Selection of Artificial Lift for a Permian Basin Waterflood Project

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INTRODUCTION

The proper selection of an artificial lift system for a waterflood project will greatly influence the overall economics of the project. To achieve the most favorable economics, the lift system should have sufficient flexibility to handle the predicted range in producing rates, under the anticipated operating conditions, with minimum investment and operating costs.

The optimum selection of a lift system depends on the design engineer's knowledge of (1) the factors which will influence the operation of the lift equipment (2) the advantages and disadvantages of the basic lift system and (3) the investment and operating costs.

Two factors, common to all waterflood projects, normally considered first in the analysis of the optimum lift system are maximum anticipated fluid production and lift depth. Graphical correlation of these factors with investment cost is presented. Operating cost and other specific factors, such as casing size and condition, influence the final selection and design. A limited amount of operating cost data was collected and is presented.

An evaluation of the four basic type lift systems in use today was made for Continental Oil Company's MCA Unit Waterflood project near Maljamar, New Mexico. A pilot flood was started in November, 1963. The unit contains 233 wells and utilizes a five-spot flood pattern, Fig. 1. Prior to the start of the waterflood, the majority of the wells were flowing due to a gas repressuring program initiated in 1942. Development of waterflood operations was planned by stages with curtailment of gas repressuring in each stage as water injection was initiated. It was anticipated that artificial lift would be required on producing wells in each stage shortly after the start of water injection.

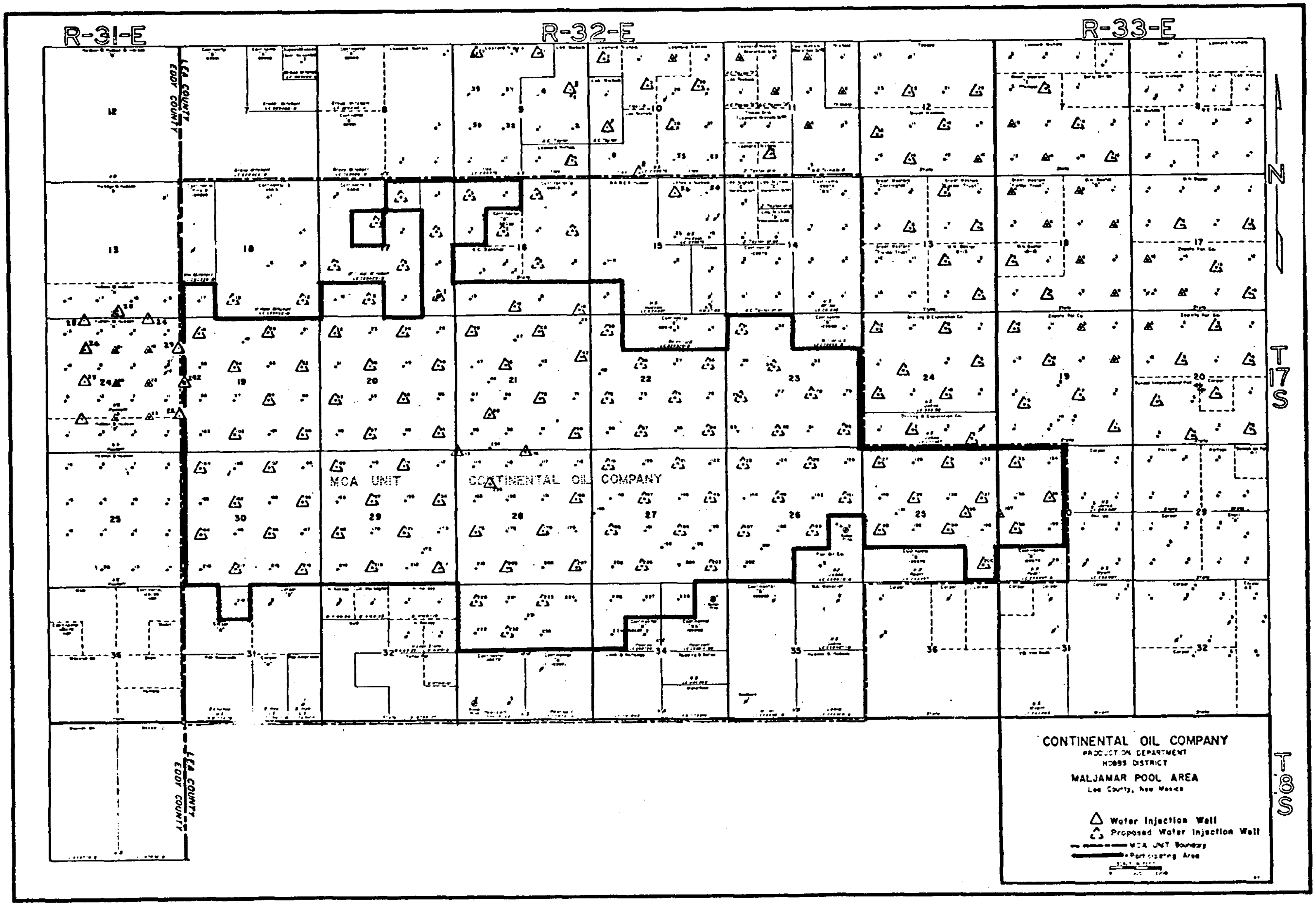
Based on calculated water injection rates, the maximum fluid production volumes would range from 400 to 700 BFPD per well. The lift depth averaged 4000 ft. The consideration used in making the optimum lift selection for this project are presented.

FACTORS AFFECTING LIFT SELECTION

Pertinent information is normally available to the design engineer from the reservoir study prepared prior to the initiation of the waterflood project. This information provides for a more efficient design than is normally possible during primary operations. The waterflood design engineer has the additional advantage in that primary operations will have indicated potential operating problems.

The factors which must be considered in making an artificial lift system study are:

(1) Number of wells in need of artificial lift equipment
(2) Location of wells and proximity of wells to each other
(3) Casing size and condition
(4) Single or multiple completion
(5) Type and condition of existing lift equipment
(6) Operating problems such as corrosion, scale, paraffin, and sand
(7) Compatibility of injection and formation waters
(8) Maximum fluid volume
(9) Depth of lift
(10) Available power
(11) Availability of service and parts
(12) Availability of manpower to operate equipment
(13) Degree of automation
(14) Familiarity of operating personnel with artificial lift system
(15) Flexibility of system to meet changing producing conditions
(16) Safety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N
T 17 S
LEA COUNTY
EDDY COUNTY
MCA UNIT
CONTINENTAL OIL COMPANY
CONTINENTAL OIL COMPANY
PRODUCTION DEPARTMENT
HOBBS DISTRICT
MALJAMAR POOL AREA
Lea County, New Mexico
Water Injection Well
Proposed Water Injection Well
MCA UNIT Boundary
Participating Area

FIGURE 1

(17) Investment cost

(18) Operating cost

The factors which were considered the most important in selecting the optimum lift system for the MCA Unit were operating costs, investment cost, fluid volume, depth, casing size and condition, existing lift equipment, and flexibility to meet changing producing conditions.

BASIC TYPES OF LIFT SYSTEMS

There are four basic artificial lift systems in use today: gas lift, rod pumping units, subsurface centrifugal, and subsurface hydraulic. All of these systems are time proven and will satisfactorily perform the task for which they were designed. Once the factors which will influence the operation of a lift system have been defined, the design engineer must consider the advantages of the basic systems.

The more common oilfield problems which affect artificial lift are listed in Table 1. The relative merits of each system with these problems are noted; however, the severity of any one of these conditions may dictate the optimum system.

The advantages and disadvantages of the four systems are presented with references to their influence on the selection of the MCA Unit system.

TABLE I

COMMON PROBLEMS AFFECTING LIFT SELECTION

PROBLEM	TYPE OF LIFT			
	Rod Pump	Hydraulic	Centrifugal	Gas Lift
Sand	Fair	Fair	Fair	Excellent
Paraffin	Poor	Good	Good	Poor
High GOR	Fair	Fair	Fair	Excellent
Crooked Hole	Poor	Good	Fair	Good
Corrosion	Good	Good	Fair	Fair
High Volume	Poor	Good	Excellent	*Good
Depth	Fair	Excellent	Fair	*Good
Simple Design	Yes	No	Yes	No
Casing Size	Fair	Fair	Good	Good
Flexibility	Fair	Excellent	Poor	Good
Scale	Good	Fair	Poor	Fair

*Higher volumes and depths are dependent on greater gas pressure and volume.

Gas Lift

Advantages

(1) Low investment for deep wells
(2) Most efficient in high GOR wells
(3) Low operating cost for high sand-producing wells
(4) Flexible in meeting changing producing conditions
(5) Adaptable in crooked holes
(6) Capable of lifting large volumes of fluid

Disadvantages

(1) Requires a continuous source of make-up gas
(2) High operating cost if make-up gas is purchased
(3) High operating cost due to corrosive gases in Permian Basin Area
(4) Long open-hole sections make it impractical to maintain low producing fluid levels
(5) System requires high back-pressure on producing wells
(6) Safety hazard handling high-pressure gas
(7) Casing condition to withstand lift pressure

A dependable and economical source of make-up gas for the estimated 25-year project life of the MCA Unit Waterflood was the primary factor eliminating gas lift. A continuous lift system would be required to produce estimated fluid volumes. This design would result in a producing bottom-hole pressure of 530 psi (4000 feet X fluid gradient of 0.12 psi/ft + 50 psi wellhead tubing pressure). This was undesirable in order to maintain maximum efficient recovery in the MCA Unit. The desired degree of automation and poor casing condition were also contributing factors.

Additional data are not presented in this paper due to the limitations of this type lift system in Permian Basin waterflood operations.

Rod Pumping Unit

Advantages

(1) Familiar to design engineers and operating personnel
(2) Simple to design
(3) Low investment for relatively low fluid volumes from shallow to medium depths
(4) Allows low producing fluid levels to be maintained
(5) Adaptable to wells with corrosive or scaling problems
(6) Adaptable to automation

Disadvantages

(1) High investment for high fluid volumes from medium depth to deep wells
(2) The limitations of sucker rods in hydrogen sulfide systems limit the depth at which a large volume pump can be set
(3) Limitation of downhole pump design in small diameter casing
(4) Not suited for crooked holes

The initial investment to install large enough units to lift maximum anticipated produced volumes was the primary reason this type lift system was not selected for the MCA Unit.

Where many wells were flowing and early selection of final equipment was necessary, inaccurate individual well producing estimates could have caused unnecessary investments due to improper rod pumping unit design. This lack of flexibility was a contributing factor in selecting another type lift system.

Subsurface Centrifugal

Advantages

(1) Ability to produce very high fluid volumes from shallow to medium depths
(2) Low investment for shallow depths
(3) Adaptable to automation
(4) Casing size not as critical for high waterflood production rates

Disadvantages

(1) Electrical cable design—weakest link
(2) Lack of flexibility to meet changing producing conditions, unless system is "time clocked". Inherent design makes this undesirable and will result in high operating costs
(3) More downtime when problems are encountered due to entire unit being downhole

(4) Requires economical source of electrical power
(5) Scaling tendency of producing fluid fatal to operation

The primary factor eliminating this type lift system for use in the MCA Unit was its lack of flexibility to meet changing producing conditions unless the system was "time clocked". It was anticipated that the flowing wells, producing up to 75 BOPD, would cease to flow shortly after the start of water injection. Time clocking of subsurface centrifugal pumps designed to produce 700 BFPD, to produce initial volumes of 75 BFPD, would result in excessive operating costs. A rod beam lift system could have been installed when wells ceased to flow; however, this interim system would have had to be designed to produce near peak rates to eliminate time clocking of the final centrifugal system. This would have resulted in excessive investment cost. Time predicted to initial response and peak producing rates was 15 and 34 months, respectively, in the MCA Unit. Anticipated scaling problem was also a key factor eliminating selection of this system.

Subsurface Hydraulic

Advantages

(1) Flexible to changing producing conditions
(2) Larger waterflood installations offer lower per well investment
(3) Pulling unit not required for servicing free pump design
(4) Adaptable to crooked holes
(5) Adaptable to automation
(6) Low investment for volumes up to 400 BPD from deep wells

Disadvantages

(1) Maintenance of clean power oil
(2) Safety hazard of high-pressure power oil system
(3) Loss of power oil in surface equipment failures
(4) Complex design
(5) Multiple tubing strings required
(6) Difficult to set pump assembly in shot open-hole section
(7) High investment for high volumes from shallow and medium depths

The anticipated high fluid producing rates from the MCA Unit and the need for a high degree of flexibility to meet changing producing conditions were two of the primary reasons for selection of this type lift system. Being a multiple well project made this type system favorable from an investment standpoint. A closed power oil system design was selected to help maintain clean power oil. A higher investment cost would be incurred using the closed power oil system; however, a good payout of this increased investment would be realized by the reduction in operating cost. High-low pressure safety shut-in valves were selected to reduce loss of power oil and make the system safer to operate.

INVESTMENT COST

Investment costs for rod pumping, subsurface hydraulic and subsurface centrifugal lift systems were determined for volumes and depths ranging from 2000 to 7000 feet and 100 to 1200 BFPD, respectively. These were the conditions considered most applicable to waterflood operations in the Permian Basin. Rod pumping systems were limited to API 640 D unit size. The minimum fluid production rate for the subsurface centrifugal was set at 400 BFPD. Cost for centrifugal units to produce lower rates is the same as for the 400 BFPD rate.

It is necessary to assume certain conditions for comparison of investment costs for the different lift systems. Conditions assumed for this paper are:

(1) Casing size sufficient to accommodate the particular design
(2) Prime movers will be electric motors
(3) All wells are single completions
(4) All wells requiring artificial lift are equipped with only wellhead and casing
(5) Hydraulic lift system will be a free parallel, closed power oil, hydraulic type consisting of four or more wells
(6) Investment costs based on manufacturer's list price

The investment costs for each system producing at various volumes and depths are presented in Table 2. Data in Table 2 is shown graphically in Figs. 2, 3 and 4. The change o

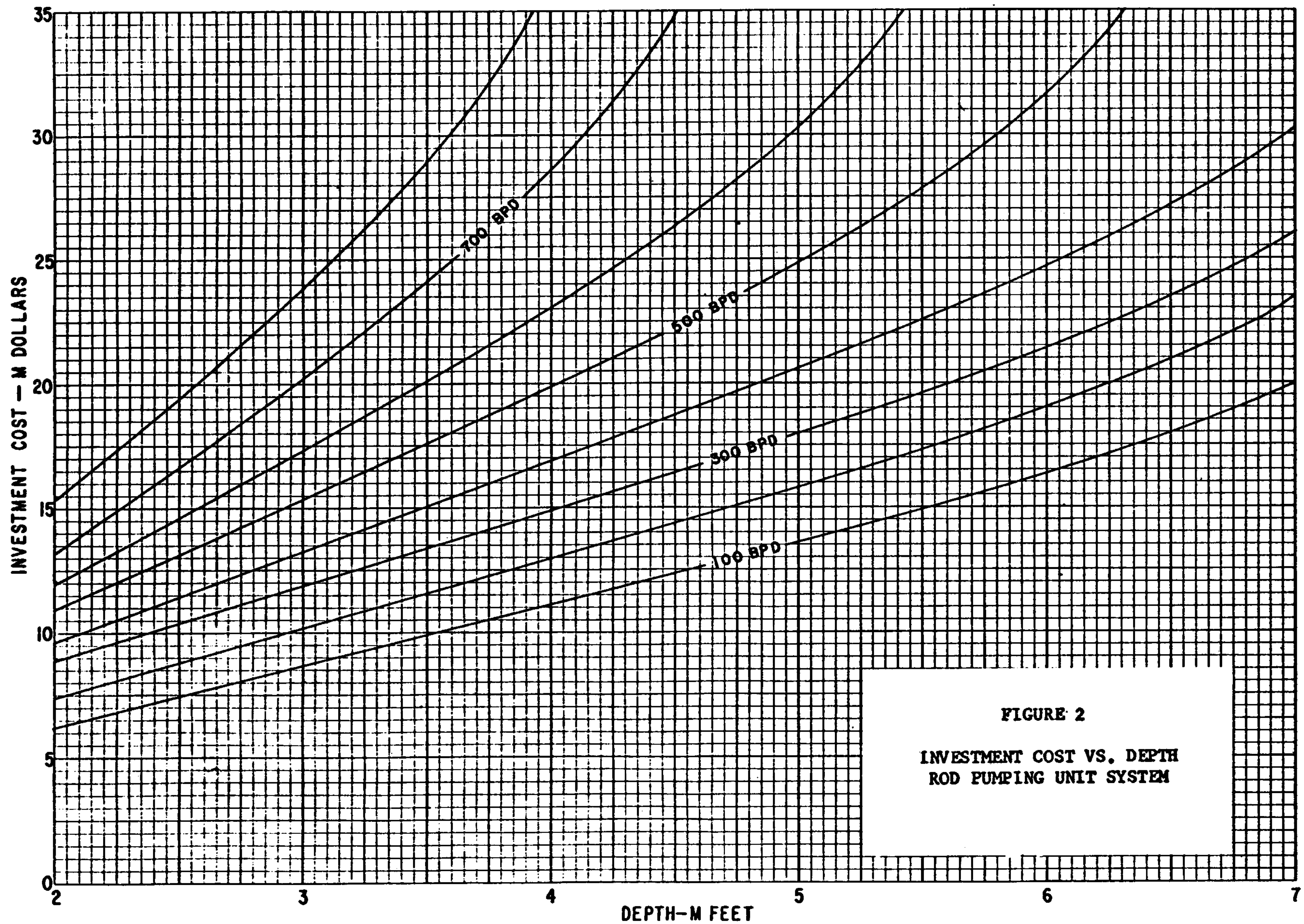
35
30
25
20
15
10
5
0
INVESTMENT COST — M DOLLARS
2
3
4
5
6
7
DEPTH-M FEET
700 BPD
500 BPD
300 BPD
100 BPD
FIGURE 2
INVESTMENT COST VS. DEPTH
ROD PUMPING UNIT SYSTEM

FIGURE 2

- PER WELL INVESTMENT COST - DOLLARS

ROD PUMPING UNITS

Lift Depth - Feet

Prod. Rate BPD	2000	3000	4000	5000	6000	7000
100	6,345	8,675	11,235	13,595	16,520	19.930
200	7,455	10,115	12,845	16,000	19.770	21.640
300	8,635	11,935	14,410	18.760	22.050	25,840
400	9,685	13,630	17.370	22,210	28.570	26.480
500	10,720	15,870	19,160	25,990	32,850	
600	11,840	18,380	22,990	31,150		
700	12,950	20,210	25,290			
800	15,700	20,400	28,710			
900	16.190	20,620				
1000	16,590	23,220				
1100	17,690	26,180				
1200	17,890					

SUBSURFACE HYDRAULIC

Lift Depth - Feet

Prod. Rate BPD	2000	3000	4000	5000	6000	7000
100	12,240	13,860	15,480	17,100	18,720	20,340
200	13,140	14,750	16.360	17,920	19,540	21,160
300	13,650	15,270	16,890	18,510	20,130	21,750
400	14,830	16,450	18,070	19,690	21,310	22,930
500	15,820	17,440	19,060	20,680	22,300	23,920
600	15,820	17,440	19,060	20,680	22,300	23,920
700	17,380	19,300	21,220	23,140	25,060	26.980
800	19,610	21,530	23,450	25.370	27,290	29,210
900	23,190	25,510	27,830	30,150	32,470	34,790
1000	23,930	26,250	28,570	30,890	33,210	35,130
1100	25,935	28,350	30,770	33,190	35,610	37,830
1200	28,180	30,600	33,020	35,440	37,860	40,280

SUBSURFACE CENTRIFUGAL

Lift Depth - Feet

Prod. Rate BPD	2000	3000	4000	5000	6000	7000
400	12,170	15,650	18,900	22,740	26,470	30,660
600	12,420	16,010	19,960	23,910	28,130	33,040
800	12,620	16,780	21,060	25,820	30,610	35,580
1000	13,020	17,110	21,690	26.910	31,710	36,720
1200	13,490	17,740	23,500	27,530	32,870	38,060

TABLE II

slope of the constant volume curves in Fig. 2 points out the high investment cost for rod pumping systems at high volumes from medium to deep depths.

The slope of the constant volume curves in Fig. 3 remains relatively constant in the lower and medium depth range and increases at deeper depths. This is an indication that at deeper depths subsurface, centrifugal lift becomes limited in its application.

The slope of the constant volume curves in Fig. 4 remains constant throughout the range of volumes and depths considered due to the operating principle of hydraulic lift systems. Hydraulic systems have the advantage of being a positive volume type lift without the disadvantages of rod stretch, as in rod pumping, and poor operating efficiency at high head pressures as with subsurface centrifugals. The abnormal increase in investment cost from the 800 BPD to 900 BPD curve is due to the increase in subsurface pump size and tubing size for this increase in volume.

Figure 5, a composite curve of Figs. 2, 3 and 4, indicates the economic investment range for each type lift system at various volumes and depths. Once the producing range and depth for a given waterflood project have been determined, Fig. 5 can be utilized to select the most desirable lift system from an investment standpoint. The investment costs will vary, however, if the assumptions used in this paper are not applicable to the particular project under consideration. For example, if an operator selects gas engines as prime movers for subsurface hydraulics and rod pumping systems, all curves in Fig. 5 will be altered. This change will show a wider investment cost application for subsurface centrifugal systems due to the increased investment cost of gas engines. The selection of prime movers will be dependent upon evaluation of investment versus operating cost and is beyond the scope of this paper.

OPERATING COST

Operating cost should be considered in the evaluation of artificial lift systems. In many cases, operating costs would not influence the operator in selecting one sytsem over the other. In other cases, specific operating problems that will affect operating costs and ultimate profit could cause him to reverse his selection. Therefore, operating conditions and cost must be forecasted and considered at the time the lift system is selected and designed. A survey of numerous leases in the Permian Basin was made and operating costs were tabulated as shown in Table 3. The operating costs shown are the direct lifting cost for each system. This data is plotted in Fig. 6 in cents per barrel per 1000 feet of lift versus total fluid production in barrels per day. The tabulated data indicates a surprising closeness of lifting cost for the rod pumping and subsurface hydraulic systems.

The data presented in Fig. 6 infers that the operating cost for subsurface centrifugal systems is higher than the other two systems. This inference may be a result of the limited operating cost data available and the method of plotting. Since insufficient data were available for the three lift systems at the same depth and volume, it was necessary to utilize the common denominator of cents per barrel per 1000 feet of lift.

Depth appears to be the primary factor causing the variations in the operating cost plotted in Fig. 6. The deeper the producing depth and the higher the volume being lifted, the more advantageous a particular properly designed and operated system will appear evaluated on a cost per barrel per 1000 feet of lift basis. This is true since many of the costs such as crude oil dehydration, chemical treating, pumper labor, etc. are not directly related to producing depth. For example, a lease producing from 6000 ft would not cost twice as much to operate as one producing the same volume and with the same number of wells as one from 3000 ft.

It cannot be definitely concluded, from the limited data collected, which system offers the most economical operating cost for a given depth and volume; however, operating cost will be a factor in selecting the optimum lift system in many instances and should be seriously considered in the selection and original design.

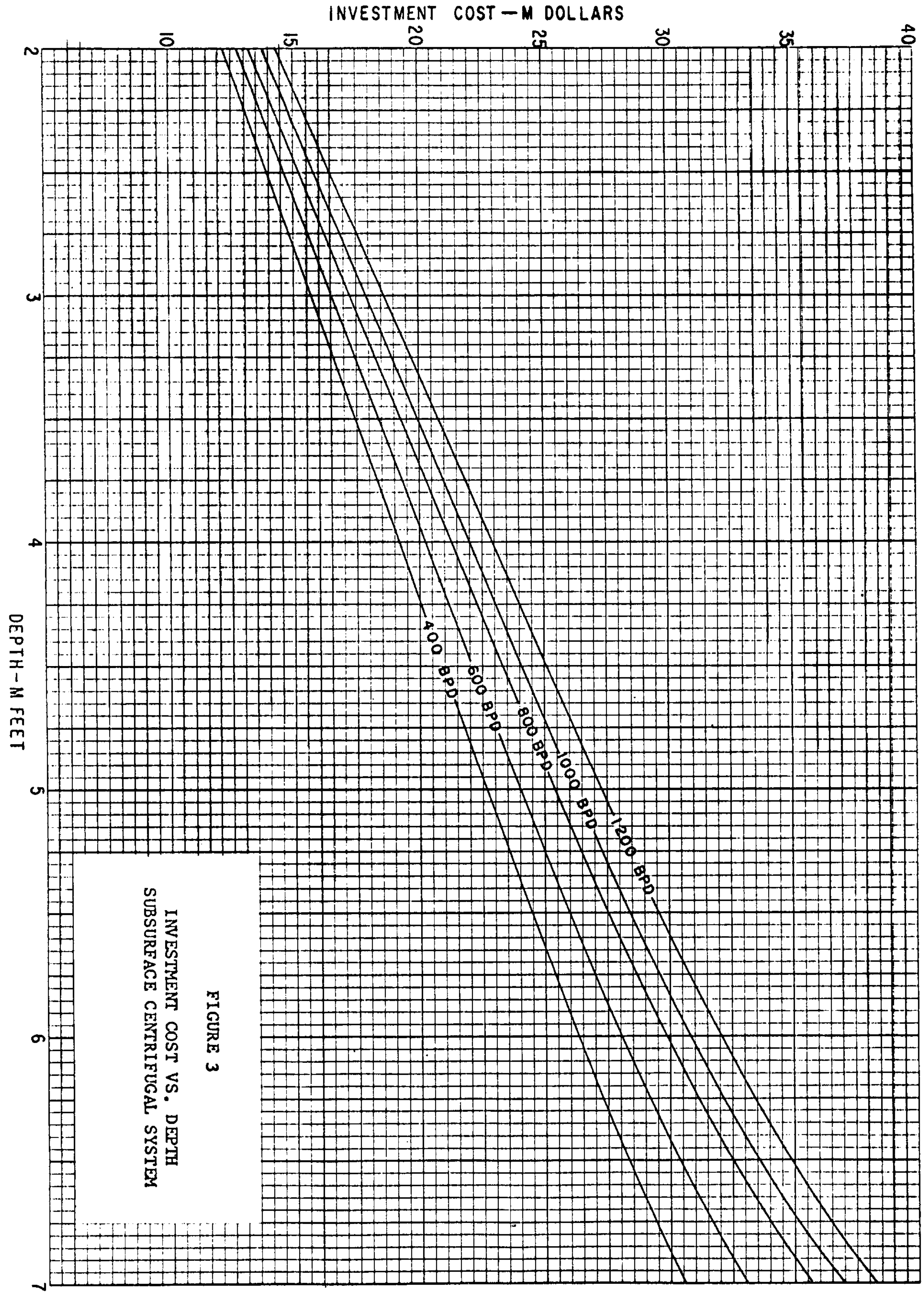

FIGURE 3
INVESTMENT COST VS. DEPTH
SUBSURFACE CENTRIFUGAL SYSTEM

FIGURE 3

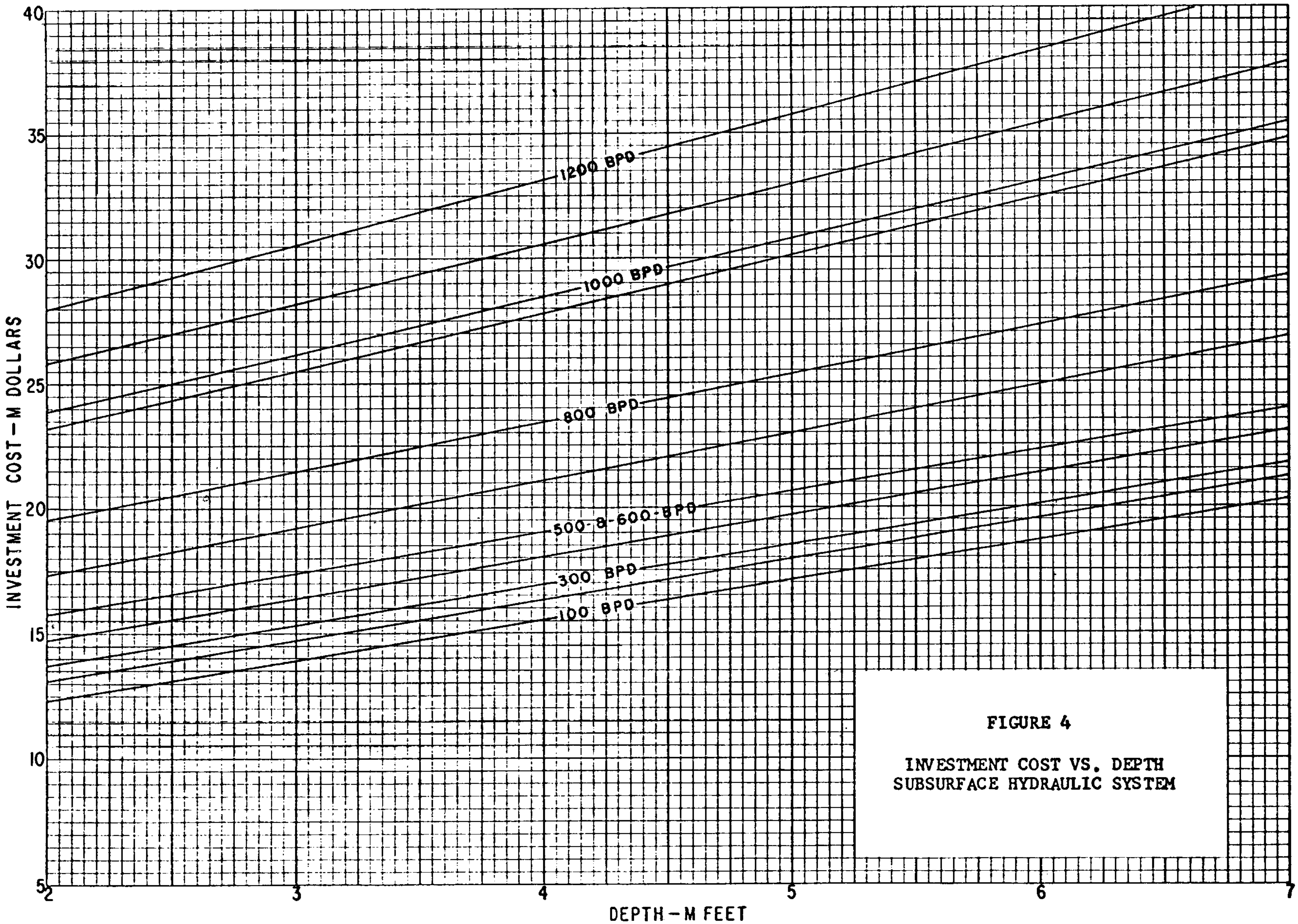
FIGURE 4
INVESTMENT COST VS. DEPTH
SUBSURFACE HYDRAULIC SYSTEM
1200 BPD
1000 BPD
800 BPD
500-&-600-BPD
300 BPD
100 BPD
INVESTMENT COST—M DOLLARS
DEPTH—M FEET
40
35
30
25
20
15
10
5
2
3
4
5
6
7

FIGURE 4

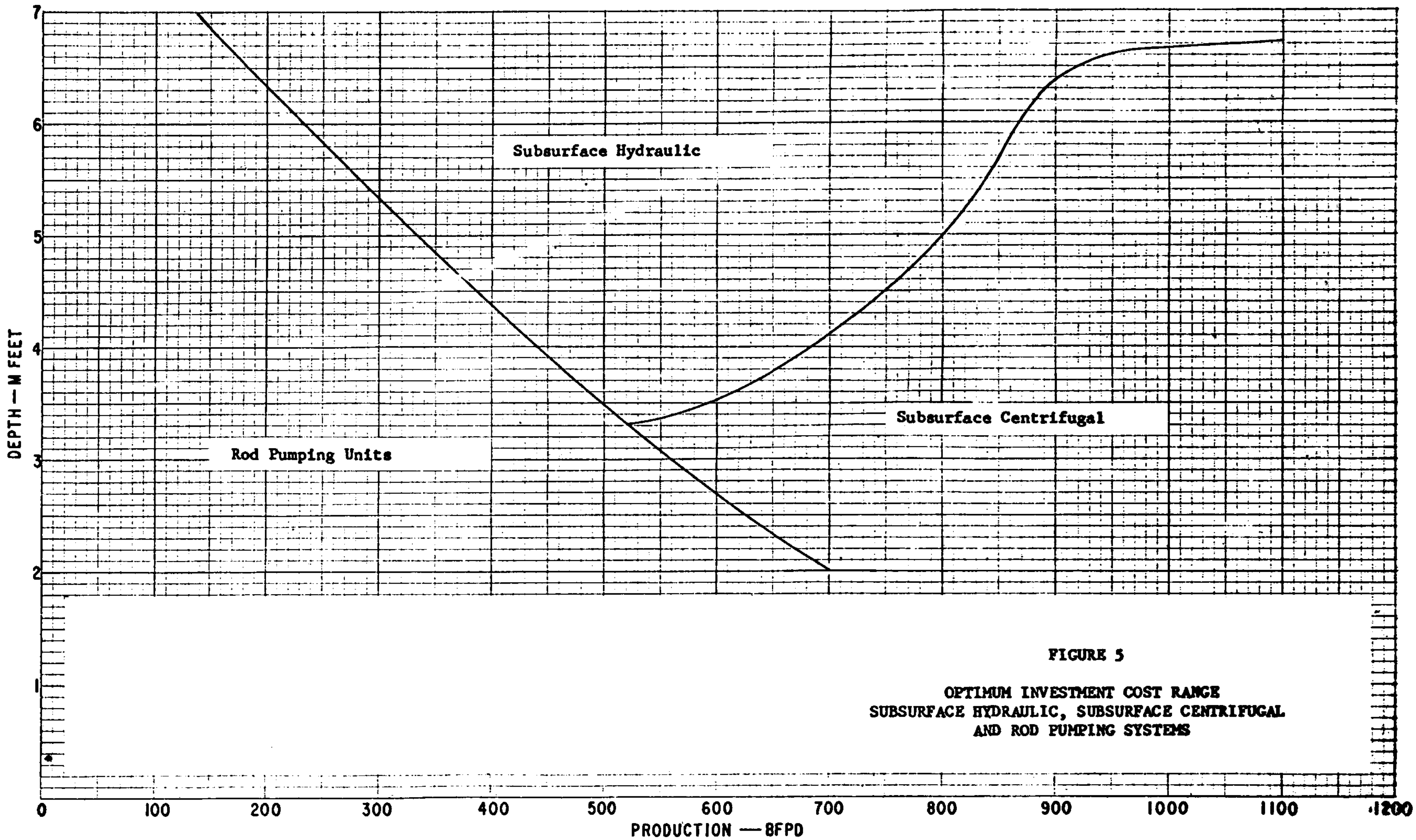

FIGURE 5

OPTIMUM INVESTMENT COST RANGE
SUBSURFACE HYDRAULIC, SUBSURFACE CENTRIFUGAL
AND ROD PUMPING SYSTEMS

FIGURE 5

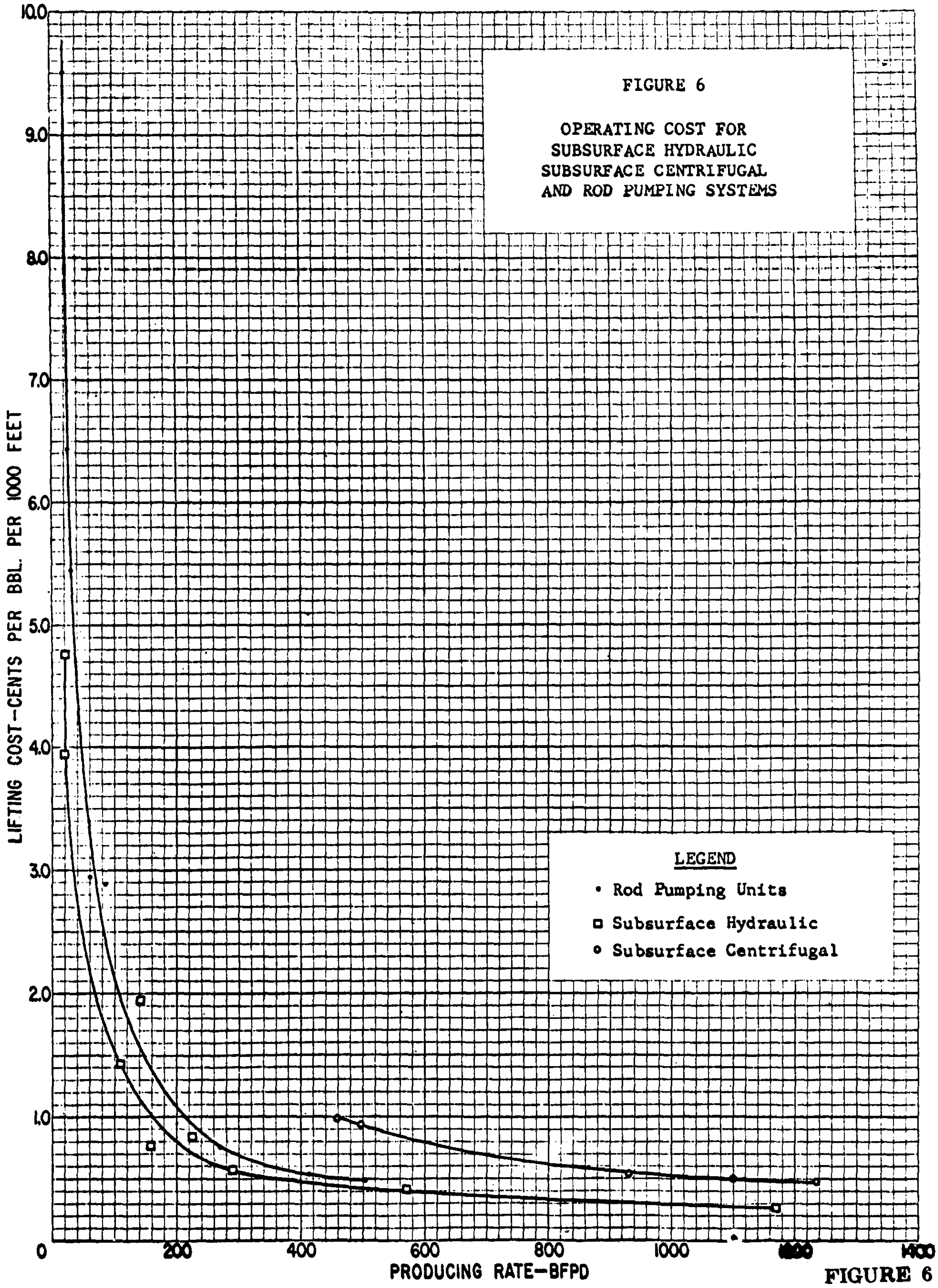
FIGURE 6
OPERATING COST FOR
SUBSURFACE HYDRAULIC
SUBSURFACE CENTRIFUGAL
AND ROD PUMPING SYSTEMS
LEGEND
• Rod Pumping Units
□ Subsurface Hydraulic
○ Subsurface Centrifugal
LIFTING COST-CENTS PER BBL. PER 1000 FEET
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
200
400
600
800
1000
1200
1400
PRODUCING RATE-BFPD

FIGURE 6

CONCLUSION

The three artificial lift systems considered, rod pumping units, subsurface centrifugal and subsurface hydraulic, have application in waterflood operations in the Permian Basin. The two factors common to all waterfloods, depth and producing volume, can be utilized to select which systems justify detailed study.

Optimum lift selection for a waterflood project is dependent on both the investment cost and specific factors affecting operating cost. Under normal operating conditions, the operating cost of the systems considered would be very close for specific depths and volumes within their design range.

Once the system or systems have been defined from an investment standpoint, other factors will control the final selection. Two important factors usually affecting the final choice are (1) the flexibility to meet the producing volume range and (2) the casing size and condition.

Additional operating cost data are needed at specific depths and producing volumes to define the actual effect of operating cost on optimum artificial lift selection for a waterflood.

TABLE III

OPERATING COST

SUBSURFACE HYDRAULIC

Formation	Lift Depth Ft.	No. of Wells	Evaluation Period	Avg. Production-BPD/Well Oil	Water	Total Fluid	Avg. Yearly Lifting Cost-$	Lifting Cost Per BFPD - $	Lifting Cost Per Bbl. Per 1000' - $
Devonian	12,000	4	1 yr.	144	119	263	28,846	.075	.0063
Devonian	12,000	1	1 yr.	54	169	223	8,384	.103	.0086
Devonian	10,500	3	1 yr.	190	980	1170	32,400	.028	.0027
Pennsylvanian	10,300	11	2 yrs.	39	103	142	120,228	.201	.0196
Devonian	12,000	2	1 yr.	78	490	568	20,270	.049	.0041
Devonian	11,100	2	1 yr.	42	2078	2120	19,800	.020	.0018
Devonian	11,000	15	2 yrs.	98	192	290	99,305	.064	.0058
Devonian	8,000	12	1 1/2 yrs.	72	41	113	54,883	.113	.0141
Clearfork	6,700	7	1 1/2 yrs.	18	2	20	14,400	.263	.0393
Clearfork	6,700	14	1 1/2 yrs.	20	2	22	34,800	.317	.0473
Ellenburger	12,200	2	1 1/2 yrs.	157	0	157	20,825	.091	.0075
				ROD PUMPING UNITS					
Grayburg - San Andres	2,600	30	2 yrs.	15	487	502	68,283	.0125	.0049
Delaware Sand	4.600	4	2 yrs.	12	11	23	14,649	.439	.0954
Delaware Sand	4,600	11	2 yrs.	13	19	32	32,342	.251	.0545
Premier Sand	2,450	24	1 1/2 yrs.	34	50	84	50,267	.068	.0278
Queen Sand	3,100	16	2 yrs.	85	50	135	19,433	.025	.0081
San Andres	4,200	6	1 1/2 yrs.	47	4	51	6,173	.056	.0133
Grayburg - San Andres	4,200	4	1 1/2 yrs.	46	13	59	10,717	.124	.0295
Queen	3,100	16	1 yr.	150	120	270	23,546	.0239	.0077
Queen	3,100	16	1 yr.	102	310	412	36,117	.0164	.0053
				SUBSURFACE CENTRIFUGAL					
Devonian	5,800	2	1 yr.	20	471	491	19,443	.054	.0093
Devonian	5,000	3	1 yr.	28	398	926	26,488	.026	.0052
Devonian	5,800	1	1 yr.	136	358	494	10,075	.055	.0095
Devonian	5,250	4	1 yr.	104	350	454	42,480	.053	.0100
Grayburg - San Andres	2,600	4	2 yr.	19	1215	1215	22,278	.0124	.0049
Woodbine	2,500	24	1 yr.	10	1090	1090	120,300	.0126	.0050