IMPROVING THE YIELD OF SILICA GEL IN A CHEMICAL PLANT

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Key Words

Silica gel; Moisture absorption; Experimentation; Crystal size; Second grade; Scrap and density.

Background

Silica gel in a crystalline form is used for absorption of the moisture from the environment. Silica gel packets are kept inside the packing boxes used for the transportation of equipment and machinery by sea. The gel absorbs the moisture from the surrounding environment and protects the machinery and equipment from getting rusted; it is also used as a dehumidifier in different applications.

The quality of silica gel is decided by moisture absorption capacity. Moisture absorption is directly related to density and crystal size. Its moisture absorption capacity reduces when the crystal size is less than 2 mm and the density is below 6. However, the material below 2 mm is sold as second grade at a 40% discount; material in powder form is totally scrapped.

The profitability of a small-scale industry employing 10 people with only one product line was adversely affected due to the production of approximately 20% of the product in the second-grade category and about 5% of the product in the scrap category. The hit-and-miss method of varying one variable at a time and keeping others at constant level was tried, but it did not improve the situation. Thus, the challenge to management was to find a permanent solution to this problem. Plant-scale experiments on process variables and quality of input material were attempted to improve the yield (1) of the first-grade material.

Manufacturing Process

Silica gel is a chemical-based product, manufactured from sodium silicate and hydrochloric acid (HCL). Forty-five liters of HCL at 33% concentration is placed in a mixing tank to which sodium silicate of a specified density is pumped until it reaches a specified pH value (judged by the color of the solution). The color of the solution is checked by the production supervisor by comparing it with a color chart. Mixing is complete as soon as the pH value reaches a desired level. The mixed solution is transferred to a 25-L plastic container. The solution is solidified slowly and this solid block is sun dried, washed with water, and again sun dried. Final drying is done in a hot-air chamber at 150°C for 4 hr. Dried material is then tested using IS 3401-1979 (2) and sieved with different meshes as per customer requirements. The finished product is packed in airtight polythene lined tins. The flow diagram of the manufacturing process is given in Figure 1.

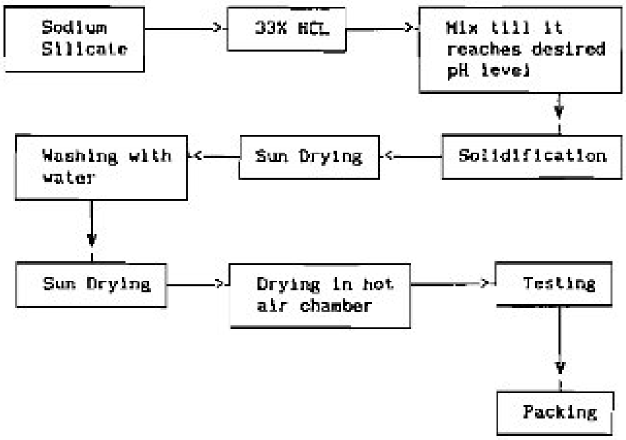

Figure 1. Flow diagram.

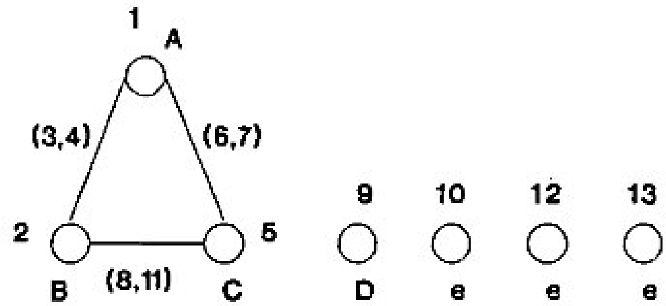

Figure 2. Linear graph for the experiment.

Factors and Levels for the Experiment

Technical discussion with the plant personnel helped in the identification of factors likely to influence the density and crystal size of silica gel. The factors and levels selected for the experiment are given in Table 1.

Four factors at three levels each were identified for experimentation. Apart from the estimation of main effects, the estimation of the three first-order interactions AB, AC, and BC were also considered in the experiment. The experiment was designed in L_{27} (3^{13}) orthogonal array (OA) design (3); that is, 27 experiments. Whereas full factorial experiments require 81 trials. The linear graph technique (4) invented by Taguchi was used to design the present experiment. The required linear graph for the present experiment is given in Figure 2 and the layout of the experiment is given in Table 2.

Table 1. Factors and Levels

	LEVEL		
FACTOR	1	2	3
A Sodium silicate density	1.125	1.121[a]	1.123
B pH Value of sodium silicate and HCL solution	3.5	3.0[a]	4.0
C Setting time (hr)—solidification time	40	50	30[a]
D Drying temperature (°C) in hot-air chamber	150[a]	120	135

[a]Existing level.

Table 2. Layout of the Experiment L_{27} (3^{13})

	FACTOR COLUMN NO.			
EXPERIMENT	A (1)	B (2)	C (5)	D (9)
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	2
5	1	2	2	3
6	1	2	3	1
7	1	3	1	3
8	1	3	2	1
9	1	3	3	2
10	2	1	1	2
11	2	1	2	3
12	2	1	3	1
13	2	2	1	3
14	2	2	2	1
15	2	2	3	2
16	2	3	1	1
17	2	3	2	2
18	2	3	3	3
19	3	1	1	3
20	3	1	2	1
21	3	1	3	2
22	3	2	1	1
23	3	2	2	2
24	3	2	3	3
25	3	3	1	2
26	3	3	2	3
27	3	3	3	1

Responses

Responses considered during the experimentation were as follows:

1. Quantity of material (kg) scrapped—expressed as percentage of total quantity processed
2. Quantity of material of second grade—expressed in percentage
3. Density of silica gel

Conduction of the Experiment

Thirty kilograms of sodium silicate were processed for each experimental combination, as per the layout. Finished material was tested for density and sieved into three groups: (1) crystal size greater than 2 mm (first-grade material); (2) crystal size less than or equal to 2 mm (second-grade material); (3) powder form (scrap material). The responses of 27 experiments along with physical layout is given in Table 3.

Analysis and Results

Analysis of variance (ANOVA) (3) was carried out on the three responses separately. The results are given in Tables 4–6.

It is seen that factor A (density of sodium silicate), factor B (pH value of sodium silicate and HCL solution), and the interaction between factors A and B are significant for second-grade and scrap-quality material. Factor B, factor C (solidification time), and the interaction between factor A and factor B (i.e, AB) are significant for density. The

Table 3. Physical Layout of the Experiment and Responses

EXPT. NO.	SODIUM SILICATE DENSITY A (1)	pH VALUE B (2)	SETTING TIME (hr) C (5)	DRYING TEMP. (°C) D (9)	RESPONSE SECOND GRADE (%)	SCRAP (%)	DENSITY
1	1.125	3.5	40	150	14.0	3.6	7.10
2	1.125	3.5	50	120	13.5	3.8	7.25
3	1.125	3.5	30	135	18.3	4.5	6.90
4	1.125	3.0	40	120	17.4	4.2	6.41
5	1.125	3.0	50	135	16.3	3.9	6.53
6	1.125	3.0	30	150	13.9	2.8	6.20
7	1.125	4.0	40	135	14.1	2.7	6.90
8	1.125	4.0	50	150	12.0	2.9	6.98
9	1.125	4.0	30	120	12.0	3.0	6.51
10	1.121	3.5	40	120	17.0	4.3	6.83
11	1.121	3.5	50	135	10.5	4.2	6.98
12	1.121	3.5	30	150	15.3	4.0	6.41
13	1.121	3.0	40	135	21.0	4.9	6.23
14	1.121	3.0	50	150	20.5	4.7	6.47
15	1.121	3.0	30	120	19.8	4.5	6.01
16	1.121	4.0	40	150	12.3	3.2	7.27
17	1.121	4.0	50	120	11.3	2.1	7.32
18	1.121	4.0	30	135	10.5	2.3	7.12
19	1.123	3.5	40	135	15.2	3.1	7.00
20	1.123	3.5	50	150	12.3	2.9	7.00
21	1.123	3.5	30	120	12.0	2.7	6.98
22	1.123	3.0	40	150	11.1	1.9	6.27
23	1.123	3.0	50	120	12.8	2.4	6.32
24	1.123	3.0	30	135	13.4	2.2	5.90
25	1.123	4.0	40	120	10.3	1.8	7.22
26	1.123	4.0	50	135	10.4	2.2	7.28
27	1.123	4.0	30	150	11.7	2.5	7.12

Table 4. ANOVA on Second Grade Material

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SUM OF SQUARES	F	ρ (%)[a]
A	2	51.23	25.61	7.86[b]	16.9
B	2	96.68	48.34	14.83[b]	34.1
C	2	9.16[c]	4.58		
D	2	2.43[c]	1.21		
A × B	4	57.74	14.44	4.43[d]	16.9
B × C	4	14.43[c]	3.61		
A × C	4	4.41[c]	1.10		
Error	6	28.24	4.71		
Total (S_T)	26	264.32			67.9
Pooled error (S_e)	18	58.67	3.26		

Note: Table values: $F_{2,18}$ at 0.05 = 3.55; $F_{4,18}$ at 0.05 = 2.93; $F_{2,18}$ at 0.01 = 6.01.

[a]ρ = Components

$$\rho_A = \frac{S_A - 2S_e}{S_T} \times 100 = \frac{51.23 - (2 \times 3.26)}{264.32} \times 100$$
$$= 16.9\%$$

[b]Significant at 1%.
[c]Pooled with error.
[d]Significant at 5%.

Table 5. ANOVA on Scrap Data

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SUM OF SQUARES	F	ρ (%)[a]
A	2	9.56	4.78	30.02[b]	40.1
B	2	6.97	3.48	22.0[b]	28.7
C	2	0.08[c]	0.04		
D	2	0.14[c]	0.07		
A × B	4	3.66	0.92	5.8[d]	13.2
B × C	4	0.50[c]	0.12		
A × C	4	0.54[c]	0.14		
Error	6	1.58	0.26		
Total (S_T)	26	23.04			82.2
Pooled error (S_e)	18	2.85	0.16		

Note: Table values: $F_{2,18}$ at 0.05 = 3.55; $F_{4,18}$ at 0.05 = 2.93; $F_{2,18}$ at 0.01 = 6.01; $F_{4,18}$ at 0.01 = 4.58.

[a]ρ = Components

$$\rho_A = \frac{S_A - 2S_e}{S_T} \times 100 = \frac{9.56 - (2 \times 0.16)}{23.88} \times 100$$
$$= 40.1\%$$

[b]Significant at 1%.
[c]Pooled with error.
[d]Significant at 5%.

Table 6. ANOVA on Density Data

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SUM OF SQUARES	F	ρ (%)[a]
A	2	0.01	0.005		
B	2	3.46	1.730	194.3[b]	72.5
C	2	0.52[c]	0.260	29.1[b]	10.6
D	2	0.00[c]	0.000		
A × B	4	0.61	0.171	17.1[d]	12.1
B × C	4	0.01[c]	0.002		
A × C	4	0.04[c]	0.010		
Error	6	0.10	0.016		
Total (S_T)	26	4.75			95.2
Pooled error (S_e)	18	0.16	0.009		

Note: Table values: $F_{2,18}$ at 0.05 = 3.55; $F_{4,18}$ at 0.05 = 2.93; $F_{2,18}$ at 0.01 = 6.01; $F_{4,18}$ at 0.01 = 4.58.

[a]ρ = components

$$\rho_A = \frac{S_A - 2S_e}{S_T} \times 100 = \frac{3.46 - (2 \times 0.009)}{4.75} \times 100$$

$$= 72.5\%$$

[b]Significant at 1%.
[c]Pooled with error.
[d]Significant at 5%.

last column in the ANOVA tables gives the (ρ) percentage (degrees of contribution) for critical factors. The result of three analyses are summarized in Table 7.

Factors in the Three Analyses

The average responses for different levels of significant factors in the analyses for scrap material, second-grade material, and density as well as for different combinations of AB are computed and given in Table 8.

The effect curves for critical factors are given in Figure 3.

The best levels of significant factors on scrap material, second-grade material, and density based on average responses are summarized in Table 9.

Optimum Combination

An examination of the best levels of significant factors in the above analyses reveals that third level of factor B is

Table 7. F-Ratio and ρ (%) of Significant Factors in the Three Analyses

SOURCE OF VARIATION	F-Ratio			ρ (%)		
	SCRAP	SECOND GRADE	DENSITY	SCRAP	SECOND GRADE	DENSITY
A	30.2	7.86	—	40.1	16.9	—
B	22.0	14.83	197.9	28.9	34.1	72.5
C	—	—	29.7	—	—	10.6
AB	5.8	4.43	17.6	13.2	16.9	12.1
Total				82.2	67.9	95.2

Table 8. Average Responses of Significant Factors

FACTOR/ LEVEL	SCRAP (%)	SECOND GRADE (%)	DENSITY
A1	3.49	14.6	
A2	3.80	15.4	
A3	2.41	12.1	
B1	3.68	14.2	6.94
B2	3.50	16.2	6.26
B3	2.52	11.6	7.02
C1			6.8
C2			6.9
C3			6.6
A1B1	3.97	15.3	7.08
A1B2	3.63	15.9	6.38
A1B3	2.87	12.7	6.80
A2B1	4.17	14.3	6.74
A2B2	4.70	20.4	6.24
A2B3	2.53	11.4	7.24
A3B1	2.70	13.2	6.99
A3B2	2.17	12.4	6.16
A3B3	2.17	10.8	7.21

found to be good for producing low scrap, low second-grade material, and high density. Therefore, the third level of factor B is selected as the optimum level. Thus, the optimum combination arrived at is A3B3C2.

The expected results with regard to scrap material, second grade-material, and density for the optimum combination are given by

$$\text{Scrap} = (\overline{A3B3} - \overline{T}) + \overline{T} = \overline{A3B3} = 2.17,$$

$$\text{Second} = \overline{A3B3} = 10.8,$$

$$\text{Grade density} = \overline{A3B3} + \overline{C2} - \overline{T} = 7.21 + 6.90 - 6.76 = 7.35,$$

where T is the overall average.

Confirmatory Trials

The results of the two confirmatory trials carried out with the optimum combination (A3B3C2) are given in Table 10.

The optimum combination thus achieved is implemented by the plant on a regular basis. Thus, the recovery of silica gel of first grade increased from 74.5% to the average yield of 87.7%.

Conclusion

Many practicing engineers are not aware of the existence of the design of experiments technique. As a conse-

Table 9. Best Level of Critical Factors

RESPONSE	BEST LEVEL OF CRITICAL FACTORS
Scrap	A3B3
Second grade	A3B3
Density	A3B3C2

Table 10. Results of Confirmatory Trials

TRIAL RESPONSE	SCRAP (%)	SECOND GRADE (%)	DENSITY
I	2.19	10.15	7.35
II	2.03	10.29	7.23
Average	2.11	10.22	7.29

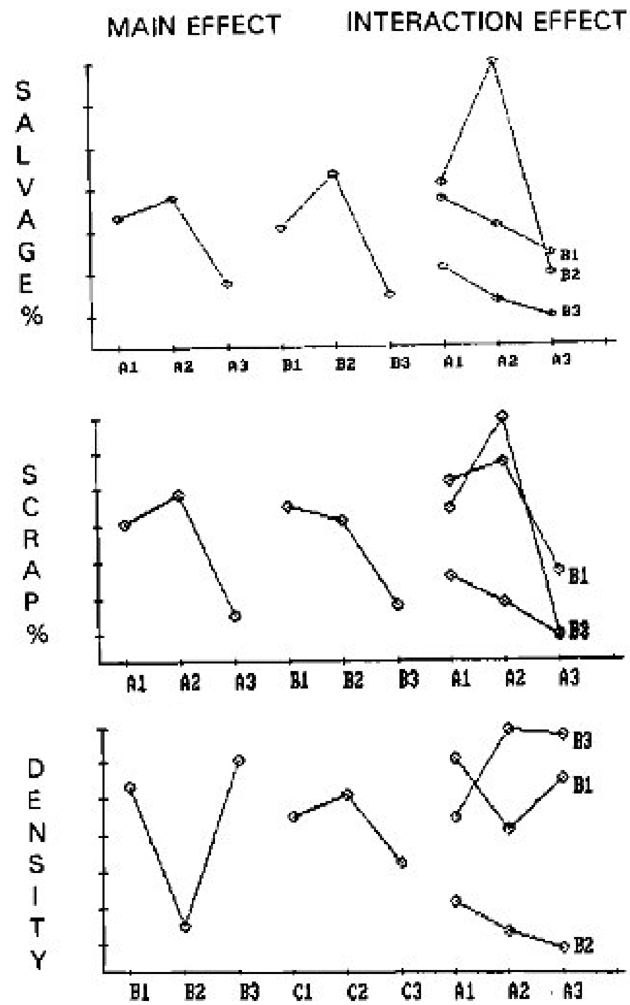

Figure 3. Effect curves on salvage %, scrap, and density.

quence, they use the inefficient and expensive practice of one variable at a time experimentation, incurring higher cost and suffering a much higher incidence of failure, as a result.

It is been shown how a fractional factorial experiment using the orthogonal array layout developed by Taguchi has helped in identifying the critical process parameters and their best levels for improving the yield for first-grade quality (density) of silica gel.

The yield of silica gel of first grade has been improved to 87.7% (from 74.5% earlier), second-grade and scrap material has been reduced to 10.22% and 2.11%, respectively (from around 20% and 5%, respectively). Moisture absorption capacity, a quality parameter having direct relation with density, has improved from around 6.0% to 7.35%. The experimentation has been highly successful, as it has helped in improving the profit by 8.7% and making the unit economically viable.

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