PREDICTING POWER COSTS FOR ESP INSTALLATIONS

Brown Lyle Wilson
Oil Dynamics Inc.

ABSTRACT

This paper discusses the role of power cost in the economics of artificial lift. It is specifically directed to the application of electrical submersible pumps (ESP's). A method for estimating the power required by an ESP is presented along with a computer program to assist in the calculations.

This paper is directed toward the Engineers and supervisors whose responsibility include the specification of the type of lift systems to be employed and the sizing and selection of equipment.

INTRODUCTION

The yearly cost of operation of a properly sized ESP is likely higher than the initial equipment cost. Often "on hand equipment" is used in preference to obtaining properly sized equipment. This can lead to false economics. Without a clear indication of the costs of the alternatives, utilizing the on hand equipment appears to make the most sense.

Recently, papers have been published that have been concerned with the economics of ESP's[1,2,3]. This paper presents a method for ESP power cost calculations including a listing for a computer program which follows the method published in SPE paper #17522[1]. When used, this program provides an organized path through the various charts and tables and removes some of the tediousness from the reiterative calculations.

The program will operate on most desk top computers that run Microsoft(TM) Basic.[1] The program was structured to be "user friendly" and is therefore somewhat more complex than it could be. It will prompt the user for the required information and will allow the user to go back and make changes in the data for analyzing a series of choices.

REQUIRED DATA

Before starting to calculate power cost it is advisable to have all the necessary data on hand. The user will have to supply information about the well and field. Information about the equipment is specific to the brand to be used and is available from the manufacturer. The following is needed:

1, Design flow rate, Bottom hole temperature, specific gravity of the fluid, and the head requirement for the pump.

2, The pump performance curve for the type of pump that is going to be used (Fig. 1) and the horsepower requirement of the gas separator, if used.

3, Motor data (volts, amps, horsepower), and the motor performance characteristic curve for the brand and model of motor that is going to be used (Fig. 2).

4, The size and type of cable that will be used, along with resistance and conductor temperature information (Fig. 3 and Table #1).

POWER COSTS CALCULATION

The procedure that is outlined for the analysis of the operating cost can be used when analysing new installations, or for units that are already in operation. Most ESP sizing procedures[4,5] can be broken into five basic steps:

1, Given the design flow rate, calculate the total dynamic head (TDH) required. The THD includes the lift, the surface pressure and the friction losses minus the height of the column of fluid over the pump.

2, Use the manufacturers published curves to select a pump which will meet these conditions.

3, Select a motor which can produce the power required by the pump.

4, Size the cable to meet the casing clearance and motor power requirements.

5, Select the surface equipment to meet the requirements of the other equipment.

The original approach used to analyze the power cost was to calculate the percent of full load power of the motor then use the manufacturers motor performance curve to find the associated efficiency and amperage. The one major flaw in this method is that it does not take into account the variation in the speed on the motor. The pump performance curves are drawn for a specific RPM. Due either to the load or the design, the motor will most likely not be operating at the pump curve RPM. Because the power required by the pump is related to the cube of the RPM a small variation of in the shaft speed can cause significant error in the power calculation.

In order to properly account for this, it is necessary to perform a reiterative solution. After selecting the motor, the RPM related to the motor load is found and used to calculate a new power requirement for the pump. This is related to a new motor load and the process repeated. Luckily, the method homes in very quickly so it is seldom necessary to perform more than two iterations.

This change in operating speed of the pump brings up another problem, the flow and head produced are also subject to the change in the RPM. If the pump is already installed this may provide an explanation as to why the pump is not producing at the design rate. If the pump is not yet installed, this provides an opportunity to change the number of pump stages in order to meet the flow rate.

Pump Power Consumption

The flow rate through the pump is calculated using the stock tank flow and the formation volume factor. This flow rate is used in conjunction with the pump performance curve (Fig 1) to find the actual required horsepower per stage. The total pump horsepower load (Hp_N) is this value times the number of stages plus any additional horsepower requirements such as a gas separator, times the specific gravity of the fluid.

$$Hp_N = ((\text{Hp/stage} \times \#\ \text{Stages}) + \text{Gas Sep Hp.})) \times \text{Sp. Gr.} \qquad (1)$$

The percent of motor load is calculated by dividing the pump horsepower by the motor nameplate horsepower (HPm).

$$\%\ \text{Load} = Hp_N / Hp_M \qquad (2)$$

Using the % load and the motor performance characteristic curve, determine the speed of the motor (Fig #2).

This is the point of the first reiteration. If the motor speed does not match the speed on the published pump curve, it is necessary to adjust the speed of the pump. This is done with the affinity law for power which states that the power required by the pump varies to the cube of the RPM. The new power required by the pump (Hp_{N1}) is calculated.

$$Hp_{N1} = Hp_N \times (RPMm/3500)^3 \qquad (3)$$

The % load is calculated for the new value of power and another value for motor RPM is found. These steps are repeated until there is no significant change in the RPM.

The fact that the pump is operating at an RPM that is different from its performance curve, means that the pump will be producing at a different flow rate. Predicting the exact flow rate of the pump in this situation requires information about the formation flow, the tubing performance and the surface requirements. The situation is more complex and beyond the scope of this paper. It is sufficient to say that if the pump is operating at a speed lower than the pump curve speed, it will be producing at a rate lower than that indicated by the pump curve. The computer program allows the option of changing the number of stages in the pump. This can be used to change the performance of the pump if it is desired.

Motor Power Consumption

The motor power requirement is determined by the motor horsepower output, the percent of full load and the efficiency of the motor. The motor power output in KW is equal to the pump horsepower input times a conversion factor.

$$\text{Output KW} = Hp_{N1} \times .7457 \text{ KW/Hp.} \tag{4}$$

Using the motor characteristics curve, find the motor efficiency for the percent of load. The Input motor power KWm is the output KW times the efficiency,

$$\text{KWm} = \text{Output KW} \times \text{Efficiency} \tag{5}$$

Cable Power Consumption

The cable, due to its resistance consumes some power. The amount of power that the cable will consume is a function of the motor amperage, the length and the cable resistance. The cable resistance is a function of its size and its temperature. The power that the cable consumes is turned into heat and therefore must be counted when establishing the temperature of the cable.

The first step is to establish the amperage that the motor will require. Using the motor performance characteristics curve find the percent of full load amps associated with the percent of load . The actual current drawn by the motor will be the nameplate amps times the percent of full load amps.

$$\text{Amps} = \%\ \text{FL Amps} \times \text{Nameplate Amps} \tag{6}$$

The cable conductor temperature is established using the ambient downhole well temperature and motor amperage with conductor temperature curve (Figure 3). The cable resistance (Rt) in Ohms per thousand feet, is found by using the resistance value (R_{20}) from the cable data table (Table 1), the conductor temperature in degrees Fahrenheit and the following formula:

$$Rt = R_{20} \times (390 + Tc)/459 \tag{7}$$

The power consumed by the cable (KWc) is a function of the resistance, the length of the cable (L) and the current, and is given by the following formula:

$$KWc = (Amps^2 \times Rt \times 3 \times L)/1{,}000{,}000 \quad (8)$$

System Power Consumption

The power consumption for the total system (KWt) is the summation of the power required by each component. In a rigorous analysis, it would be necessary to calculate the consumption for each individual component. To simplify the calculations, only the major power consuming elements are calculated then a factor of 2.5% is added to account for the power required by the control panel, transformers and other power consuming elements.

$$KWt = (KWm + KWc) \times 1.025 \quad (9)$$

The monthly operating cost is the total power consumed times the cost of power in dollars per KWH for a thirty day period.

$$\text{Power Cost/month} = KWt \times \$/KWH \times 24 \times 30 \quad (10)$$

ACCURACY AND VALIDATION OF METHOD

This method of power cost prediction does not take into account a number of variables that would be thought to make a great deal of difference. Specifically the method ignores the viscosity of the fluid and the possibility of gas interference with the pump. A sample of thirty-five wells analyzed by this method showed an average error of 0.8% when compared to a power meter. Twenty-seven of the wells were within a +/- 7% error band.

The method will give the proper ranking of alternative selections of ESP equipment, and an accurate estimate of the relative cost differences.

OVER ALL ECONOMICS

The total economic picture of any equipment must include the initial investment (purchase price), the operational cost, the life expectancy of the equipment and the cost of money (time value) during the period of the investment. The time value of money is calculated using the "Capital Recovery Factor" (CRF)[6] and is calculated from the interest rate (i) and the life expectancy of the investment (n).

$$CRF = i/(1-1/((1+i)^n)) \quad (11)$$

To determine the cost per month of the equipment and its operation, the cost of the investment is multiplied times the PVIFa factor and added to the operating cost.

$$\text{Total Cost/month} = \text{CRF} \times \text{Initial Cost} + \text{Power Cost/month} \quad (12)$$

Figure 4 shows an example of three different ESP systems, all sized for the same well. The most expensive equipment, "A" has the lowest operating cost. It does not become the most economical choice unless the expected life is greater than 12 months. Likewise the least expensive equipment "C" may be a better choice if the life of the equipment is short. It should be noted that the three systems are being compared at intervals of equal operating life. If there is a documented difference in equipment life, each should be analyzed at its own life expectancy.

CONCLUSION

This paper has presented a method for calculating the power cost and economics for electrical submersible pumps.

This method requires only published performance data from the manufacturer and well data that is normally available. This together with some straight forward calculation procedures will aid in the calculation and prediction of power costs. A computer program is provided to simplify application.

The power cost combined with initial cost and run life data will allow a simple ranking of alternatives to aid in making the proper economic choices,

ACKNOWLEDGMENTS

1. Microsoft Basic is the trademark of Microsoft Corporation.

REFERENCES

1. Pankratz, R.E., Wilson, B. L.:"Prediction Power Cost and its Role in ESP Economics", presented at the SPE Rocky Mtn. Regional Meeting, Casper Wyo, May 11-13, 1988, Paper # 17522

2. Vandevier, J.E.:"Optimum Power Cable Sizing for Electrical Submersible Pumps", presented at the 1987 SPE Production Operation Symposium, Oklahoma City, Ok. March 8-10, 1987, Paper # 16195

3. Powers, M. L.: "Economic Consideration for Sizing Tubing and Power Cable for Electrical Submersible Pumps", presented at the SPE 61st Annual Technical Conference and Exhibition, New Orleans, LA October 5-8, 1986, Paper #15423

4. API RP 11U: API Recommended Practices for Sizing and Selection of Electrical Submersible Pumps", Second Edition, May 1986

5. Brown K.E., et al.: "The Technology of Artificial Lift Methods", Penwell Publishing Co., Tulsa Ok. (1977)

6. Newnan, D.G.:"Engineering Economic Analysis", 1980, Engineering Press, Inc

Table 1

Cable Resistance

EPDM, Round

AWG	Cond.	R_{20} Ω /1000
6	1 Solid	0.411
4	1 Solid	0.259
4	7 Strand	0.263
2	7 Solid	0.165
2	7 Strand	0.165
1	7 Strand	0.131

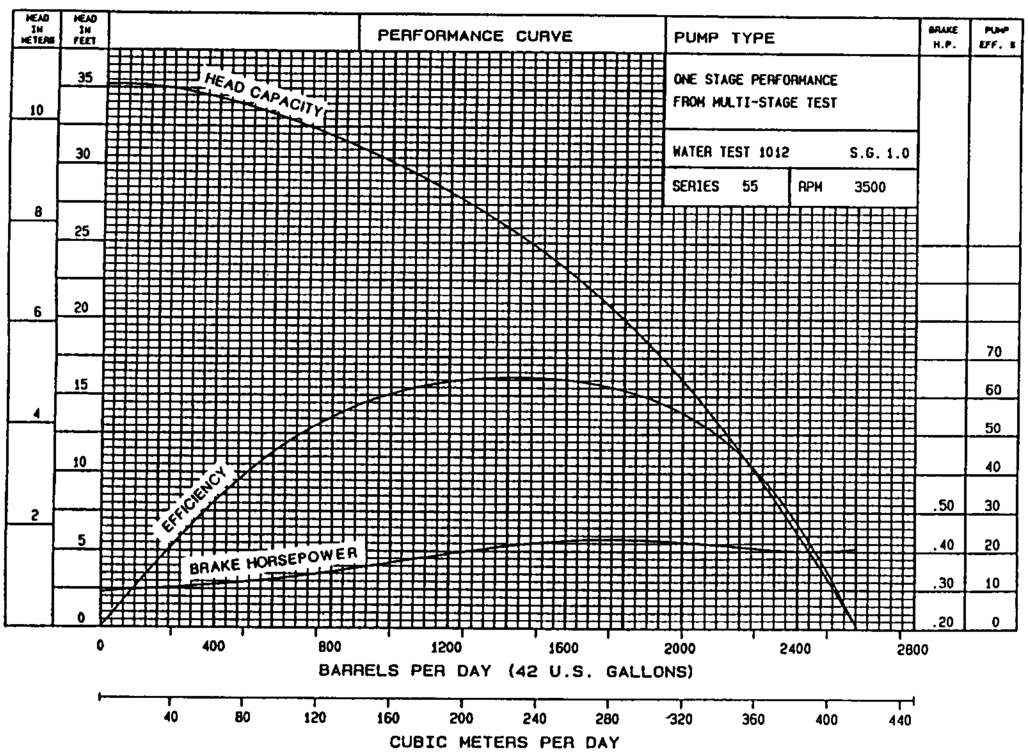

Figure 1 — Pump performance curve

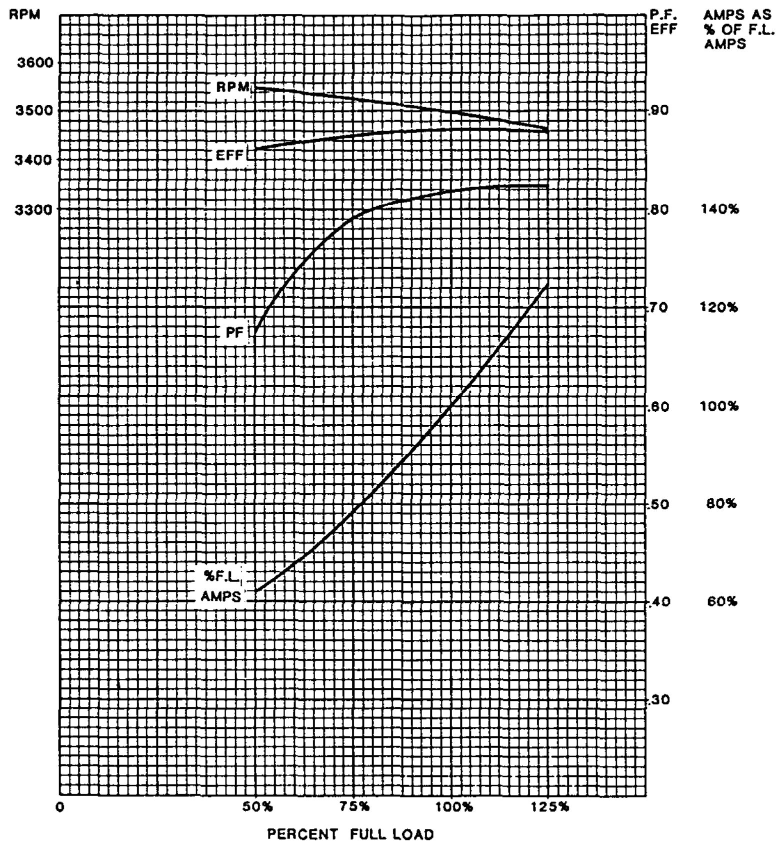

Figure 2 — Motor characteristic curve

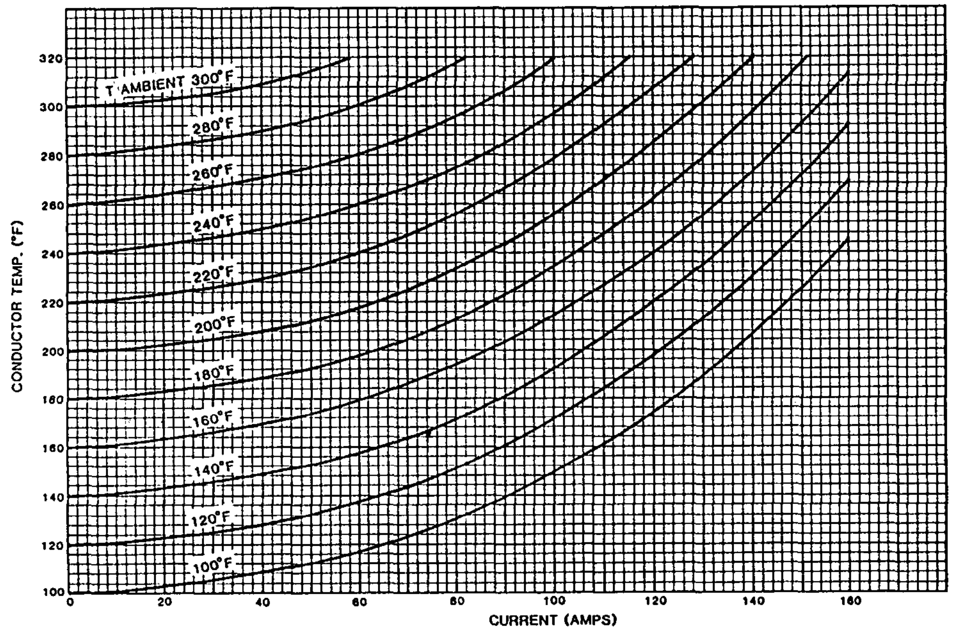

Figure 3 — Conductor temperature #4 AWG

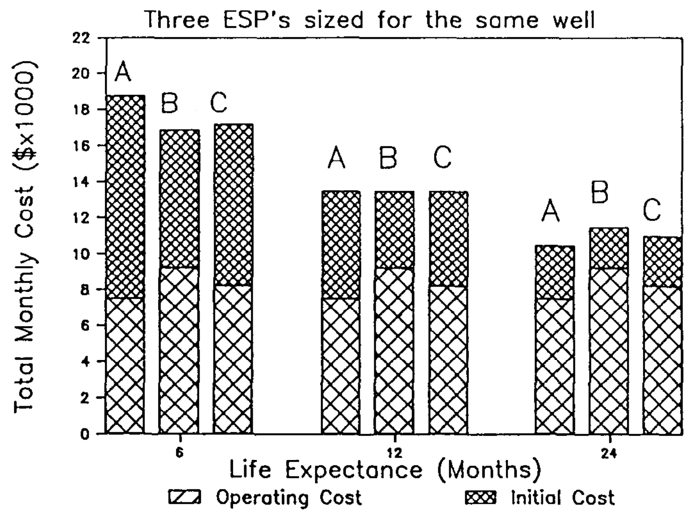

Figure 4 — ESP monthly cost as a function of life

ESP POWER COST PROGRAM

```
10 KEY OFF:DIM A$(28,2),A(28):FOR J=Ø TO 2:FOR I=Ø TO 28:READ A$(I,J)
2Ø NEXT I:NEXT J:A$(13,2)="                                        "
3Ø F=4:GOSUB 77Ø:A=1:B=9:C=4:GOSUB 7ØØ:FOR I=1 TO 23:A(I)=VAL(A$(I,1))
4Ø NEXT I:H=(A(4)*A(5)+A(6))*A(7):A(1Ø)=H/A(8):GOSUB 77Ø
5Ø PRINT,"The unadjusted Hp. required by the pump is ";
6Ø PRINT USING"###.#";H;:PRINT" Hp.":PRINT:PRINT,"The motor load is ";
7Ø PRINT USING"###.#";A(1Ø)*1ØØ;:PRINT" percent of its capacity"
8Ø PRINT:PRINT"     The motor load percent is used with the ";
9Ø PRINT"manufactures motor performance":PRINT"     curve to determ";
1ØØ PRINT"ine the operating RPM.  Read the motor RPM from the curve.":
11Ø A=11:B=11:C=15:GOSUB 7ØØ:IF A(A)=VAL(A$(A,1)) THEN D=H:GOTO 2ØØ
12Ø A(A)=VAL(A$(A,1)):R3=(A(A)/A(1))^3:D=H*R3:A(1Ø)=D/A(8):E=A(1Ø)*1ØØ
13Ø F=6:GOSUB 77Ø:PRINT,"The adjusted Hp. required by the pump is ";
14Ø PRINT USING"###.#";D;:PRINT" Hp.":PRINT:PRINT,"The motor load is";
15Ø PRINT USING"###.#";E;:PRINT" percent of its capacity":PRINT:PRINT
16Ø PRINT"     Check this adjusted motor load with the manufactures ";
17Ø PRINT"motor performance":PRINT"     curve to determine it the RPM";
18Ø PRINT" needs further adjustment.  If so press -N-."
19Ø GOSUB 7ØØ:IF A(A)<>VAL(A$(A,1)) THEN A(A)=VAL(A$(A,1)):GOTO 12Ø
2ØØ X= INT(A(3)*(A(A)/A(1))^2*1Ø)/1Ø:Y=A(A)/A(1)*1ØØ:F=7:GOSUB 77Ø
21Ø PRINT,"The pump will produce"X"feet of head per stage, for a"
22Ø PRINT:PRINT,"total of"X*A(5)"feet TDH.  The flow will be ";
23Ø PRINT USING "###.#";Y;:PRINT"% of the":PRINT:PRINT,"original ";
24Ø PRINT"design flow, for a total of"INT(Y/1ØØ*A(2))"BPD.  The flow"
25Ø PRINT:PRINT,"can be adjusted by changing the number of pump stages.
26Ø LOCATE 23,2Ø,Ø:PRINT A$(3,2):GOSUB 75Ø:IF B$="N" GOTO 3Ø
27Ø GOSUB 77Ø:PRINT,"Use The ";
28Ø PRINT" motor characteristics curve for"INT(A(1Ø)*1ØØØ)/1Ø"%"
29Ø PRINT,"load to find the motor efficiency and current":A=12:B=13
3ØØ PRINT,"as a percent of full load amps":C=9:GOSUB 7ØØ:FOR I=A TO 14
31Ø LOCATE 15,17,Ø:A(I)=VAL(A$(I,1)):IF A(I)>1 THEN A(I)=A(I)/1ØØ
32Ø NEXT:A(15)=A(13)*A(9):A(14)=D*.7457/A(12):PRINT A$(14,Ø);
33Ø PRINT,INT(A(14)*1Ø)/1Ø"KW":LOCATE 17,17,Ø:Z=INT(A(15)*1Ø)/1Ø
34Ø PRINT A$(15,Ø),Z" Amp":LOCATE 23,25,Ø:PRINT A$(2,2):GOSUB 75Ø
35Ø GOSUB 77Ø:PRINT,"Use the cable data table and the graph to find ";
36Ø PRINT"the":PRINT,"cable resistance and the conductor temperature";
37Ø PRINT" in":PRINT,"degrees Fahrenheit for the ambient well temper";
38Ø PRINT"ature":PRINT,"and "INT(A(15)*1Ø)/1Ø"Amps":A=16:B=18:C=1Ø
39Ø GOSUB 7ØØ:FOR I=A TO B:A(I)=VAL(A$(I,1)):NEXT I:T=A(A)*(39Ø+A(17))
4ØØ A(2Ø)=A(2Ø)*1.Ø25:A(19)=A(15)^2*T*A(18)/1.53E+Ø8:GOSUB 77Ø
41Ø PRINT,A$(14,Ø),INT(A(14)*1ØØ)/1ØØ"KW":PRINT,,,"+"
42Ø PRINT,A$(19,Ø),INT(A(19)*1ØØ)/1ØØ"KW":PRINT:A(2Ø)=A(19)+A(14)
43Ø PRINT,"Well Head Power Consumed",INT(A(2Ø)*1ØØ)/1ØØ"KW":PRINT
44Ø PRINT"     A factor of 2.5% is used to represent the power consumed
45Ø PRINT"     by the transformers, switchboard and other surface gear
46Ø A(2Ø)=A(2Ø)*1.Ø25:PRINT:PRINT,A$(2Ø,Ø),INT(A(2Ø)*1ØØ)/1ØØ"KW"
47Ø LOCATE 16,1,Ø:PRINT,A$(21,Ø):LOCATE 16,42,Ø:PRINT A$(21,1)" $/KWH"
48Ø LOCATE 23,25,Ø:PRINT A$(1,2):GOSUB 75Ø
49Ø IF B$="Y" THEN GOTO 51Ø ELSE LOCATE 16,4Ø,Ø
5ØØ INPUT A$(21,1):LOCATE 15,4Ø,Ø:PRINT A$(13,2):GOTO 47Ø
51Ø A(21)=VAL(A$(21,1)):A(22)=A(2Ø)*A(21)*72Ø:LOCATE 18,1,Ø
52Ø PRINT,A$(22,Ø):LOCATE 18,42,Ø:PRINT USING"$$#####";A(22)
53Ø A(23)=A(22)*12.167:LOCATE 2Ø,1,Ø:PRINT,A$(23,Ø):LOCATE 2Ø,42,Ø
54Ø PRINT USING"$$######";A(23):LOCATE 23,25,Ø:PRINT A$(2,2):GOSUB 75Ø
55Ø F=11:GOSUB 77Ø:A=24:B=26:C=6:GOSUB 7ØØ:FOR I= 24 TO 26
56Ø A(I)=VAL(A$(I,1)):NEXT I:LOCATE 1Ø,17,Ø:PRINT A$(26,Ø)
57Ø IF A(25)>.4 THEN A(25)=A(25)/1ØØ:L=A(25)/12:LOCATE 1Ø,41,Ø
58Ø PRINT USING"$$#####";A(26):LOCATE 12,17,Ø:PRINT A$(22,Ø)
59Ø LOCATE 12,41,Ø:PRINT USING"$$#####";A(22):C=(1-1/((1+L)^A(24)))/L
6ØØ LOCATE 18,1,Ø:PRINT,A$(27,Ø):A(27)=A(26)+A(22)*C:LOCATE 18,42,Ø
61Ø PRINT USING"$$#######";A(27):A(28)=A(22)+A(26)/C:LOCATE 2Ø,1,Ø
62Ø PRINT,A$(28,Ø):LOCATE 2Ø,42,Ø:PRINT USING"$$#####";A(28)
63Ø LOCATE 23,22,Ø:PRINT A$(4,2):GOSUB 75Ø
64Ø IF B$="C" THEN LOCATE 23,22,Ø:PRINT A$(13,2):GOTO 55Ø
65Ø IF B$="V" THEN GOTO 66Ø ELSE GOTO 3Ø
66Ø F=4:GOSUB 77Ø:PRINT,,A$(14,2):FOR I=1 TO 14
67Ø LOCATE I+7,1,Ø:PRINT A$(I,Ø);:LOCATE I+7,26,Ø:PRINT A(I)
68Ø LOCATE I+7,4Ø,Ø:PRINT A$(I+14,Ø);:LOCATE I+7,64,Ø:PRINT A(I+14)
69Ø NEXT I:LOCATE 23,25,Ø:PRINT A$(2,2):GOSUB 75Ø:GOTO 3Ø
7ØØ FOR J = A TO B:LOCATE ((J-A)*2+C),17,Ø:PRINT A$(J,Ø),A$(J,1):NEXT
71Ø LOCATE 23,25,Ø:PRINT A$(1,2):GOSUB 75Ø:IF B$="Y" THEN RETURN
72Ø IF B$<>"N" GOTO 71Ø ELSE FOR J=A TO B:U=(J-A)*2+C:LOCATE U,41,Ø
73Ø INPUT B$:IF B$<>""THEN A$(J,1)=B$ :LOCATE U,4Ø,Ø
74Ø PRINT A$(13,2):LOCATE U,41,Ø:PRINT "  "A$(J,1):NEXT:GOTO 71Ø
75Ø B$="":WHILE B$="":B$=INKEY$:WEND:O=ASC(B$):IF O>9Ø THEN O=O-32
76Ø B$=CHR$(O):LOCATE 23,25,Ø:PRINT A$(13,2):RETURN
77Ø CLS:PRINT:F=F+1:PRINT,, A$(F,2):PRINT:PRINT:RETURN
78Ø DATA ,Pump Curve RPM,Flow Rate  BPD,Pump Head/stage,Pump Hp/stage,
    Number of stages, Gas Separator Hp.,Well Fluid Sp.Gr.
79Ø DATA Motor Nameplate Hp,Motor Nameplate Amps,% Motor Load,Motor Op
    erating RPM,Motor Efficiency,% Full Load Amps,Motor Power Consumed
8ØØ DATA Motor Operating Amps,Resistance (Ohm/Kft) Conductor Temp (
    deg F),Cable Length (ft),Cable Power Consumed,Total Power Required
81Ø DATA Electrical Cost ($/KWH),Power Cost per Month,Power Cost per
    Year,Expected life (Months),Interest rate (%/year)
82Ø DATA Initial Unit Cost,Total Investment Cost,Total Monthly Cost,
    b,35ØØ,14ØØ,25.946,.4138,185,Ø,1.Ø5,9Ø,46,c,351Ø,87.94,91.22,d,e,
    .259,171,5ØØØ,f,g,.Ø5,h,i,24,12,3ØØØØ,j,k,l,Is This Correct? (Y/N)
83Ø DATA Press Any Key To Continue,Is Pump Performance Satisfactory?
    (Y/N),Press -C- to Change -V- to View DataESP Power Cost Program,
    RPM Adjustment for Motor Load,RPM Reiteration
84Ø DATA ESP Performance Adjustment for RPM,Motor Efficiency and Amper
    age,Cable Power Consumption,System Power Consumption,Economic Cons
    iderations,m,Input and Calculated Data,n,o,p,q,r,s,t,u,v,w,x,y,z,A
```