Optimization of a Pulping Model through Application of Taguchi Techniques to evaluate Pulp

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"Even a slight deviation from the Target is a loss to the society" are the words of Sir, Taguchi a famous quality Guru. The amount of variability can be related to economic loss through TAGUCHI LOSS FUNCTION. Under this concept any deviation from a target value results in a loss. Taguchi's approach to experimental design and off - line quality control can help identifying the factors relevant and significant to the process. Taguchi's quality improvement technique that uses experimental design methods for efficient characterization of a product or process, combined with a statistical analysis of its variability has helped in identifying significant factors in the production of pulp from wheat straw by the oxygen alkali method at laboratory level. The response of interest were the pulp yield, breaking length, tear strength, folding endurance and the whiteness of paper pulp.

INTRODUCTION

In Process industries variation is the root cause of all-evil and it is to be minimized or eliminated. There is, at last, a world wide recognition of the fact that pre-production experiments, properly designed and analyzed, can significantly contribute to efforts towards the accurate characterization and optimization of industrial processes, quality improvement of products, and reduction of costs and waste. Different designs exist to suit the experimental capability. Full factorial designs and Fractional Factorial designs are the most commonly used design as they provide the cost - effective way of studying many factors in one experiment. One area of current development in manufacturing industry involves statistical experimentation as its main tool; in general terms, it is concerned with the application of modern off - line quality control techniques. This idea was taken up by Professor Genichi Taguchi a famous Quality Guru. He devised a quality improvement technique that uses experimental design methods for efficient characterization of a product or process, combined with a statistical analysis of its variability.

The Taguchi Loss Function and its Objective : Taguchi Loss function says, "Even a slight deviation from the target vale is a loss to the society". This loss would include the cost of customer dissatisfaction also. Taguchi loss function can be used to establish a value base for the development of quality products. The function recognizes the need for average performance to match customer requirements, and the fact that variability in this performance should be as small as possible. This means that a product does not cause a loss only when it is outside specification but also whenever it deviates from its target value. Any Quality improvement program should have as its main objective the minimization of the variation of product performance about its target value. The smaller the performance variation, the better the quality. The larger the deviation from the target, the larger the society's loss (Producer's and consumer's). In general this loss is proportional to the square of the deviation from the target. The objective of the Taguchi's efforts is process and product - design improvement through the identification of easily controllable factors and their settings, which minimize the variation in product response while keeping the mean response on target. By setting those factors at their optimal levels, the product can be made robust to changes and higher quality products can be obtained.

There are two main aspects to the Taguchi Technique. First, the behavior of a product or process is characterized in terms of factors that are separated into two types :

1. Controllable (or design) factors - those whose values may be set or easily adjusted by the designer or process engineer.

2. Uncontrollable (or Noise) factors, which are sources of variation often associated with the production or operational environment; overall performance should, ideally, be insensitive to their variation.

Table 1

Factors		Levels			
T	Temperature (°C)	50	65	80	95
t	Time (min)	30	50	70	90
Po	Oxygen Pressure (atm)	1	5	9	
C	NaOH Concentration (%)	40	50	60	
Q	Gas Flow Rate (Ltr/Hr.)	1	1.4	1.8	

Second are the Controllable factors, which are divided into

1. Those, which affect the average levels of the response of interest, referred to as Target Control factors (TCF), sometimes called SIGNAL FACTORS.

2. Those which affect the variability in the response, the variability Control Factors (VCF)

3. Those which affect neither the mean response nor the variability, and can be adjusted to fit economic requirements, called the cost factors.

Case-Study : The following experiment took place in a mill for production of paper pulp from wheat straw by the Oxygen Alkali method to determine the effects of Temperature (T), oxygen Pressure (Po), NaOH Concentration (C), time (t) and gas flow rate (Q). The Temperature and Time were set at four levels and the rest of the factors were set at three levels. Table 1 shows the setting of the experimentation and Tables 2 and 3 show the Taguchi design matrix for the settings. The responses of interest were pulp yield; breaking length; tear strength; folding endurance and whiteness of the paper pulp. In the present study only the whiteness will be analyzed.

The experiment Design used was OA_{16} (4^5), which was constructed from OA_{16} (2^{15}) combining its columns (Table 2) as indicated in the heading of the array shown in the table. The five factors of interest were assigned to the five columns of OA_{16} (4^5) using the dummy - level Technique

Table 2

(1,2,3)	(4,8,12)	(5,10,15)	(7,9,14)	(6,11,13)
1	1	1	1	1
1	2	2	2	2
1	3	3	3	3
1	4	4	4	4
2	1	2	3	4
2	2	1	4	3
2	3	4	1	2
2	4	3	2	1
3	1	3	4	2
3	2	4	3	1
3	3	1	2	4
3	4	2	1	3
4	1	4	2	3
4	2	3	1	4
4	3	2	4	1
4	4	1	3	2

Table 3

Factors					Response Data	
T	t	Po	C	Q	R(A)	R(B)
1	1	1	1	1	25.1	26.8
1	2	2	2	2	25.7	28.2
1	3	3	3	3	23.0	26.6
1	4	2'(4)	1'(4)	3'(4)	25.7	28.3
2	1	2	3	3'(4)	22.5	25.8
2	2	1	1'(4)	3	25.8	25.5
2	3	2'(4)	1	2	29.1	27.3
2	4	3	2	1	20.4	25.7
3	1	3	1'(4)	2	26.2	29.6
3	2	2'(4)	3	1	27.5	27.7
3	3	1	2	3'(4)	30.8	32.3
3	4	2	1	3	25.2	30.3
4	1	2'(4)	2	3	24.2	24.1
4	2	3	1	3'(4)	24.8	21.7
4	3	2	1'(4)	3'(4)	25.0	23.3
4	4	1	3	2	25.3	26.9

as shown in table - 3. Two replicate observations for the Whiteness of the paper pulp after each treatment combination was taken and further an ANOVA analysis was carried out to test the significance of each factor.

ANALYSIS

1. Correction Factor CF = (sum total)^2/Number of Observations

   = (25.1+ .....+26.9)^2/32 = (836.4)^2 / 32 = 21861.405.

2. Total Sum of Squares = $SS_{tot} = \sum Y^2 - CF$ = (25.1)^2 + ... + (26.9)^2 – 21861.405 = 212.215

3. For the Sum of Squares of Factor T

   SS_T = ((sum total in level 1)^2 + ... + (sum of Total in level 4)^2/8) – CF) = ((25.1+.....+28.3)^2 + ... + (24.2+....+26.9)^2)/8 – 21861.405. = 82.473

4. Similarly, SSt = ((204.3)^2 + (206.9)^2 + (217.4)^2 + (207.8)^2)/8 – CF = 12.308

5. SSpo = (total in level 1)^2/8 + (total in levels 2 and 2')^2/16+(total in level 3)^2/8 – CF

   = (218.5)^2/8 + (206+213.9)^2/16 + (198)2/8 – CF = 26.626

6. Similarly, SSc =

   (total in levels 1 and 1')^2/16 +(total in level 2)^2/8+(total in level 3)2/8 – CF =

   (210.3 + 209.4)^2/16 + (211.4)^2/8 + (205.3)^2/8 – 2.607

7. SS_Q=(total in level 1)^2/8 + (total in level in 2)^2/8 = (total in levels 3 and 3')^2 – CF

   =(201.5)^2/8+(218.3)^2/8+(204.7 + 211.9)^2/16 – CF = 17.96

8. The Residual Sum of Squares = SSe

   SSe = SStot – SS_T – SSt – SSpo – SSc – SS_Q = 70.2

RESULTS AND DISCUSSIONS

1. Table 4. Depicts the ANOVA table for the factors under study and the significance of those factors on the response i.e. the Whiteness of the paper pulp.

2. It can be observed from the ANOVA table that Temperature T and Oxygen Pressure Po are the most significant factors that affect the whiteness of pulp manufactured from oxygen alkali method from wheat straw.

3. The following are the level averages calculated from the response data for the above significant factors affecting whiteness of paper pulp.

Table 4

Source	df	SS	MSS = SS/df	F-Ratio	Resut
T	3	82.473	27.49	7.4	Significant
t	3	12.308	4.10	1.1	Insignificant
Po	2	26.626	13.31	3.6	Significant
C	2	2.607	1.30	0.4	Insignificant
Q	2	17.960	8.98	2.4	Insignificant
Residual	19	70.241	3.7		
Total	31	212.215			

Factors	Level Averages			
	1	2	3	4
T	26.18	25.26	28.70	24.41
Po	27.31	26.24	24.75	

Evidently level 3 for Temperature (80 deg C) and Level 1 for Oxygen Pressure (1 atm) seem to affect the whiteness of paper pulp positively.

CONCLUSION

Application of Screening Experiments like Taguchi Models can lead to significant robustness in the design of a product. Studying the parameter significance using Taguchi Techniques will lead to setting the relevant factors at their optimum levels leading to reduction in loss due to variance during the manufacturing process.

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