 2 / tpr ^ 3 * (1 + (0.68446549 * denpr ^ 2)) * 10 ^ (-0.68446549 * denpr ^ 2))

denpr = (0.27 * pavg / (702.5 - (50 * gg)) / z3 * (167 + (316.67 * gg)) / ttavg)

z4 = 1 + (denpr * (0.31506237 + (-1.0467099 / tpr) + (-0.57832729 / tpr ^ 3))) + (denpr ^ 2 * (0.53530771 + (-0.61232032 / tpr))) + (0.06422513 * denpr ^ 5 / tpr) + (0.68157001 * denpr ^ 2 / tpr ^ 3 * (1 + (0.68446549 * denpr ^ 2)) * 10 ^ (-0.68446549 * denpr ^ 2))

denpr = (0.27 * pavg / (702.5 - (50 * gg)) / z4 * (167 + (316.67 * gg)) / ttavg)

z5 = 1 + (denpr * (0.31506237 + (-1.0467099 / tpr) + (-0.57832729 / tpr ^ 3))) + (denpr ^ 2 * (0.53530771 + (-0.61232032 / tpr))) + (0.06422513 * denpr ^ 5 / tpr) + (0.68157001 * denpr ^ 2 / tpr ^ 3 * (1 + (0.68446549 * denpr ^ 2)) * 10 ^ (-0.68446549 * denpr ^ 2))

denpr = (0.27 * pavg / (702.5 - (50 * gg)) / z5 * (167 + (316.67 * gg)) / ttavg)

z6 = 1 + (denpr * (0.31506237 + (-1.0467099 / tpr) + (-0.57832729 / tpr ^ 3))) + (denpr ^ 2 * (0.53530771 + (-0.61232032 / tpr))) + (0.06422513 * denpr ^ 5 / tpr) + (0.68157001 * denpr ^ 2 / tpr ^ 3 * (1 + (0.68446549 * denpr ^ 2)) * 10 ^ (-0.68446549 * denpr ^ 2))

denpr = (0.27 * pavg / (702.5 - (50 * gg)) / z6 * (167 + (316.67 * gg)) / ttavg)

z7 = 1 + (denpr * (0.31506237 + (-1.0467099 / tpr) + (-0.57832729 / tpr ^ 3))) + (denpr ^ 2 * (0.53530771 + (-0.61232032 / tpr))) + (0.06422513 * denpr ^ 5 / tpr) + (0.68157001 * denpr ^ 2 / tpr ^ 3 * (1 + (0.68446549 * denpr ^ 2)) * 10 ^ (-0.68446549 * denpr ^ 2))

denpr = (0.27 * pavg / (702.5 - (50 * gg)) / z7 * (167 + (316.67 * gg)) / ttavg)

z8 = 1 + (denpr * (0.31506237 + (-1.0467099 / tpr) + (-0.57832729 / tpr ^ 3))) + (denpr ^ 2 * (0.53530771 + (-0.61232032 / tpr))) + (0.06422513 * denpr ^ 5 / tpr) + (0.68157001 * denpr ^ 2 / tpr ^ 3 * (1 + (0.68446549 * denpr ^ 2)) * 10 ^ (-0.68446549 * denpr ^ 2))

denpr = (0.27 * pavg / (702.5 - (50 * gg)) / z8 * (167 + (316.67 * gg)) / ttavg)

z9 = 1 + (denpr * (0.31506237 + (-1.0467099 / tpr) + (-0.57832729 / tpr ^ 3))) + (denpr ^ 2 * (0.53530771 + (-0.61232032 / tpr))) + (0.06422513 * denpr ^ 5 / tpr) + (0.68157001 * denpr ^ 2 / tpr ^ 3 * (1 + (0.68446549 * denpr ^ 2)) * 10 ^ (-0.68446549 * denpr ^ 2))

denpr = (0.27 * pavg / (702.5 - (50 * gg)) / z9 * (167 + (316.67 * gg)) / ttavg)

z10 = 1 + (denpr * (0.31506237 + (-1.0467099 / tpr) + (-0.57832729 / tpr ^ 3))) + (denpr ^ 2 * (0.53530771 + (-0.61232032 / tpr))) + (0.06422513 * denpr ^ 5 / tpr) + (0.68157001 * denpr ^ 2 / tpr ^ 3 * (1 + (0.68446549 * denpr ^ 2)) * 10 ^ (-0.68446549 * denpr ^ 2))

denpr = (0.27 * pavg / (702.5 - (50 * gg)) / z10 * (167 + (316.67 * gg)) / ttavg)

```
    z = Round(1 + (denpr * (0.31506237 + (-1.0467099 / tpr) + (-0.57832729 / tpr ^ 3))) + (denpr ^ 2 * (0.53530771 + (-
0.61232032 / tpr))) + (0.06422513 * denpr ^ 5 / tpr) + (0.68157001 * denpr ^ 2 / tpr ^ 3 * (1 + (0.68446549 * denpr ^ 2)) * 10 ^ (-
0.68446549 * denpr ^ 2)), 4)
    vsc = Round(s * pavg / 14.7 * 520 / ttavg / z, 2)
    migor = Round(vsc / nooc, 2)
    cmdcal.Visible = False
    d.Enabled = True
    pws.Enabled = True
    qo.Enabled = True
    qw.Enabled = True
    j.Enabled = True
    go.Enabled = True
    gw.Enabled = True
    gg.Enabled = True
    ts.Enabled = True
    pt.Enabled = True
    ttavg.Enabled = True
    ct.Enabled = True
    fb.Enabled = True
End Sub
```

B.3.3.3 Source code of save and print button of intermittent flow gas lift module

```
Private Sub Command1_Click()
dlg.ShowPrinter
    Printer.Print "     Intermittent Flow Gas Lift Design"
    Printer.Print "================================================================="
    Printer.Print "     Input"
    Printer.Print "Depth of Well, ft (D) = "; IIf(d.Text = "", "No Data", d.Text)
    Printer.Print "Static Bottom Hole Pressure, psi (Pws) = "; IIf(pws.Text = "", "No Data", pws.Text)
    Printer.Print "Oil Production, bbl/day (qo) = "; IIf(qo.Text = "", "No Data", qo.Text)
    Printer.Print "Water Production, bbl/day (qw) = "; IIf(qw.Text = "", "No Data", qw.Text)
    Printer.Print "Productivity Index, bbl/day/psi (J) = "; IIf(j.Text = "", "No Data", j.Text)
    Printer.Print "Specific Gravity of Oil (Go) = "; IIf(go.Text = "", "No Data", go.Text)
    Printer.Print "Specific Gravity of Water (Gw) = "; IIf(gw.Text = "", "No Data", gw.Text)
    Printer.Print "Specific Gravity of Gas Injection (Gg) = "; IIf(gg.Text = "", "No Data", gg.Text)
```

```
    Printer.Print "Tubing Size, in = "; IIf(ts.Text = "", "No Data", IIf(ts.Text = "1", "1.315", IIf(ts.Text = "2", "1.660", IIf(ts.Text = "3", "1.900", IIf(ts.Text = "4", "2.375", IIf(ts.Text = "5", "2.875", "3.500"))))))
    Printer.Print "Tubing Pressure, psi = "; IIf(pt.Text = "", "No Data", pt.Text)
    Printer.Print "Average Tubing Temperature, °R = "; IIf(ttavg.Text = "", "No Data", ttavg.Text)
    Printer.Print "Cycle Time, min = "; IIf(ct.Text = "", "No Data", ct.Text)
    Printer.Print "Total Liquid Slug is lost due to Slippage or Fall Back, %  = "; IIf(fb.Text = "", "No Data", fb.Text)
    Printer.Print "=================================================================="
    Printer.Print "     Output"
    Printer.Print "Static Gradient, psi/ft (Gs) = "; IIf(gs.Text = "", "No Data", gs.Text)
    Printer.Print "Bottom Hole Pressure Drawdown for Oil Production, psi = "; IIf(pd.Text = "", "No Data", pd.Text)
    Printer.Print "Average Flowing Bottom Hole Pressure, psi (Pwf)  = "; IIf(pwf.Text = "", "No Data", pwf.Text)
    Printer.Print "Static Fluid Level with Tubing Pressure, ft (SFL) = "; IIf(sfl.Text = "", "No Data", sfl.Text)
    Printer.Print "Hydrostatic Head, ft = "; IIf(hh.Text = "", "No Data", hh.Text)
    Printer.Print "Working Fluid Level, ft (WFL) = "; IIf(wfl.Text = "", "No Data", wfl.Text)
    Printer.Print "Number of Cycle, cycles/day = "; IIf(nB.Text = "", "No Data", noB.Text)
    Printer.Print "Number of Oil's Cycle, bbl/cycle = "; IIf(noB.Text = "", "No Data", nooB.Text)
    Printer.Print "Volume of Starting Slug, bbl = "; IIf(vss.Text = "", "No Data", vss.Text)
    Printer.Print "Capacity of Tubing, bbl/ft = "; IIf(cot.Text = "", "No Data", cot.Text)
    Printer.Print "Slug Length, ft = "; IIf(sl.Text = "", "No Data", sl.Text)
    Printer.Print "Operating Valve should be located below WFL, ft = "; IIf(bwfl.Text = "", "No Data", bwfl.Text)
    Printer.Print "Depth to Operating Valve, ft = "; IIf(dov.Text = "", "No Data", dov.Text)
    Printer.Print "Pressure in Tubing Opposite Valve with Tubing Pressure Neglecting Weight of Gas Column, psi = "; IIf(ptov.Text = "", "No Data", ptov.Text)
    Printer.Print "Valve Opening Pressure, psi = "; IIf(vop.Text = "", "No Data", vop.Text)
    Printer.Print "Surface Operating Pressure, psi = "; IIf(sop.Text = "", "No Data", sop.Text)
    Printer.Print "Volume of Oil Tubing, bbl = "; IIf(vot.Text = "", "No Data", vot.Text)
    Printer.Print "Space occuiped by gas just as Starting Slug reaches Surface, bbl = "; IIf(s.Text = "", "No Data", s.Text)
    Printer.Print "Pressure under Slug, psi = "; IIf(pus.Text = "", "No Data", pus.Text)
    Printer.Print "Average Pressure, psi (Pavg) = "; IIf(pavg.Text = "", "No Data", pavg.Text)
    Printer.Print "Compressibility Factor of Gas Injection (z) = "; IIf(z.Text = "", "No Data", z.Text)
    Printer.Print "Minimum Gas Required, SCF = "; IIf(vsB.Text = "", "No Data", vsB.Text)
    Printer.Print "Minimum Injection Gas Oil Ratio, SCF/STB = "; IIf(migor.Text = "", "No Data", migor.Text)
        Printer.EndDoc
End Sub
```

B.3.3.4 Source code of clear button of intermittent flow gas lift module

```
Private Sub Command2_Click()
  d.Text = ""
  pws.Text = ""
  qo.Text = ""
  qw.Text = ""
  j.Text = ""
  go.Text = ""
  gw.Text = ""
  gg.Text = ""
  ts.Text = ""
  pt.Text = ""
  ct.Text = ""
  fb.Text = ""
  gs.Text = ""
  pd.Text = ""
  pwf.Text = ""
  sfl.Text = ""
  hh.Text = ""
  wfl.Text = ""
  nB.Text = ""
  noB.Text = ""
  vss.Text = ""
  cot.Text = ""
  sl.Text = ""
  bwfl.Text = ""
  dov.Text = ""
  ptov.Text = ""
  vop.Text = ""
  sop.Text = ""
  vot.Text = ""
  s.Text = ""
  pus.Text = ""
  pavg.Text = ""
```

```
 z.Text = ""
  vsB.Text = ""
  mgior.Text = ""
End Sub
```

B.3.3.5 Source code of back button of intermittent flow gas lift module

```
Private Sub Command3_Click()
   Gas_Lift.Show
End Sub
```

B.3.4 Sucker rod pump module

The sucker rod pump module includes 5 command buttons (gray color) that are checking input, design, save and print documents, clear screen and back to main menu as follow as in Figure B.8.

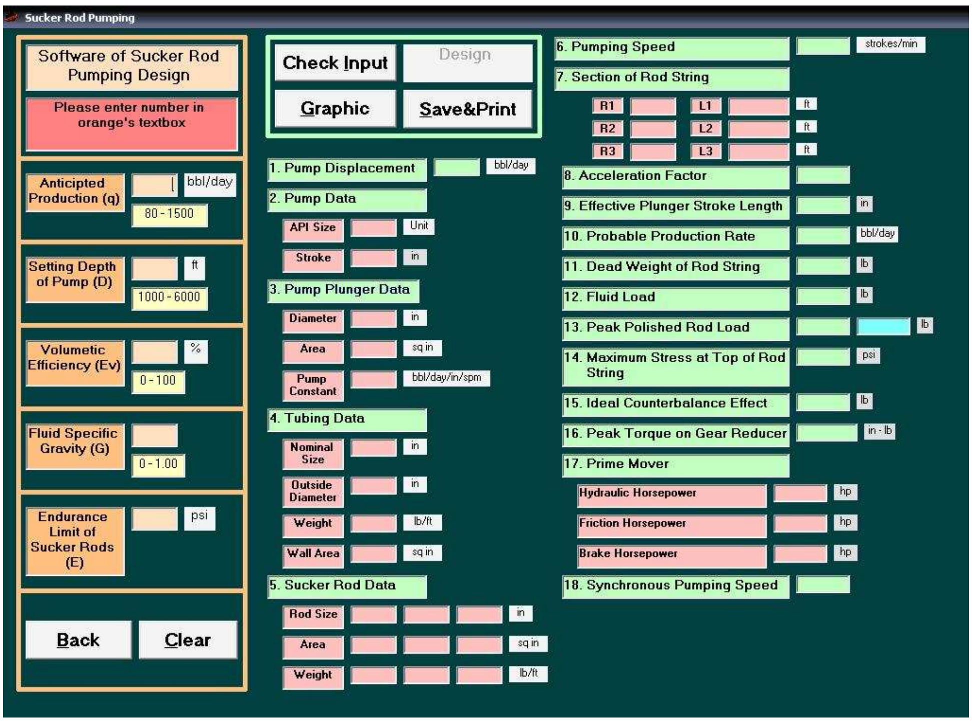

Figure B.8 sucker rod pump design.

B.3.4.1 Source code of checking input button of sucker rod pump module

```
Private Sub Cmdcheck_Click()
    Dim Response As Variant
    Dim Again As Variant
    Qo.Text = ""
    D.Text = ""
    Ev.Text = ""
    Go.Text = ""
    E.Text = ""
    Pd.Text = ""
    Pud.Text = ""
    Api.Text = ""
    Str.Text = ""
    Pg.Text = ""
    Dpg.Text = ""
    Apg.Text = ""
    Pc.Text = ""
    Td.Text = ""
    Go8.Text = ""
    Nst.Text = ""
    Ot.Text = ""
    Wt.Text = ""
    Wat.Text = ""
    Srd.Text = ""
    Rs1.Text = ""
    Rs2.Text = ""
    Rs3.Text = ""
    Ars1.Text = ""
```

```
Ars2.Text = ""
Ars3.Text = ""
Wrs1.Text = ""
Wrs2.Text = ""
Wrs3.Text = ""
Ps.Text = ""
Srs.Text = ""
Af.Text = ""
Ep.Text = ""
Pqo.Text = ""
Dwr.Text = ""
Ppr.Text = ""
Ms.Text = ""
Ice.Text = ""
Pt.Text = ""
Pm.Text = ""
Hh.Text = ""
Fh.Text = ""
cmdcal.Visible = False
lbl10(4).BackColor = &HC0FFC0
lbl10(6).BackColor = &HC0FFC0
lbl10(7).BackColor = &HC0FFC0
lbl10(10).BackColor = &HC0FFC0
If Production.Text = "" Or D.Text = "" Or Ev.Text = "" Or Go.Text = "" Or Fl.Text = "" Then
    Response = MsgBox("Please enter number in orange's text box", vbCritical + vbOKOnly, "Error !!")
    Exit Sub
End If
Qo = Round(Production / Ev * 100, 2)
If Qo > 2000 Or Qo < 80 Then
    lbl4.BackColor = &HFF&
    lbl6.BackColor = &HFF&
    Response = MsgBox("The pump displacement should be between 1000 to 1,400 bbl/day", vbCritical + vbOKOnly, "Error !!")
    Again = MsgBox("Please enter new anticipated production or volumetric efficiency", vbInformation + vbOKOnly, "New number !!")
End If
```

```
If D > 6000 Or D < 1000 Then
  lbl5.BackColor = &HFF&
  Response = MsgBox("The setting Depth of depth should be between 1000 to 6,000 ft", vbCritical + vbOKOnly, "Error !!")
  Again = MsgBox("Please enter new setting Depth of depth", vbInformation + vbOKOnly, "New number !!")
End If
If Ev > 100 Or Ev < 0 Then
  lbl4.BackColor = &HFF&
  lbl6.BackColor = &HFF&
  Response = MsgBox("The volumetric Efficiency should be between 0 to 100 %", vbCritical + vbOKOnly, "Error !!")
  Again = MsgBox("Please enter new volumetric efficiency", vbInformation + vbOKOnly, "New number !!")
End If
If Go > 1 Or Go < 0 Then
  Label1(0).BackColor = &HFF&
  Response = MsgBox("The fluid specific gravity should be between 0 to 1", vbCritical + vbOKOnly, "Error !!")
  Again = MsgBox("Please enter new fluid specific gravity", vbInformation + vbOKOnly, "New number !!")
End If
If Qo <= 2000 And Qo >= 80 And D <= 6000 And D >= 1000 And Ev <= 100 And Ev > 0 And Go < 1 And Go > 0 Then
  lbl4.BackColor = &H80C0FF
  lbl5.BackColor = &H80C0FF
  lbl6.BackColor = &H80C0FF
  Label1(0).BackColor = &H80C0FF
  MsgBox "Clear and go to design of a pumping installation"
  cmdcal.Visible = True
  Timer1.Enabled = False
  Production.Enabled = False
  Go.Enabled = False
  D.Enabled = False
  Ev.Enabled = False
  Fl.Enabled = False
End If
If (Qo <= 1520 And Qo >= 1480 And D <= 6000 And D > 3200) Or (Qo < 1480 And Qo >= 1360 And D <= 6000 And D >
3300) Or (Qo < 1360 And Qo >= 1280 And D <= 6000 And D > 3400) Or (Qo < 1280 And Qo >= 1160 And D <= 6000 And D >
3500) Or (Qo < 1160 And Qo >= 1120 And D <= 6000 And D > 3600) Or (Qo < 1120 And Qo >= 1040 And D <= 6000 And D >
3700) Or (Qo < 1040 And Qo >= 1000 And D <= 6000 And D > 3800) Or (Qo < 1000 And Qo >= 960 And D <= 6000 And D >
3900) Or (Qo < 960 And Qo >= 920 And D <= 6000 And D > 4000) Or (Qo < 920 And Qo >= 880 And D <= 6000 And D >
4100) Or (Qo < 880 And Qo >= 840 And D <= 6000 And D > 4200) Or (Qo < 840 And Qo >= 800 And D <= 6000 And D >
```

```
4300) Or (Qo < 800 And Qo >= 720 And D <= 6000 And D > 4500) Or (Qo < 720 And Qo >= 680 And D <= 6000 And D >
4700) Then
        D = "640"
        Ev = "144"
    End If
    If (Qo <= 1520 And Qo >= 720 And D <= 1700 And D > 1400) Or (Qo < 720 And Qo >= 680 And D <= 1800 And D > 1400)
Or (Qo < 680 And Qo >= 600 And D <= 1900 And D > 1500) Or (Qo < 600 And Qo >= 560 And D <= 2000 And D > 1600) Or
(Qo < 560 And Qo >= 520 And D <= 2100 And D > 1700) Or (Qo < 520 And Qo >= 480 And D <= 2200 And D > 1800) Or (Qo
< 480 And Qo >= 440 And D <= 2300 And D > 1900) Or (Qo < 440 And Qo >= 400 And D <= 2400 And D > 2000) Or (Qo <
400 And Qo >= 360 And D <= 2700 And D > 2100) Or (Qo < 360 And Qo >= 320 And D <= 2800 And D > 2100) Or (Qo < 320
And Qo >= 280 And D <= 3000 And D > 2400) Or (Qo < 280 And Qo >= 240 And D <= 3200 And D > 2600) Or (Qo < 240 And
Qo >= 200 And D <= 3600 And D > 2900) Or (Qo < 200 And Qo >= 160 And D <= 4100 And D > 3200) Then
        D = "80"
        Ev = "48"
    End If
    If (Qo < 160 And Qo >= 120 And D <= 4800 And D > 3900) Or (Qo < 120 And Qo >= 80 And D <= 5700 And D > 4700)
Then
        D = "80"
        Ev = "48"
    End If
    If (Qo <= 1520 And Qo >= 640 And D <= 1400 And D > 1150) Or (Qo < 640 And Qo >= 600 And D <= 1500 And D > 1200)
Or (Qo < 600 And Qo >= 560 And D <= 1600 And D > 1200) Or (Qo < 560 And Qo >= 520 And D <= 1700 And D > 1300) Or
(Qo < 520 And Qo >= 480 And D <= 1800 And D > 1400) Or (Qo < 480 And Qo >= 440 And D <= 1900 And D > 1400) Or (Qo
< 440 And Qo >= 400 And D <= 2000 And D > 1500) Or (Qo < 400 And Qo >= 360 And D <= 2100 And D > 1600) Or (Qo <
360 And Qo >= 320 And D <= 2100 And D > 1700) Or (Qo < 320 And Qo >= 280 And D <= 2400 And D > 1800) Or (Qo < 280
And Qo >= 240 And D <= 2600 And D > 2100) Or (Qo < 240 And Qo >= 200 And D <= 2900 And D > 2300) Or (Qo < 200 And
Qo >= 160 And D <= 3200 And D > 2500) Or (Qo < 160 And Qo >= 120 And D <= 3900 And D > 3200) Then
        D = "57"
        Ev = "42"
    End If
    If (Qo < 120 And Qo >= 80 And D <= 4700 And D > 3800) Then
        D = "57"
        Ev = "42"
    End If
    If (Qo <= 1520 And Qo >= 640 And D <= 1150 And D >= 1000) Or (Qo < 640 And Qo >= 600 And D <= 1200 And D >=
1000) Or (Qo < 600 And Qo >= 560 And D <= 1200 And D >= 1000) Or (Qo < 560 And Qo >= 520 And D <= 1300 And D >=
```

```
1000) Or (Qo < 520 And Qo >= 480 And D <= 1400 And D >= 1000) Or (Qo < 480 And Qo >= 440 And D <= 1400 And D >=
1000) Or (Qo < 440 And Qo >= 400 And D <= 1500 And D >= 1000) Or (Qo < 400 And Qo >= 360 And D <= 1600 And D >=
1000) Or (Qo < 360 And Qo >= 320 And D <= 1700 And D >= 1000) Or (Qo < 320 And Qo >= 280 And D <= 1800 And D >=
1000) Or (Qo < 280 And Qo >= 240 And D <= 2100 And D >= 1000) Or (Qo < 240 And Qo >= 200 And D <= 2300 And D >=
1000) Or (Qo < 200 And Qo >= 160 And D <= 2500 And D >= 1000) Or (Qo < 160 And Qo >= 120 And D <= 3200 And D >=
1000) Then
      D = "40"
      Ev = "34"
  End If
  If (Qo < 120 And Qo >= 80 And D <= 3800 And D >= 1000) Then
      D = "40"
      Ev = "34"
  End If
End Sub
```

B.3.4.2 Source code of design button of sucker rod pump module

```
Private Sub cmdcal_Click()
  Dim Response As Variant
  Beep
  If Production.Text = "" Or D.Text = "" Or Ev.Text = "" Or Go.Text = "" Or Fl.Text = "" Then
    cmdcal.Visible = False
    Response = MsgBox("Please enter number in orange's text box", vbCritical + vbOKOnly, "Error !!")
    Exit Sub
  End If
  If Qo.Text = "" Or Production > 2000 Or Production < 80 Or D > 6000 Or D < 1000 Or Ev > 100 Or Ev < 0 Or Go > 1 Or Go
< 0 Then
    cmdcal.Visible = False
    Response = MsgBox("Please select input check before", vbInformation + vbOKOnly, "Please check input !!")
    Exit Sub
  End If
   If Val(D) = 40 And Val(Ev) = 34 Then
    If D >= 1000 And D <= 1100 Then
      Go = "2 3/4"
      Api = "5.94"
      Str = "0.881"
      E = "3.00"
```

```
    Pg = "3.50"
    Dpg = "9.30"
    Apg = "2.59"
    Pd = "7/8"
    Ppr = "0.00"
    Ms = "0.00"
    Pc = "0.601"
    Ice = "0.00"
    Pt = "0.00"
    Td = "2.16"
    Pm = "0.00"
    Hh = "0.00"
    Pud = Round(19 - (-5 / 100 * (1100 - Val(D))), 2)
    Go8 = "1.00"
    Nst = "0.00"
    Ot = "0.00"
    Wt = D
    Wat = "0.00"
    Srd = "0.00"
End If
If D > 1100 And D <= 1250 Then
    Go = "2 1/2"
    Api = "4.909"
    Str = "0.728"
    E = "3.00"
    Pg = "3.50"
    Dpg = "9.30"
    Apg = "2.59"
    Pd = "7/8"
    Pc = "0.601"
    Td = "2.16"
    Pud = Round(19 - (-5 / 150 * (1250 - Val(D))), 2)
    Go8 = "1.00"
    Nst = "0.00"
    Ot = "0.00"
    Wt = D
```

```
    Wat = "0.00"
    Srd = "0.00"
    Ppr = "0.00"
    Ms = "0.00"
    Ice = "0.00"
    Pt = "0.785"
    Td = "1.63"
    Pm = "2.16"
    Hh = "2.88"
    Pud = Round(12 - (-3 / 1000 * (5700 - Val(D))), 2)
    Go8 = "0.38"
    Nst = "0.33"
    Ot = "0.39"
    Wt = D * 0.38
    Wat = D * 0.33
    Srd = D * 0.39
End If
If D > 5700 And D <= 6600 Then
    Go = "1 3/4"
    Api = "2.405"
    Str = "0.357"
    E = "2 1/2"
    Pg = "2.875"
    Dpg = "6.50"
    Apg = "1.812"
    Pd = "3/4"
    Ppr = "7/8"
    Ms = "1.00"
    Pc = "0.442"
    Ice = "0.601"
    Pt = "0.785"
    Td = "1.63"
    Pm = "2.16"
    Hh = "2.88"
    Pud = Round(12 - (-2 / 900 * (6600 - Val(D))), 2)
    Go8 = "0.45"
```

```
        Nst = "0.30"
        Ot = "0.25"
        Wt = D * 0.45
        Wat = D * 0.3
        Srd = D * 0.25
    End If
End If
'Command2.Visible = True
'MsgBox ("**** Successfully Design '1-7' ****")
'cmdcal.Visible = False
Rs1 = Round(Val(Ev) * Pud * Pud / 70500, 2)
If Val(Ppr) = 0 And Val(Ms) = 0 And Val(Ice) = 0 And Val(Pt) = 0 And Val(Pm) = 0 And Val(Hh) = 0 Then
    Rs2 = Round(Val(Ev) + (40.8 * D * D * Rs1 / 30 / 10 ^ 6) - (5.2 * Go * D * Val(Api) / 30 / 10 ^ 6 * ((D / Val(Apg)) + (Wt / Val(Pc)))), 2)
    Rs3 = Round(Str * Rs2 * Pud * Ev / 100, 2)
    Ars1 = Round(((Td * Wt) + (Pm * Wat) + (Hh * Srd)), 2)
    Ars2 = Round(0.433 * Go * ((D * Val(Api)) - (0.294 * Ars1)), 2)
    Ars3 = Round(Ars2 + (Ars1 * (1 + Rs1)), 2)
    Wrs1 = Round(Ars3 / Pc, 2)
End If
If Val(Ppr) <> 0 And Val(Ms) = 0 Then
    Rs2 = Round(Val(Ev) + (40.8 * D * D * Rs1 / 30 / 10 ^ 6) - (5.2 * Go * D * Val(Api) / 30 / 10 ^ 6 * ((D / Val(Apg)) + (Wt / Val(Pc)) + (Wat / Val(Ice)))), 2)
    Rs3 = Round(Str * Rs2 * Pud * Ev / 100, 2)
    Ars1 = Round(((Td * Wt) + (Pm * Wat) + (Hh * Srd)), 2)
    Ars2 = Round(0.433 * Go * ((D * Val(Api)) - (0.294 * Ars1)), 2)
    Ars3 = Round(Ars2 + (Ars1 * (1 + Rs1)), 2)
    Wrs1 = Round(Ars3 / Ice, 2)
End If
If Val(Ms) <> 0 Then
    Rs2 = Round(Val(Ev) + (40.8 * D * D * Rs1 / 30 / 10 ^ 6) - (5.2 * Go * D * Val(Api) / 30 / 10 ^ 6 * ((D / Val(Apg)) + (Wt / Val(Pc)) + (Wat / Val(Ice)) + (Srd / Val(Pt)))), 2)
    Rs3 = Round(Str * Rs2 * Pud * Ev / 100, 2)
    Ars1 = Round(((Td * Wt) + (Pm * Wat) + (Hh * Srd)), 2)
    Ars2 = Round(0.433 * Go * ((D * Val(Api)) - (0.294 * Ars1)), 2)
    Ars3 = Round(Ars2 + (Ars1 * (1 + Rs1)), 2)
```

```
    Wrs1 = Round(Ars3 / Pt, 2)
  End If
  Wrs2 = Round((0.5 * Ars2) + (Ars1 * (1 - (0.0635 * Go))), 2)
  Ps = Round((Ars3 - (0.95 * Wrs2)) * Val(Ev) / 2, 2)
  Srs = Round(7.36 * 10 ^ -6 * Rs3 * Go * D, 2)
  Af = Round(6.31 * 10 ^ -7 * Ars1 * Val(Ev) * Pud, 2)
  Ep = Round(1.5 * (Val(Srs) + Val(Af)), 2)
  Dwr = Round(237000 / Pud / D, 2)
  'MsgBox ("**** Successfully Design '8-22' ****")
  'Command2.Visible = False
  MsgBox ("     Successfully Design")
  MsgBox ("Programe checking allowasble limit")
  If Rs3 > Production Then
    lbl10(4).BackColor = &H8000&
    Response = MsgBox("Probable Production Rate > Anticipted Production", vbOKOnly, "Clear")
  Else
    lbl10(4).BackColor = &HFF&
    Response = MsgBox("Probable Production Rate < Anticipted Production", vbCritical + vbOKOnly, "Critical")
  End If
    MsgBox ("*************Complete*************")
  cmdcal.Visible = False
  Production.Enabled = True
  Go.Enabled = True
  D.Enabled = True
  Ev.Enabled = True
  Fl.Enabled = True
End Sub
```

B.3.4.3 Source code of save and print button of sucker rod pump module

```
Private Sub cmdprint_Click()
  dlg.ShowPrinter
  Printer.Print "     Sucker Rod Pumping Design"
  Printer.Print "=================================================="
  Printer.Print "     Input"
  Printer.Print "Anticipted Production (bbl/day)  = "; IIf(Production.Text = "", "No Data", Production.Text)
```

```
Printer.Print "Setting Depth of Pump (ft)       = "; IIf(D.Text = "", "No Data", D.Text)
Printer.Print "Volumetic Efficiency (%)          = "; IIf(Ev.Text = "", "No Data", Ev.Text)
Printer.Print "Fluid Specific Gravity              = "; IIf(Go.Text = "", "No Data", Go.Text)
Printer.Print "Endurance Limit of Sucker Rods (psi) = "; IIf(Fl.Text = "", "No Data", Fl.Text)
Printer.Print "=================================================="
Printer.Print "     Output"
Printer.Print "1. Pump Displacement = "; IIf(Qo.Text = "", "No Data", Qo.Text)
Printer.Print "2. Pump Data"
Printer.Print "     API Size (unit) = "; IIf(D.Text = "", "No Data", D.Text)
Printer.Print "     Stroke (in)      = "; IIf(Ev.Text = "", "No Data", Ev.Text)
Printer.Print "3. Pump Plunger Data"
Printer.Print "     Diameter (in) = "; IIf(Go.Text = "", "No Data", Go.Text)
Printer.Print "     Area (sq in)   = "; IIf(Api.Text = "", "No Data", Str.Text)
Printer.Print "     Pump Constant (bbl/day/in/spm) = "; IIf(Str.Text = "", "No Data", Str.Text)
Printer.Print "4. Tubing Data"
Printer.Print "     Nominal Size (in)       = "; IIf(E.Text = "", "No Data", E.Text)
Printer.Print "     Outside Diameter (in) = "; IIf(Pg.Text = "", "No Data", Pg.Text)
Printer.Print "     Weight (lb/ft)           = "; IIf(Dpg.Text = "", "No Data", Dpg.Text)
Printer.Print "     Wall Area (sq in)       = "; IIf(Apg.Text = "", "No Data", Apg.Text)
Printer.Print "5. Sucker Rod Data"
Printer.Print "     Rod Size (in)  = "; IIf(Pd.Text = "", "No Data", (Pd.Text + " - " + Ppr.Text + " - " + Ms.Text))
Printer.Print "     Area (sq in)   = "; IIf(Pc.Text = "", "No Data", (Pc.Text + " - " + Ice.Text + " - " + Pt.Text))
Printer.Print "     Weight (lb/ft) = "; IIf(Td.Text = "", "No Data", (Td.Text + " - " + Pm.Text + " - " + Hh.Text))
Printer.Print "6. Pumping Speed (Strokes/min) = "; IIf(Pud.Text = "", "No Data", Pud.Text)
Printer.Print "7. Section of Rod String"
Printer.Print "     R1 = "; IIf(Go8.Text = "", "No Data", Go8.Text); "    L1 (ft) = "; IIf(Wt.Text = "", "No Data", Wt.Text)
Printer.Print "     R2 = "; IIf(Nst.Text = "", "No Data", Nst.Text); "    L2 (ft) = "; IIf(Wat.Text = "", "No Data", Wat.Text)
Printer.Print "     R3 = "; IIf(Ot.Text = "", "No Data", Ot.Text); "    L1 (ft) = "; IIf(Srd.Text = "", "No Data", Srd.Text)
Printer.Print "8. Acceleration Factor                        = "; IIf(Rs1.Text = "", "No Data", Rs1.Text)
Printer.Print "9. Effective Plunger Stroke Length (in)   = "; IIf(Rs2.Text = "", "No Data", Rs2.Text)
Printer.Print "10. Probable Production Rate (bbl/day) = "; IIf(Rs3.Text = "", "No Data", Rs3.Text)
Printer.Print "11. Dead Weight of Rod String (lb)  = "; IIf(Ars1.Text = "", "No Data", Ars1.Text)
Printer.Print "12. Fluid Load (lb)                        = "; IIf(Ars2.Text = "", "No Data", Ars2.Text)
Printer.Print "13. Peak Polished Rod Load(lb)      = "; IIf(Ars3.Text = "", "No Data", Ars3.Text)
Printer.Print "14. Maximum Stress at Top of Rod String (psi) = "; IIf(Wrs1.Text = "", "No Data", Wrs1.Text)
Printer.Print "15. Ideal Counterbalance Effect (lb)               = "; IIf(Wrs2.Text = "", "No Data", Wrs2.Text)
```

```
    Printer.Print "16. Position of Counter Weight to obtain Counter Balance Effect (in) = "; IIf(Wrs3.Text = "", "No Data"
, Wrs3.Text)
    Printer.Print "17. Peak Torque on Gear Reducer (in-lb) = "; IIf(Ps.Text = "", "No Data", Ps.Text)
    Printer.Print "18. Prime Mover"
    Printer.Print "     Hydraulic Horsepower (hp)= "; IIf(Srs.Text = "", "No Data", Srs.Text)
    Printer.Print "     Friction Horsepower (hp)  = "; IIf(Af.Text = "", "No Data", Af.Text)
    Printer.Print "     Brake Horsepower(hp)     = "; IIf(Ep.Text = "", "No Data", Ep.Text)
    Printer.Print "19. Engine Sheave Size to obtain the desired pumping speed (in) = "; IIf(Pqo.Text = "", "No Data", Pqo.Text)
    Printer.Print "20. Synchronous Pumping Speed = "; IIf(Dwr.Text = "", "No Data", Dwr.Text)
    Printer.EndDoc
End Sub
```


B.3.4.4 Source code of clear button of sucker rod pump module

```
Private Sub Command1_Click()
    Production.Text = ""
    Go.Text = ""
    D.Text = ""
    Ev.Text = ""
    Qo.Text = ""
    D.Text = ""
    Ev.Text = ""
    Go.Text = ""
    E.Text = ""
    Pd.Text = ""
    Pud.Text = ""
    Api.Text = ""
    Str.Text = ""
    Pg.Text = ""
    Dpg.Text = ""
    Apg.Text = ""
    Pc.Text = ""
    Td.Text = ""
    Go8.Text = ""
    Nst.Text = ""
    Ot.Text = ""
    Wt.Text = ""
```

```
    Wat.Text = ""
    Srd.Text = ""
    Rs1.Text = ""
    Rs2.Text = ""
    Rs3.Text = ""
    Ars1.Text = ""
    Ars2.Text = ""
    Ars3.Text = ""
    Wrs1.Text = ""
    Wrs2.Text = ""
    Wrs3.Text = ""
    Ps.Text = ""
    Srs.Text = ""
    Af.Text = ""
    Ep.Text = ""
    Pqo.Text = ""
    Dwr.Text = ""
    Fl.Text = ""
    Ppr.Text = ""
    Ms.Text = ""
    Ice.Text = ""
    Pt.Text = ""
    Pm.Text = ""
    Hh.Text = ""
    Fh.Text = ""
End Sub
```

B.3.4.5 Source code of back button of sucker rod pump module

```
Private Sub cmdEx_Click()
    Artificial_Lift.Show
End Sub
```

APPENDIX C

PUBLICATION

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Software Development for Optimizing Artificial Lift System at Phitsanulok Oil Fields

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Abstract

The software has been developed for optimizing artificial lift selection at Phitsanulok oil fields and support design of artificial lift system under various geological conditions and engineering requirements, including electrical submersible pump, intermittent flow gas lift and sucker rod pump. The software hereafter is called ARPOF. The proposed system is based on the known analytical solutions and theories, but is not based on the heuristic knowledge, inference procedure and experience of artificial lift expert backed by the rationale and logic. The program structure is developed on Microsoft Visual Basic version 6 software, and hence makes it interactive, user-friendly and revisable. The input artificial lift parameters are hierarchically characterized into several groups using various criteria, e.g., production, reservoir and well conditions, engineering requirements, design constraints and project goals, etc. The input analysis is first performed to check probable process of data base, e.g., fluid specific gravity, depth, tubing size, tubing type and volumetric efficiency. The predictive capability of the proposed system has been verified by comparing with 7 actual wells under Lan Kra Bur oil fields. There are divided into 106 case studies that comprise a case of natural flow, 42 cases of electrical submersible pump, 42 cases of intermittent flow gas lift and 21 cases of sucker rod pump. The results are satisfactory. For the support design, the system first identifies detail, step of design, basic facilities and necessary information. Based on production rates, the system selects the most suitable and available design solution for each artificial lift system. They comprise different combinations of the design components (e.g., pump data, minimum gas required, etc.). In term of technical consideration, gas liquid ratio, productivity index, side of tubing and variable rates are the controlling factors in the selection of the lift method. The probable application of artificial lift at Phitsanulok oil fields are 37.5% intermittent flow gas lift, 35% sucker rod pump and 27.5% electrical submersible pump respectively. In term of economic consideration, the IRR and PIR for natural flow are 43.62% and 0.52 respectively. The IRR and PIR for intermittent flow gas lift are 49.62 – 73.73% and 0.65 – 2.07 respectively. The IRR and PIR for sucker rod pump are 49.72 – 68.34% and 0.69 – 1.84 respectively. The IRR and PIR for electrical submersible pump are 49.56 – 57.46% and 0.6 – 1.47 respectively.

Literature Review

Application of artificial lift at Sirikit oil field have 2 systems that are gas lift and pump about 75% and 9 % respectively. The gas lift system has 3 methods that are continuous, intermittent and modified chamber gas lift. In addition, the pump system has 3 methods that are progressive cavity, electrical submersible pump and sucker rod pump, each pump first introduced in 1998, 2001 and 2007 respectively. The commercial software for study, analysis and design electrical submersible pump, gas lift and sucker rod pump are csSubs Suite, WinGlue, and Echometer QRod respectively.

Scope and Limitations of the Study

- The ARPOF has been developed for optimizing artificial lift selection at Phitsanulok oil fields and support design under various geological conditions and engineering requirements, including electrical submersible pump, intermittent flow gas lift and sucker rod pump.
- The proposed system is based on the known analytical solutions and theories, but is not based on the heuristic knowledge and experience of artificial lift expert backed by the rationale and logic.
- The program structure is developed on Microsoft visual basic 6.0 that is enterprise edition with source code and utilities, service pack 5.
- The input artificial lift parameters are production, reservoir and well conditions and engineering requirements.

- The input analysis is first performed to check probable process of data base, e.g., fluid specific gravity, depth, tubing size, tubing type and volumetric efficiency.
- The predictive capability of the proposed system has been verified by comparing with 7 actual wells under Lan Kra Bur oil fields. There are divided into 106 case studies that comprise a case of natural flow, 42 cases of electrical submersible pump, 42 cases of intermittent flow gas lift and 21 cases of sucker rod pump.
- For the support design, the system first identifies detail, step of design, basic facilities and necessary information.
- Based on production rates, the system selects the most suitable and available design solution for each artificial lift system.
- In term of technical consideration, this study determines the most suitable artificial lift method which can improve oil recovery.
- In term of economic consideration, cost of each artificial lift system will be studied and analyzed to determine the best Internal Rate of Return (IRR) and Profit to Investment Ratio (PIR).

Software Development

The ARPOF includes a main page and 3 modules. Interface of the main page includes 2 main parts that are a helpful label (green color) and three modules (including electrical submersible pump, intermittent flow gas lift and sucker rod pump) as follow as in Figure 1. Hot keys are developed for quick and comfortable usage as follow as in Table 1.

Table 1. The hot keys

Hot key	*Function*
Alt + E	Electrical submersible pump
Alt + G	Intermittent Flow Gas lift
Alt + S	Sucker rod pump

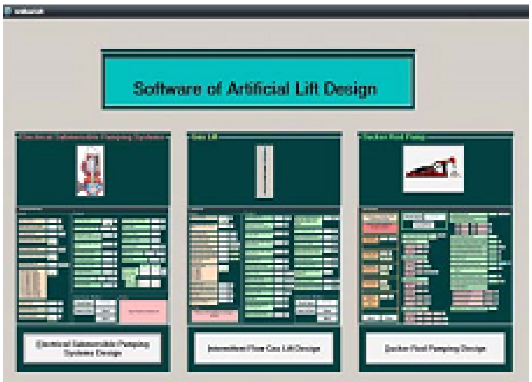

Figure 1. The main page of ARPOF

Interface of each module is developed and composed with four functions; each function is showed and displayed by different color as follow as in Table 2 and Figure 2 - 4.

Table 2. The color is related with function.

Color	*Function*
Orange	Input data
Green	Out put
Gray	Command button: Check Input, Design, Save& Print, Clear and Back.
Pink	Help: Texts show procedure of using software which is changed to next text within 4 seconds.

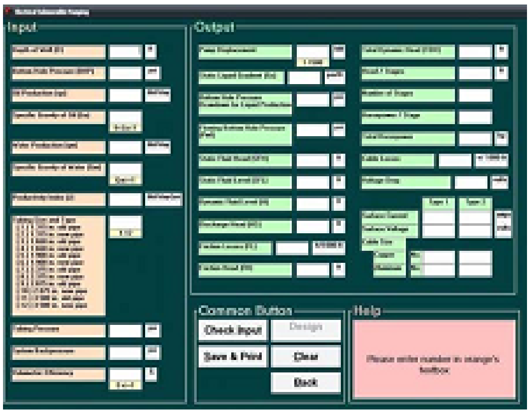

Figure 2. Software of electrical submersible pump (Manufacturer's motor refer Adam Person Associates Engineering Production Manual and data base of Byron Jackson pump division)

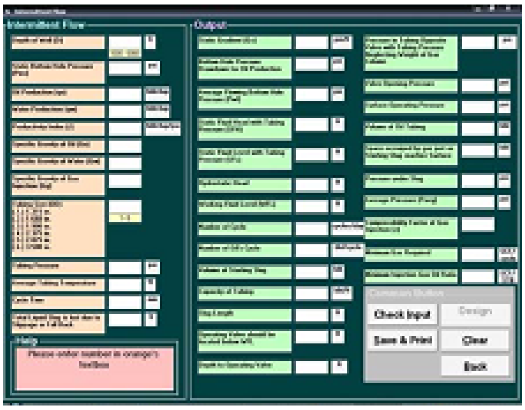

Figure 3. Software of intermittent flow gas lift (Kirkpatrick has illustrated the design technique for intermittent flow gas lift)

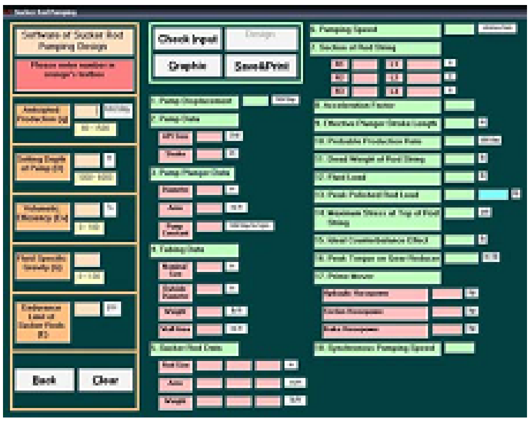

Figure 4. Software of sucker rod pump (Manufacturer's Pump refer Data Base of Lufkin Pump Division)

Flowchart is a step for software development which identifies step, procedure and compile of software in terms of pictures or symbols. Compile of software includes manual input, checking input, calculation and compile, output as follow as in Figure 5.

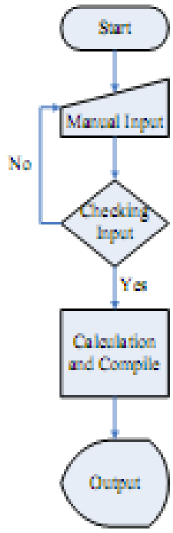

Figure 5. Compile of software

Technical Considerations

The predictive capability of the proposed system has been verified by comparing with 7 actual wells under Lan Kra Bur oil fields. There are divided into 106 cases study that comprise a case of natural flow, 42 cases of electrical submersible pump, 42 cases of intermittent flow gas lift and 21 cases of sucker rod pump as follow as in Table 3. The input artificial lift parameters are production, reservoir, well conditions and engineering requirements under Lan Kra Bur oil fields as follow as in Table 4.

Table 3. Study cases in testing

Well No.	*J (b/d/psi)*	*GLR (SCF/STB)*
I	2.07	558
II	1.70	1229
III	1.38	698
IV	0.27	2545
V	0.24	3799
VI	0.16	7014
VII	0.15	4280

In term of technical consideration, gas liquid ratio, productivity index, side of tubing and variable rates are the controlling factors in the selection of the method of lift as follow as in Table 5 - 6.

Where

- Gas liquid ratio

  Low = 500 – 1,300 SCF/STB

  High = 2,000 – 8,000 SCF/STB

- Productivity Index

Low = 0.15 – 0.27 b/d/psi
High = 1.38 – 2.07 b/d/psi

- O.D. of Tubing
  Small (S) = 1.315, 1.660, 1.900 and 2.375 in.
  Large (L) = 2.875 and 3.500 in.
- Type of artificial lift
  ESP = Electrical Submersible Pump
  IFGL = Intermittent Flow Gas Lift
  SRP = Sucker Rod Pump
- Other
  1 = Poor d_o = Outside Diameter of Tubing (in)
  2 = Medium   J = Productivity Index (b/d/psi)
  3 = Good

Table 4. Minimum requirement information

Conditions	*Parameters*	*Units*	Artificial Lift System		
			Electrical Submersible Pump	*Intermittent Flow Gas Lift*	*Sucker Rod Pump*
Production	Water production	b/d	0	0	-
Reservoir	Bottom hole temperature	°R	-	587	-
	Specific gravity of oil	-	0.828	0.828	0.828
	Specific gravity of water	-	1	1	-
	Depth of well	ft	3,715	3,715	3,715
Well	System backpressure	psi	400	-	-
	Tubing size (O.D)	In	1.315, 1.660, 1.900, 2.375, 2.875, 3.500	1.315, 1.660, 1.900, 2.375, 2.875, 3.500	2.375, 2.875, 3.500
	Tubing temperature	°R	-	587	-
	Tubing type		New	-	-
	Tubing pressure	psi	50	-	-
	Cycle Time	min	-	15	-
Other	Endurance limit	psi	-	-	30,000
	Liquid Slug	%	-	60	-
	Specific gravity of gas injection		-	0.6	-
	Volumetric Efficiency	%	80	80	80

Table 5. Maximum production rates in all cases study

Well No.	*Type*	*q_o(b/d) at O.D. of Tubing (in)*	
		Small	*Large*
I	ESP	298 – 472	487 – 495
	IFGL	77 – 278	417 – 626
	SRP	167	711 – 1,196
II	ESP	271 – 393	401 – 407
	IFGL	77 – 278	417 – 626
	SRP	167	711 – 1,120
III	ESP	241 – 323	326 – 331
	IFGL	77 – 278	417 – 626
	SRP	167	711 – 909
IV	ESP	63 – 64	64
	IFGL	77 – 155	164 – 172
	SRP	167	172
V	ESP	56 – 57	57
	IFGL	77 – 140	148 – 149
	SRP	149	149
VI	ESP	38	38
	IFGL	76 – 99	103 – 105
	SRP	107	107
VII	ESP	35	35
	IFGL	72 – 93	97 – 99
	SRP	105	105

Table 6. Selection of artificial lift technique

Type	*Productivity Index*			*Variable Rates*		*Gas Liquid Ratio*			
	Low	*High*		*Low*	*High*	*Low*		*High*	
	d_o	*d_o*		*J*	*J*	*d_o*		*d_o*	
	All	*S*	*L*			*S*	*L*	*S*	*L*
ESP	1	3	1	1	1	3	1	1	1
IFGL	2	2	2	3	2	2	2	2	2
SRP	3	1	3	1	3	-	3	-	2

Economic Considerations

The exploration and production periods under the Petroleum Acts "Thailand III" is divided into 3 years of exploration period and 20 years of production period. This study will be early production on the 4th year of investment. The total production wells are 25. The artificial lift will be applied between 4th - 15th years, which are determined under case of natural flow as follow as in Table 7. The original oil inplace of this study is 109 MMbbl.

Table 7. Case of natural flow

Year.	*Production rate (b/d/well)*	*Year.*	*Production rate (b/d/well)*
4	400	14	38
5	400	15	34
6	401	16	31
7	400	17	28
8	387	18	25
9	208	19	23
10	100	20	21
11	68	21	20
12	54	22	18
13	44	23	17

The basic and other assumptions cost under the Petroleum Acts "Thailand III" as follow as in Table 8.

Table 8. The basic and other assumptions cost

Type	*Number*	*Unit*
Exchange rate	35	Baht/US$
Oil price	80	US$/bbl
Discount rate	10	%
Capital cost	12.36	MMMBaht
Operation cost	600	Baht/bbl
Facilities cost		
- ESP	8.75	MMBaht/well
- IFGL	5.25	MMBaht/well
- SRP	1.02	MMBaht/well
Maintenances cost		
- ESP	2.4	MMBaht/well/yr
- IFGL	1.9	MMBaht/well/yr
- SRP	2.1	MMBaht/well/yr

In term of economic consideration, cost of each artificial lift system will be studied and analyzed to determine the best Internal Rate of Return (IRR) and Profit to Investment Ratio (PIR) as follow as in Table 9.

Table 9. The IRR and PIR in all cases study.

Type	*Recovery Factor (%)*	*IRR*	*PIR*
Natural flow	22.74	43.62	0.52
ESP	23.56 – 84.50	49.56 – 57.46	0.60 – 1.47
IFGL	29.46 – 99.91	49.62 – 73.73	0.65 – 2.07
SRP	29.33 – 99.91	49.72 – 68.34	0.69 – 1.84

Conclusion

In term of technical consideration, gas liquid ratio, productivity index, side of tubing and variable rates are the controlling factors in the selection of the lift method. The probable application of artificial lift at Phitsanulok oil fields are 37.5% intermittent flow gas lift, 35% sucker rod pump and 27.5% electrical submersible pump respectively. In term of economic consideration, the IRR and PIR for natural flow are 43.62% and 0.52 respectively. The IRR and PIR for intermittent flow gas lift are 49.62 – 73.73% and 0.65 – 2.07 respectively. The IRR and PIR for sucker rod pump are 49.72 – 68.34% and 0.69 – 1.84 respectively. The IRR and PIR for electrical submersible pump are 49.56 – 57.46% and 0.6 – 1.47 respectively.

Discussion

The research studies the factors that affect production rate under application of artificial lift. In testing, all methods of lift have reduced efficiency with increasing gas liquid ratio and improved efficiency with increasing productivity index and side of tubing. Some artificial lift can produces high rate but it is poor for variable rate.

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BIOGRAPHY

Mr. Nasornkrit Vatcharakup was born on the 4th of July 1983 in Nakhon Ratchasima province. He earned his high school diploma in science-math from Boonwattana School in 2001 and his bachelor's degree in Petroleum Engineering from School of Geotechnology, Suranaree University of Technology (SUT) in 2005. After graduation, he continued with his master's degree in the School of Geotechnology, Institute of Engineering at SUT with the major in Petroleum Engineering. During 2006-2008, he was a laboratory assistant, teaching assistant and research assistant at SUT. His strong background is in the areas of artificial lift.