An Efficient Computer Program for Decline Curve Analysis of Oil and Gas Wells

M. C. "Aaron" Cheng

Marietta College
Marietta, Ohio

ABSTRACT

This paper explains the development and the applications of a simple, accurate, and efficient computer program for decline curve analysis of both oil and gas wells. By utilizing root extraction technique in numerical methods, the decline exponent n of a given oil/gas property with production rate - time data can be computed directly and the initial decline rate D_i can then be determined. With the values of n and D_i, the governing decline equation for the property can be formulated and used to predict its future performance. The computer program uses very little computer memory space and it runs very fast. Three examples are included to show the accuracy and speed of the program.

INTRODUCTION

In the petroleum industry, decline curve analysis is one of the most widely used techniques for evaluating oil and gas reservoirs. The technique makes use of the existing hydrocarbon production data and extrapolates them to predict the future production; the prediction is valid only if the future follows the producing pattern that prevailed in the past. The main model equations for decline curve analysis, as developed by Arps[1], are the rate - time and the rate - cumulative equations, both of which contain a decline exponent for characterizing the oil/gas property as being exponential, hyperbolic, or harmonic. Among the three, the exponential decline is the easiest to handle and can be done by extrapolating the production rate vs. time data plotted on a semi-log graph paper for prediction of future performance. However, actual hydrocarbon production is normally on hyperbolic decline and the decline curve analysis under this case is quite difficult and more time consuming than the exponential case. This paper presents an efficient computer program for decline curve analysis of oil and gas wells.

ALGORITHM

The algorithm for developing the present decline cure analysis program is based on the Gentry's[2] graphical technique for solving the three types of production decline described before. Instead of finding the property decline exponent n and the initial decline rate D_i graphically[2], these two variables are to be computed directly. Once n and D_i are found, the decline model for the property is fixed and its future performance can be projected. The main procedures are:

1. Input property production data: time of production t, initial production rate q_i, current production rate q_t, cummulative production Q_t, economic producing limit q_e, etc.

2. Test for exponential decline, n = 0 .

$$\left| \frac{Q_t}{q_i t} - \frac{1-(q_i/q_t)^{-1}}{\ln (q_i/q_t)} \right| \leq \varepsilon \qquad ?$$

ε, a predetermined convergence criterion.

If no, go to step

If yes, n = 0, production is on exponential decline.

$$D_i = \frac{\ln (q_i/q_t)}{t}$$

$$t_e = \frac{\ln (q_i/q_e)}{D_i}$$

$$Q_e = \frac{q_i - q_e}{D_i}$$

The rate - time relationship is

$$q_t = q_i e^{-D_i t}$$

The rate - cumulative relationship is

$$Q_t = \frac{(q_i - q_t)}{D_i}$$

Output results and stop.

3. Test for harmonic decline, n = 1.

$$\left| \frac{Q_t}{q_i t} - \frac{\ln (q_i/q_t)}{(q_i/q_t)-1} \right| \leq \varepsilon \quad ?$$

If no, go to step 4.

If yes, n = 1, production is on harmonic decline.

$$D_i = \frac{(q_i/q_t) - 1}{t}$$

$$t_e = \frac{(q_i/q_e) - 1}{D_i}$$

$$Q_e = \frac{q_i \ln (q_i/q_e)}{D_i}$$

The rate - time relationship is

$$q_t = q_i (1 + D_i t)^{-1}$$

The rate - cumulative relationship is

$$Q_t = \frac{q_i \ln (q_i/q_e)}{D_i}$$

Output results and stop.

4. Production is on hyperbolic decline, determine decline exponent n by solving the following equation:

$$f(n) = \frac{Q_i}{q_i t} - \left(\frac{1 - (q_i/q_t)^{n-1}}{(q_i/q_t)^{n}-1}\right) \cdot \left(\frac{n}{1-n}\right) = 0$$

The above equation can be solved by the simple inverse linear interpolation technique, a numerical root-solving method. In the literature, the range of n is normally considered to be between 0 and 1 under hyperbolic decline. However, the above equation indicates that values of n beyond 1 are possible and will be adequate for characterizing producing hydrocarbon properties. Therefore, the decline exponent n is determined in the range $0 < n < 1$ as well as $n > 1$. Once n is computed we have:

$$D_i = \frac{(q_i/q_t)^n - 1}{n}$$

$$t_e = \frac{(q_i/q_e)^n - 1}{n}$$

$$Q_e = \frac{q_i^n}{(1 - n) D_i} (q_i^{1-n} - q_e^{1-n})$$

The rate - time relationship is

$$q_t = q_i (1 + n D_i t)^{-1/n}$$

The rate - cumulative relationship is

$$Q_t = \frac{q_i^n}{(1 - n) D_i} (q_i^{1-n} - q_t^{1-n})$$

Output results and stop.

The decline curve analysis program was coded in FORTRAN and was implemented on an Interdata 32 computer system. The program table space used was 3K. The only input data are the name of the oil/gas property, time of production, initial production rate, current production rate, cumulative production, and economic producing limit. The output results give the decline exponent, total time of production, total production, remaining time and remaining reserves. The program will also output a production forecast of the property for a period of 30 years.

PROGRAM APPLICATIONS

Case 1. Oil Well in Gentry's Example[2]

For this well, the input production data are given in Gentry[2] as: t = 27 months, q_i = 6,292 bbl/month, q_t = 730 bbl/month, Q_t = 55,900 bbl, q_e = 100 bbl/month. The computer program results are shown in Table 1. The following compares the results obtained from Gentry[2] and the current program.

	Gentry	Current program
n	0.6	0.592
t_e, months	112	111.04
Q_e, bbl	77,500	77,928.31

As shown, the two results agree very well. The computer CPU time is 0.231 second.

Case 2. Oil Well A in Locke et al.[3]

The input production data are interpreted from the production rate vs. time plot for Well A in Locke et al.[3]: t = 36 months, q_i = 630 bbl/month, q_t = 93 bbl/month; Q_t = 5,500 bbl/month and q_e = 30 bbl/month, given. The computer program results are shown in Table 2. The decline exponent is computed to be 2.299, outside the normal hyperbolic exponent range $0 < n < 1$. Locke et al[3] used the nonlinear least squares technique to analyze Well A. The following compares the results from these authors and the current program.

	Locke et al.	Current Program
Q_e, bbl	25,000	25,577.63

The current program result of Q_e compares favorably with the value of Locke et al. The computer CPU time is 0.223 second.

Case 3. Gas Well 6 - 2 in Redic [4]

The input production data are: t = 240 months, q_i = 15,000 Mcf/month, q_t = 590 Mcf/month, Q_t = 400.1 MMcf. q_e = 500 Mcf/month. The computer program results are shown in Table 3. The decline exponent is 1.250. Redic generated a decline curve for Well 6 - 2 and the equation was

$$q_t = 51{,}632.9\ (3.727 + t)^{-0.820}$$

Using this equation, q_t is computed at selected t's and the values are compared with those from this current program:

	Redic	Current Program
t, month	q_t, Mcf/month	q_t, Mcf/month
12	5391.10	5149.30
60	1711.52	1716.45
120	993.36	1012.98
180	718.30	739.20
240	569.73	590.00

As shown, the current program gives results of q_t that agree quite well with those of Redic. The computer CPU time is 0.233 second.

CONCLUSIONS

A decline curve analysis computer program has been developed for analysing oil or gas properties. The program uses very little computer space (3K) and it is very efficient; the average CPU time for analyzing the three wells in this study was 0.229 second. Thus, the program can be implemented on a minicomputer and its usage can be inexpensive. Most important, the program requires minimum amount of data on a given property. Only time of production, initial production rate, current production rate and cummulative production are needed and these are readily available data. Also, the computer program can handle decline exponent n beyond the normal range of 0 and 1; the result is that better empirical fit of production rate data can be achieved.

NOMENCLATURE

D_i = initial decline rate

n = decline exponent

Q_e = cummulative production at economic limit

Q_t = cummulative production at time t

q_e = economic producing limit

q_i = initial production rate

q_t = production rate at time t

t = time of production, time

ε = convergence tolerance

REFERENCES

1. Arps, J.J.: "Estimation of Primary Oil Reserves," Trans., AIME (1956) 207, 182-191.
2. Gentry, R.W.: "Decline - Curve Analysis," J. Pet. Tech. (Jan. 1972) 38-41.
3. Locke, C.D., Schrider, L.A. and Romeo, M.K.: "A Unique Approach to Oil-Production Decline Curve Analysis with Applications," paper SPE 2224 presented at SPE 43rd Annual Fall Meeting, Houston, Texas (Sept. 29 - Oct. 2, 1968).
4. Redic, J.G.: "Analysis of Appalachian Basin Economics," J.Pet. Tech. (July, 1974) 717 - 723.

TABLE 1

DECLINE CURVE ANALYSIS

WELL IN GENTRY'S EXAMPLE JPT JAN 1972

INPUT DATA
TIME OF PRODUCTION = 27.00 MONTH
INITIAL PRODUCTION RATE = 6292.00 BBL/MONTH
CURRENT PRODUCTION RATE = 730.00 BBL/MONTH
CUMULATIVE PRODUCTION = 55900.00 BBL
ECONOMIC LIMIT = 100.00 BBL/MONTH
OUTPUT RESULTS
DECLINE EXPONENT = 0.592
ECONOMIC LIMIT = 100.00 BBL/MONTH
TOTAL TIME OF PRODUCTION = 111.04 MONTH
TOTAL PRODUCTION = 77928.31 BBL
REMAINING TIME = 84.04 MONTH
REMAINING RESERVES = 22028.31 BBL

PRODUCTION FORECAST

TIME OF PRODUCTION MONTH	PRODUCTION RATE BBL/MONTH	CUMULATIVE PRODUCTION BBL
12.00	1731.97	39117.04
24.00	840.54	53538.16
36.00	507.41	61359.71
48.00	344.18	66368.81
60.00	251.07	69893.69
72.00	192.48	72530.25
84.00	153.00	74588.81
96.00	125.01	76247.88
108.00	104.37	77618.25
120.00	88.67	78772.38
132.00	76.42	79759.94
144.00	66.66	80616.25
156.00	58.74	81367.06
168.00	52.22	82031.63
180.00	46.78	82624.69
192.00	42.19	83157.81
204.00	38.28	83640.00
216.00	34.92	84078.69
228.00	32.00	84479.81
240.00	29.45	84848.19
252.00	27.21	85187.88
264.00	25.23	85502.31
276.00	23.47	85794.38
288.00	21.90	86066.44
300.00	20.49	86320.62
312.00	19.22	86558.69
324.00	18.07	86782.25
336.00	17.02	86992.69
348.00	16.07	87191.19
360.00	15.20	87378.69

TABLE 2

DECLINE CURVE ANALYSIS

WELL A LOCKE ET AL SPE 2224

INPUT DATA
TIME OF PRODUCTION = 36.00 MONTH
INITIAL PRODUCTION RATE = 630.00 BBL/MONTH
CURRENT PRODUCTION RATE = 93.00 BBL/MONTH
CUMULATIVE PRODUCTION = 5500.00 BBL
ECONOMIC LIMIT = 30.00 BBL/MONTH

OUTPUT RESULTS
DECLINE EXPONENT = 2.299
ECONOMIC LIMIT = 30.00 BBL/MONTH
TOTAL TIME OF PRODUCTION = 490.66 MONTH
TOTAL PRODUCTION = 25577.63 BBL
REMAINING TIME = 454.66 MONTH
REMAINING RESERVES = 20077.63 BBL

PRODUCTION FORECAST

TIME OF PRODUCTION MONTH	PRODUCTION RATE BBL/MONTH	CUMULATIVE PRODUCTION BBL
12.00	148.40	2769.80
24.00	110.64	4287.85
36.00	93.00	5499.62
48.00	82.17	6546.21
60.00	74.63	7484.62
72.00	68.98	8344.79
84.00	64.53	9144.80
96.00	60.90	9896.68
108.00	57.87	10608.82
120.00	55.29	11287.45
132.00	53.05	11937.20
144.00	51.09	12561.82
156.00	49.35	13164.20
168.00	47.78	13746.81
180.00	46.37	14311.59
192.00	45.09	14860.34
204.00	43.92	15394.31
216.00	42.85	15914.85
228.00	41.85	16422.91
240.00	40.93	16919.55
252.00	40.07	17405.55
264.00	39.27	17881.53
276.00	38.52	18348.74
288.00	37.81	18806.25
300.00	37.15	19255.93
312.00	36.52	19697.96
324.00	35.93	20132.68
336.00	35.37	20560.34
348.00	34.83	20981.50
360.00	34.32	21396.40

TABLE 3

DECLINE CURVE ANALYSIS

WELL 6-2 JPT JULY 1974

INPUT DATA
TIME OF PRODUCTION = 240.00 MONTH
INITIAL PRODUCTION RATE = 15000.00 MCF/MONTH
CURRENT PRODUCTION RATE = 590.00 MCF/MONTH
CUMULATIVE PRODUCTION = 400.0999 MMCF
ECONOMIC LIMIT = 500.00 MCF/MONTH

OUTPUT RESULTS
DECLINE EXPONENT = 1.250
ECONOMIC LIMIT = 500.00 MCF/MONTH
TOTAL TIME OF PRODUCTION = 296.16 MONTH
TOTAL PRODUCTION = 430.0896 MMCF
REMAINING TIME = 56.16 MONTH
REMAINING RESERVES = 29.9897 MMCF

PRODUCTION FORECAST

TIME OF PRODUCTION MONTH	PRODUCTION RATE MCF/MONTH	CUMULATIVE PRODUCTION MMCF
12.00	5149.30	98.2946
24.00	3310.44	147.2399
36.00	2494.61	181.5527
48.00	2024.96	208.4500
60.00	1716.45	230.7847
72.00	1496.82	249.9964
84.00	1331.73	266.9238
96.00	1202.65	282.1006
108.00	1098.69	295.8879
120.00	1012.98	308.5430
132.00	940.99	320.2554
144.00	879.56	331.1687
156.00	826.48	341.3977
168.00	780.11	351.0315
180.00	739.20	360.1428
192.00	702.83	368.7891
204.00	670.25	377.0254
216.00	640.88	384.8894
228.00	614.26	392.4172
240.00	590.00	399.6406
252.00	567.80	406.5857
264.00	547.39	413.2744
276.00	528.56	419.7295
288.00	511.13	425.9653
300.00	494.94	432.0007
312.00	479.86	437.8491
324.00	465.78	443.5220
336.00	452.60	449.0322
348.00	440.22	454.3870
360.00	428.53	459.5999