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Comparison of Factorial and Taguchi's Methods In Optimization of Effective Parameters of Coal Flotation

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In this work, the aspects of experimental design is described in two Taguchi's and Factorial methods and applied to optimized four factors that affecting flotation of coal (pulp density, impeller speed, the amount of gasoline and pine oil) and determined that the results of Taguchi's method with performing a few experiments, are suitable than Factorial method. In factorial method, pulp density and pine oil assuming factors have no effect on the result of experiments, however in Taguchi's method, four factors have more effect on the results.

Key Words: Experimental design, Factorial method, Taguchi's method, Flotation, Galiran mine.

INTRODUCTION

Statistical design of experiments is an approved technique that has a number of application in almost all engineering disciplines. Its importance in giving an accurate and reasonable results are well known fact to experts and engineers all over the world[1].The first idea about experimental design refer to 1920s, when Fisher used an analytical and systematic method for optimizing the experiment conditions[2]. Design of experiments is the studies of some variables in the process or is the combination of some changeable at just an individual research rather than doing research and study for each of them. In order to get an accurate results about the exchanges of output process, the number of experiments decreases considerably[3]. This method exactly differs with one factor at a time method, also study of one factor at a time, has no effect and assurances on detecting of special effects from factor's compound and interaction effect[4].

One of the most important results of experimental design is acquiring more information at each experiment than methods without any designing. According to experts who apply design of experiments, the design has decreased the necessary time for project developing and also the effectiveness was improved specially when there are numerous important changeable factors[4].

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Other effectiveness of experimental design is to organize method or collecting and analyzing the information.The result of one designed experiment is not often clear without statistical analyses. On the other hand, study and analyzing of a random method experiment results (without designing) even with the help of statistics experts is difficult.

In this work, two methods, factorial at 2 levels and Taguchi's method at 3 levels were compared. In order to determine factors which have effect on the results of flotation of Galiran coal mine. It was determined that Taguchi's method needs less experiment than factorial method[5]. In Taguci's method with using Latin squares, the L_9 design, has been consider for this experiments[6]. Though Taguchi's method doesn't insist on determineation of the interaction effects, the main effectives has been emphasizes[7].

RESULTS AND DISCUSSION

Effective factors and their levels on flotation

Once an experiment method was determined, it is necessary to assign factors which effect on experiment and their levels, according to accuracy and capacity of experiments.

As mentioned before, two methods of Taguchi and factorial have been used for experiments designing related to flotation of Galiran coal mine.

According to the previous information on the coal flotation[8] and work capacity, four factors were considered as external controllable factors. Factors have changed in factorial method at 2 levels and in Taguchi's method at 3 level[9]. Factors and their levels are shown in Tables 1 and 2, respectively.

TABLE-1
FACTORS AND THEIR LEVELS AT FACTORIAL METHOD

Factors	Abbreviation	Factor's level	
		1	2
Pulp density	A	5	9
Impeller speed (rpm)	B	1000	1500
Gasoline (g/t)	C	1000	2000
Pine oil (g/t)	D	150	250

TABLE-2
DIFFERENT FACTORS AT 3 LEVELS

Factors	Abbreviation	Factor's level		
		1	2	3
Pulp density	A	5	7	9
Impeller speed (rpm)	B	1000	1250	1500
Gasoline (g/t)	C	1000	1500	2000
Pine oil (g/t)	D	150	200	250

Factorial method

Considering the number of factors and their levels at factorial method, the Table-3 has been used for designing of experiments. (-) is for low level of factors and (+) is for high level factors[1]. The results obtained are shown in Table-4. Considering Table-5 and comparing the (F) resulted from Table-5 with F, from standard Table, only the effects of B and C factors are correct and meaningful. Since F values, due to interaction effects of AB is close to critical value of F, it was better to omit the ineffective factors and analyze the variance again, (Table-6). As it is clear from Table-6, interaction effect of AB is meaningful too, because of obvious interaction effect which lies between A and B, factor A has been considered and not ignored.

TABLE-3
EXPERIMENTAL DESIGN AT FACTORIAL METHOD

Run	A	B	C	D	AB	AC	AD	BC	BD	CD
1	-	-	-	-	+	+	+	+	+	+
2	+	-	-	-	-	-	-	+	+	+
3	-	+	-	-	-	+	+	-	-	+
4	+	+	-	-	+	-	-	-	-	+
5	-	-	+	-	+	-	+	-	+	-
6	+	-	+	-	-	+	-	-	+	-
7	-	+	+	-	-	-	+	+	-	-
8	+	+	+	-	+	+	-	+	-	-
9	-	-	-	+	+	+	-	+	-	-
10	+	-	-	+	-	-	+	+	-	-
11	-	+	-	+	-	+	-	-	+	-
12	+	+	-	+	+	-	+	-	+	-
13	-	-	+	+	+	-	-	-	-	+
14	+	-	+	+	-	+	+	-	-	+
15	-	+	+	+	-	-	-	+	+	+
16	+	+	+	+	+	+	+	+	+	+

Analyzing data variance: A, B and AB factors have most effect on experiment results. But to accept or refuse the affect of factors, a statistical analysis must be done on experiments results (Table-5). In Table-5, DF = degree of freedom, SS = sum of square and V = variance.

Diagrams of different levels effect: After determining of obvious and meaningful factors, the improved levels of factors, should be determined. The results of different levels are illustrated in Figs. 1 and 2.

As the Figs. 1 and 2 show, changing the levels of main factors of impeller, speed, the amount of gasoline assuming and interaction effect of pulp density and impeller speed at this particular range, only affects on experiment results.

TABLE-4
RESULTS OF FACTORIAL METHOD EXPERIMENTS WITH DIFFERENT LEVELS OF FACTORS

Run	A (%)	B (rpm)	C (g/t)	D (g/t)	AB	AC	AD	BC	BD	CD	R (%)
1	5	1000	1000	150	+	+	+	+	+	+	49.53
2	9	1000	1000	150	–	–	–	+	+	+	42.41
3	5	1500	1000	150	–	+	+	–	–	+	45.61
4	9	1500	1000	150	+	–	–	–	–	+	52.10
5	5	1000	2000	150	+	–	+	–	+	–	54.08
6	9	1000	2000	150	–	+	–	–	+	–	42.15
7	5	1500	2000	150	–	–	+	+	–	–	54.62
8	9	1500	2000	150	+	+	–	+	–	–	60.37
9	5	1000	1000	250	+	+	–	+	–	–	41.76
10	9	1000	1000	250	–	–	+	+	–	–	40.79
11	5	1500	1000	250	–	+	–	–	+	–	46.28
12	9	1500	1000	250	+	–	+	–	+	–	56.18
13	5	1000	2000	250	+	–	–	–	–	+	49.02
14	9	1000	2000	250	–	+	+	–	–	+	52.02
15	5	1500	2000	250	–	–	–	+	+	+	60.03
16	9	1500	2000	250	+	+	+	+	+	+	60.00
+R	50.75	54.40	54.03	50.76	52.88	49.71	51.60	51.19	51.33	51.24	–
–R	50.11	46.47	46.83	50.11	47.99	51.15	49.26	49.48	49.54	49.53	–
E	0.637	7.927	7.20	0.65	4.89	1.44	2.34	1.51	1.79	1.81	–

E = Effect of factors on experiment results, R = Recovery.

TABLE-5
ANALYSIS OF VARIANCE OF MAIN FACTOR'S AFFECT AT FACTORIAL METHOD

S. No.	Source	DF	SS	V	F
1	A	1	1.81	1.81	0.4
2	B	1	238.24	238.24	13.15
3	C	1	224.25	224.25	12.38
4	D	1	1.49	1.49	0.08
5	AB	1	107.43	107.43	5.93
6	AC	1	5.31	5.31	0.29
7	AD	1	21.16	21.16	1.17
8	BC	1	9.58	9.58	0.53
9	BD	1	9.12	9.12	0.50
10	CD	1	9.24	9.24	0.51
11	Error	5	90.6	18.12	
12	Total	15	718.24		

F (0.05, 1, 5) = 6.60

TABLE-6
ANALYSIS OF VARIANCE OF MEANINGFUL FACTORS AT FACTORIAL METHOD

S. No.	Source	DF	SS	V	F
1	A	1	1.81	1.81	0.14
2	B	1	238.24	238.24	17.89
3	C	1	224.25	224.25	16.84
4	AB	1	107.43	107.43	8.07
5	Error	11	146.51	13.22	–
6	Total	15	–	–	–

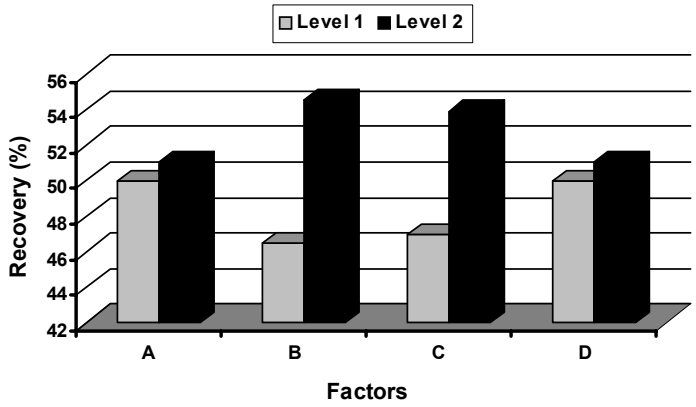

Fig. 1. Effect of factor levels on recovery

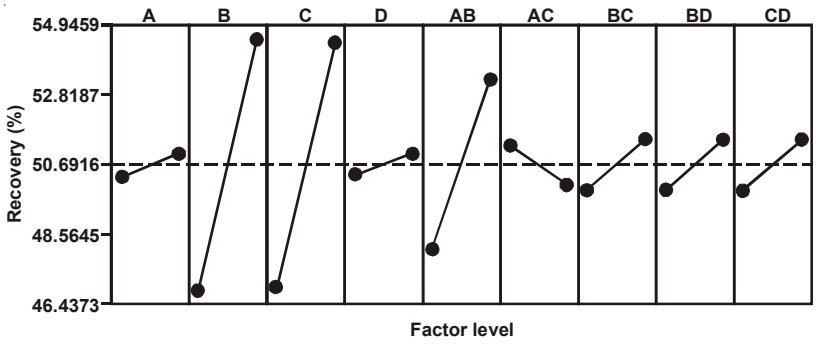

Fig. 2. Effect of different factor level on recovery

Taguchi's method

This experiment was also done by Taguchi's method, but factors have changed at 3 levels (Table-2). According to the standard Tables of Taguchi's method, L_9 design has been consider for these experiments[6].

For designing of experiments related to four factors at 3 levels by factorial method, 64 different experiments must be down[1]. With factorial method, doing such experiments, needs lot of money and time, but doing the same experiments by Taguchi's method, is possible with only 9 different experiments.

These experiments were done according to Table-7 and the levels of each experiment and their results are shown in Table-8.

TABLE-7
DESIGN OF TAGUCI'S METHOD

S. No.	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

TABLE-8
FACTORS LEVELS AND RESULTS OF EXPERIMENTS
BY TAGUCHI'S METHOD

S. No.	A (%)	B (rpm)	C (g/t)	D (g/t)	R (%)	S/N
1	5	1000	1000	150	49.01	33.81
2	5	1250	1500	200	45.61	33.185
3	5	1500	2000	250	60.17	35.59
4	7	1000	1500	250	52.02	34.32
5	7	1250	2000	150	56.25	35.00
6	7	1500	1000	200	56.18	34.99
7	9	1000	2000	200	47.12	33.46
8	9	1250	1000	250	47.83	33.59
9	9	1500	1500	150	55.75	34.92

Another parameter which is considered in Table-8 and Taguchi prefers to use in design of experiments is, S/N ratio[10]. In present work, since the main objective of experiment is to increase the recovery, the eqn. 1 is used for determination of S/N ratio

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum\frac{1}{y_i^2}\right) \quad (1)$$

where y_i is responds in i experiment with i = 1,2,3… and n is the number of experiments[7].

Besides recovery, analysis on S/N ratio is also shown in Tables 9 and 10.

TABLE-9
RESULT ANALYZING

Factor	DF	SS	V
B	2	119.80	59.90
A	2	33.23	16.62
D	2	30.09	15.04
C	2	23.78	11.89

TABLE-10
S/N ANALYZING

Factor	DF	SS	V
B	2	3.25	1.62
A	2	0.98	0.49
D	2	0.88	0.44
C	2	0.60	0.30

From Tables 9 and 10 it is clear that A and D factors are more importance than C factor. For this reason, the average responds of each factor levels was calculated (Table-11).

TABLE-11
AVERAGE RESULTS OF FACTOR RELATED TO EACH LEVEL

	A	B	C	D
R1	51.60	49.37	51.00	53.67
R2	54.82	49.90	51.13	49.64
R3	50.23	57.37	54.51	53.34

TABLE-12
S/N RATIO RELATED TO EACH LEVEL (AVERAGE)

	A	B	C	D
(S/N)1	34.19	33.86	34.13	34.57
(S/N)2	34.77	33.92	34.14	33.88
(S/N)3	33.99	35.17	34.68	34.50

Findings: According to the data, the fact that factorial method at 2 levels in determining the amount of factors effect is not as important as Taguch's method at 3 levels, is clear. At factorial method (Table-4), A and D factors have no effect on the results of experiment, but if we consider the results and diagrams from Taguch's method at 3 levels with even less experiments, the results varied considerably. Therefore, the A and D factors are not only effective but also have meaningful effect on experiments. None of these results which are obtained by 9 experiments, could be possible to determined by factorial method at 2 levels which need more experiments.

Conclusion

Taguch's method at one single experiment condition, needs less experiments and also less time and money than factorial method. There is no curve by factorial method experiment at central points and so, factors of A and C have no effect on the results by this method. It is possible to study the many factors and levels by least number of Taguchi's method experiments and four factors at 3 levels even by 9 Taguch's method experiments is possible. Factors A and D are not only have main effect on result of experiment by Taguchi's 3 levels experiment, but also factor A has more effect than factor C. Analyzing the results of Taguchi's method by analysis of variance and S/N ratio causes more assurance results. Two factors of A and D have no linear effect on experiment and their changed direction are exactly opposite and it was one of the important reason that why we couldn't determine and detect curves by doing experiment at central points by factorial method. We can use effectively the results of experiments with 2 levels design only when factors at different levels have linear effect on results, without which, even with spending more time, money and more experiments at central points, we couldn't acquire exact results. When factorial method at 2 levels is used, it is better to use Thaguchi's method in order to improve the experimental results.

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