On the Application of the Method of Exhaustion in Seeking a Proper Formula for Discharge Estimation

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ABSTRACT

In order to do the discharge estimation better, it is valuable to find out appropriate formulas for estimating discharge in various pits, based on accumulating data, summarizing discharge patterns applying optimum seeking method and principle, by seeking redical exponent with help of the method of exhaustion, as well as testing and making statistics, in accordance with the quality standards established by our practical experience.

INTRODUCTION

The workable coal bed in Meitanba Coal Mine (Ning Xiang City, Hunan) rests on the lower Permian Maekau limestone and contains a great amount of groundwater with total discharge during the exploitation reaching 8310 m^3/h. Variation in different pits indicates that there are various hydrogeological conditions in different pits within the same mine area. The urgent problem facing us is to find out an accurate formula for estimating discharge in these various pits for the purpose of control of the groundwater. Therefore, by collecting discharge statistics from production practice, and plotting correlation diagrams, a pattern has been found as follows: the discharge in pits (Q) increases with both the depth of the fall of water level (S) and area of exploitation (F) or the length of drift (L) and have a functional relationship represented by Q=f (S,F or L). So the following models of radical exponent equations have been used:

$Q = Q_o (S/S_o)^{\frac{1}{n}}$ (estimating model for shaft) ---(1)

$Q = Q_o (L/L_o)^{\frac{1}{m}}$ (estimating models for same horizon) ---(2)

$Q = Q_o (F/F_o)^{\frac{1}{m}}$ ---(3)

$Q = Q_o (L/L_o)^{\frac{1}{m}} (S/S_o)^{\frac{1}{n}}$ (estimating model for) ---(4)

$Q = Q_o (F/F_o)^{\frac{1}{m}} (S/S_o)^{\frac{1}{n}}$ (the level extended down) ---(5)

Where the:

Q, Q_o -- the discharge in pit (M^3/h), estimated; available)

F, F_o -- the area of exploitation in pit (M^2 estimated; available)

L, L_o -- the length of drift (M, designed; available)

S, S_o -- the depth of fall of water level (M, designed; available)

m, n -- radical exponents, constants to be calculated.

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The calculating formulas for discharge estimation applicable to various pits will be obtained from the parameters collected (Table 1) and with the method of exhaustion to be used to calculate the radical exponents m, n suitable to the practical situation in various pits.

QUALITY ASSESSMENT CRITERIA

As provided in the "Standard for Quality of Geological Work in Mines and regulations for its Check and Evaluation" promulgated by the Ministry of Coal Industry of P.R.C. in 1975, the difference between the estimated and practical discharges of 10% will be taken for 1-grade product, the difference 20% for 2-grade product, and the difference 20% for 3-grade product. Accordingly, four standards for accepting or rejecting a formula are as follows:

1. Where the relative error between practical and estimated discharge does not exceed 10%, the products will be of 1-grade, and frequence of appearance of 1-grade products be more than 50%;

2. Where the relative error between practical and estimated discharge does not exceed 20%, the products will be of 2-grade, and frequence of their appearance should be more than 70%;

3. The frequence of positive error in 2-grade products should be more than 50%;

4. Estimation of final discharge at several exploitation levels should be made, with a result of the frequence of positive errors being no less than 50%, and belonging to the 1-grade and 2-grade products.

It is known from the standards that the first and second articles serve to control the precision of estimate, and the third and fourth articles to ensure the safety. That is the value of estimated discharge should be greater than that of practical discharge, especially in the case of a pit with a big volume of ground water at this closing stage of certain exploitation level. Therefore, the optimum value of radical exponent of m and n is not the minimum value of error in general but the minimum value of positive error.

THE METHOD OF EXHAUSTION

The method of exhaustion is a method used to solve an incompete equation. The exhaustion refers to the assumption of the radical exponents m and n, as in equations (1) to (5), where Q, F, L and S are all known parameters. In a checking process, the discharge data obtained in a preceding year is used as a known value, and the discharge data obtained in the successing year as a designed value for an assumed radical exponent. By substituting the figure from Table 1 for each year into the formula, a Q value will be obtained for each period. In fact, each year should have discharge as Q_o, thus the Q of the same period of time can be compassed with Q_o to obtain an absolute error and a relative error of that period of time. The absolute error would have both the positive and negative values, and the relative error would show magnitude of its percentage. In accordance with the above mentioned standards and results of statistics and checks, one can judge the adaptability of each radical exponent to the formula. If the radical exponent is too large to be suitable, it should be lessened a bit next time, and vice versa. As to what radical exponent should be suggested and how to lessen or enlarge, it depends on the experience of the worker himself and the deduction during checking. Usually, a satisfactory radical exponent will be obtained by checking 2 or 3 times.

Parameters for estimating discharge **Table 1**

Year	77	78	79	80	81	82	83	84	85	86
$Q(m^3/h)$	6683	6680	6834	6755	7268	8312	7826	8100	8175	8277
S(M)	187	187	187	187	187	217	276	297	297	297
L(m)	2049	3328	4863	6268	7108	8472	9385	11072	12177	13619
$F(m^2)$	53	110	152	179	197	221	244	278	318	360

The equation of radical exponent with different power have been calculated according to that procedure and used for every pit of Meitanba Coal Mine. All these equations are shown in Table 2.

The formulas for estimating discharge in pits of Meitanba Coal Mine — Table 2

YEAR	PIT	SAME LEVEL					The LEVEL EXTENDED DOWN				
		Formula	*(1)	(2)	(3)	(4)	Formula	(1)	(2)	(3)	(4)
1976	1	$Q=Q_o\left(\frac{F}{F_o}\right)^2$	62	77	80	100	$Q=Q_o\ \frac{F}{F_o}\left(\frac{S}{S_o}\right)^{\frac{1}{2}}$	58	83	57	50
	2	$Q=Q_o\ \frac{F}{F_o}$	72	83	67	50	$Q=Q_o\ \frac{F}{F_o}\left(\frac{S}{S_o}\right)^{\frac{1}{3}}$	62	77	60	50
1986	1	$Q=Q_o\left(\frac{F}{F_o}\right)^{\frac{1}{5}}$	50	95	100	100	$Q=Q_o\left(\frac{F}{F_o}\right)^{\frac{1}{15}}\left(\frac{S}{S_o}\right)^{\frac{1}{25}}$	50	90	100	100
	2	$Q=Q_o\left(\frac{F}{F}\right)^{\frac{1}{3}}$	83	90	85	100	$Q=Q_o\ \left(\frac{F}{F}\right)^{\frac{1}{2}}\left(\frac{S}{S}\right)^{\frac{1}{4}}$	59	91	80	100
	3						$Q=Q_o\ \left(\frac{F}{F}\right)^{\frac{1}{6}}\left(\frac{S}{S}\right)^{\frac{1}{4}}$	73	82	79	100
	4	$Q=Q_o\left(\frac{F}{F}\right)^{\frac{1}{2}}$	75	94	73	100					

*(1) 1-grade products (%), (2) 2-grade products (%),
(3) Positive error among 2-grade products (%),
(4) Final positive error of the level (%).

The formulas selected in 1976 were based on three pairs of drainage pits and exploitation was carried out in the shallow parts, but the formulas selected in 1986 were based on four pairs of drainage pits and exploitation was done in deeper part. It is natural for the formulas of estimating discharge to have different radical exponents because of different intensity of exploitation and different hydrogeological conditions. Therefore, we can reasonably infer that the formulas of estimating discharge can be adjusted again in ten or more years with the change of the conditions of groundwater run-off due to the enhancement of the prevention and control of water and the decrease in the development of karat in the deeper part in order to meet the need of development of the production.

Experience shows that the hydrogeological conditions are rather different not only between different mining districts but also between different pits in the same mining area. Therefore, it is not feasible to try to find out a universal and permanent formula. It is also not possible for any Survey Team carrying out a hydrogeological exploitation in such a mine to find a very accurate formula by the exploration means now available. For this reason, mining hydrogeologists have to modify and improve the calculation of discharge by practical experience in order to direct and improve the production of a mine.

There are two necessary conditions of the application of the exhaustion method:

(1) The data of all parameters for estimating discharge has been more than a hydrogeological year;

(2) They possessed of a functional relationship between the discharge and its parameters.

THE PRACTICAL EFFECT OF THE FORMULAS OBTAINED BY THE METHOD OF EXHAUSTION

(1) The effect of formulas obtained by the method of exhaustion as compared with those obtained by other methods.

Based on the same data, the author has employed the expression (5) by means of the average method in groups. First of all, the expression is rewritten as a logarithmic form:

$$\log Q-\log Q_{o} = \frac{1}{m}(\log F-\log F_{o})+\frac{1}{n}(\log S-\log S_{o}) \qquad \text{-----(6)}$$

Transfer the values of Q, F, S, Q_o, F_o S_o for each period of time into the logarithmic values, then sum them separately according to groups and substitute the corresponding values of each group in expression (6).

$$\sum_{1}^{\frac{n}{2}}\mathrm{lg}Q-\sum_{1}^{\frac{n}{2}}\mathrm{lg}Q^{\circ}=\frac{1}{m}\left(\sum_{1}^{\frac{n}{2}}\mathrm{lg}F-\sum_{1}^{\frac{n}{2}}\mathrm{lf}F^{\circ}\right)+\frac{1}{n}\left(\sum_{1}^{\frac{n}{2}}\mathrm{lg}S-\sum_{1}^{\frac{n}{2}}\mathrm{lg}S^{\circ}\right) \qquad \text{-----(7)}$$

$$\sum_{\frac{n}{2}+1}^{n}\mathrm{lg}Q-\sum_{\frac{n}{2}+1}^{n}\mathrm{lg}Q_{o}=\frac{1}{m}\left(\sum_{\frac{n}{2}+1}^{n}\mathrm{lg}F-\sum_{\frac{n}{2}+1}^{n}\mathrm{lg}F_{o}\right)+\frac{1}{n}\left(\sum_{\frac{n}{2}+1}^{n}\mathrm{lg}S-\sum_{\frac{n}{2}+1}^{n}\mathrm{lg}S_{o}\right) \qquad \text{---(8)}$$

After solving these simultaneous equations, then m and n radical exponents will be obtained.

An other way to solve radical exponents is using least squares principle. The radical exponent equations of m and n derived from partial derivatives based on this principle is:

$$n = \frac{N\sum_1^n(\lg S-\lg S_\circ)^2-\left(\sum(_1^n(\lg S-\lg S_\circ)\right)^2}{N\sum_1^n(\lg Q-\lg Q_\circ)(\lg S-\lg S_\circ)-\sum_1^n(\lg Q-\lg Q)\sum_1^n(\lg S-\lg S_\circ)} \quad \text{----(9)}$$

$$\frac{1}{m} = \frac{\sum_1^n(\lg Q-\lg Q_\circ)-\frac{1}{n}\sum_1^n(\lg S-\lg S_\circ)}{N\sum_1^n \lg F-\sum_1^n \lg F_\circ} \quad \text{----(10)}$$

Sum the logarithmic values of the data in Table 1 then substitute them in expression (9) in order to get exponent n finally, put n and corresponding data in expression (10) and exponent m will be obtained. The equations of radical exponent obtained by above mentioned three methods are checked one by one, the results are shown in Table 3.

Results of the check of radical exponents m and n obtained by the three methods **Table 3**

Method	Method of exhaustion		Average method in groups		Method of least squares	
The Radical equation with different power	$Q=Q_\circ\left(\frac{F}{F}\right)^{\frac{1}{2}}\left(\frac{S}{S}\right)^{\frac{1}{6}}$		$Q=Q_\circ\left(\frac{F}{F}\right)^{\frac{1}{12}}\left(\frac{S}{S}\right)^{\frac{10}{17}}$		$Q=Q_\circ\left(\frac{F}{F}\right)^{\frac{10}{7}}\left(\frac{S}{S}\right)^{\frac{10}{25}}$	
Standard for Check selecting	Frequency	%	Frequency	%	Frequency	%
1-grade products relative error 10%	8	80	9	90	9	90
2-grade products relative error 20%	9	90	9	90	9	90
Positive error among 2-grade products	7	70	3	30	4	40
Final positive error of the level	1	100	0	0	0	0

(1) The radical exponents obtained by the least squares method and the average method in groups are very accurate and have a higher percentage of 1-grade and 2-grade products. But on the other hand, they are inferior to the method of exhaustion in satisfying the requirement of positive error, having lower percentage of positive error 2-grade products and the final level, so the result in these aspects cannot satisfy the standards. Mining hydrogeologist know that lower positive error means the frequency of the estimated discharge will be less than the true discharge. In other words, the negative error will be higher, that is to say, the estimated discharge will be less than the true discharge, and there will be a higher frequency of the negative error than that of the positive error, that signifies that there is a danger hidden for pits with large volume of ground water to be submerged in that case.

(2) The least square method could be taken as a first step of the method of exhaustion, because of radical precision. In this way, a beginner can avoid the blindness in seeking radical exponents by the method of exhaustion in order to get the values of m and n quicker.

(2) The effect of the practice of the formulas obtained by the method of exhaustion.

"Practice is the only criterian to check truth." The method of exhaustion has been applied to estimating the discharge in four pairs of pits at 5 exploitation levels extending down to the depth since 1963, the results of the practice are shown in Table 4.

Effect of practice of estimating the discharge by the method of exhaustion Table 4

Year	Pit	Estimated Level (m)	Estimated Discharge (m^3/h)	True Discharge (m^3/h)	Absolute Error (m^3/h)	Relative Error (%)	Grade
1965	1	-30	2000	2400	200	9	1
1967	3	-50	3500	3000	500	16.7	2
1968	2	-115	1500	1250	250	20	2
1969	4	-100	4000	3350	650	19.4	2
1972	1	-120	2800	2371	429	18	2

The data in Table 4 indicates that the results of the method of exhaustion are very good, the proportion of the qualified products amounting to 100%.

(3) The effect of the practice of the formulas obtained by the method of exhaustion in other Coal Mines.

(1) Yang Chuan Shan Coal Mine, Ning Xiang City, Hunan Province.

Parameters of Yang Chuan Shan Coal Mine **Table 5**

Levels	$Q(m^3/h)$	S(m)
+40	470	90-40=50
+5	780	85
-70	?	160

Q - S curve equation indicated that there is a functional relationship between Q and S, the model of radical exponent equation ($Q=Q_o(S/S_o)1/n$) has been used:

$$Q = Q_o \left(\frac{S}{S_o}\right)^{\frac{1}{n}} \quad , \text{ i.e. } 780=470\left(\frac{85}{50}\right)^{\frac{1}{n}} \qquad n=1.0475\approx1.1$$

The radical exponent equation is $Q=Q_o$ ----(11)

Estimated discharge at -70 level by formula (11) in 1978 was $1386m^3/h$, then the true discharge at -70 level in 1982 was $1260m^3/h$ there was a relative error 10%, and the products were 1-grade.

(2) Shang Shi Ling Coal Mine

Parameters **Table 6**

Levels	L(m)	$Q(m^3/h)$	S(m)
+20	120	150	54-20=34
0	150	400	54
-20	500	820	74
-70	2400	?	124

Because there is a functional relationship between Q, L and S, the model of eqyation (4) has been used:

Estimated discharge formula selected in 1977.

$$Q = Q_o \left(\frac{L S}{L_o S_o} \right)^{\frac{10}{14}} \quad \text{-------(12)}$$

Estimated discharge at -70 level by formula (12) in 1978 was 3652 m^3/h, then the true discharge at -70 level in 1983 was 3742m^3/h, the relative error was 2.4% and the products were 1-grade.

(4) The economic effect of the formulas obtained by the method of exhaustion.

Meitanba Coal Mine has kept a record of production with no accident happening to submerge the pits in 25 years, thus avoiding the damage of property, guaranteeing the workers' safety and providing a precondition for more rapid development and growth of the mine. The following are the results of the comparison of data obtained in 1987 with those obtained in 1963:

The discharge in the whole mine was 5 times greater in 1987 than in 1963;
The production cost per ton of raw coal decreased by 4 yaun;
The output of raw coal multiplied greatly.

(5) The formulas obtained by the method of exhaustion come up to the standards of quality premulgated by the Ministry of Coal Industry of P.R.C. in an all round way, the data of these formulas is easy for mining hydrogeologic workers to collect and it is simple, especially with the help of computers to calculate the results by these formulas.

Table 1

Initial Parameters of Variant No 1

Simulated area: 10 x 10km
Size of network (being symetrical): 25 x 25 x 3 = 1125 nodes
Thickness of aquifer: 15m
Closed boundary at symetrical axes

Parameters of reservoir:

- Porosity: 0,1
- Permeability - horizontal: 100 mD
- Permeability - vertical: 50 mD
- Compressibility of rock: $6,8.10^{-5}$ 1/bar
- Initial water head: 17 bar

Parameters of phases

	Water	Gas
Normal density kg/m^3	1012,0	1,0155
Viscosity under pressure (cP)	0,95	0,0132
Formation volume factor (B_w)	1,022-$3,15.10^{-5}$xP	0,9693xP
Degree of gas saturation	0,0468xP	-