Off-Line Quality Control, An Important Factor in Modern Industrial Statistical Quality Control

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Off-Line Quality Control techniques are used prominently in paper industry and have proved efficient and useful in controlling process parameters. Mathematical models to predict and optimize process parameters have long been used in paper industry. A Plethora of Statistical designs are available to optimize quality and factorial designs are one of them. Whenever available information is incomplete a functional study of the process or the plant is required so as to obtain the nature of the response surface and to predict the most desirable and optimum set of parameters. Here an attempt has been made to develop specific mathematical equations, uniquely representative of all possible combinations of input parameters. An attempt has been made to use off - line quality control technique to optimize few important parameters of paper developed from an admixture of two different raw pulps one being a short fibre pulp and other being a long fibre pulp. Help of Demo software for statistical modeling has been obtained to generate response surface and predict the optima.

INTRODUCTION

Full-Factorial experimental designs are rather inefficient in the sense that if a large number of factors are to be analyzed the number of trails to be done become large and experimentation becomes expensive in terms of cost and time. Nevertheless, since in a quality process only a few bad units are produced, and most of the process parameters are already at an optimum and robust setting it would indeed be relatively easy to pinpoint the causes of trouble and even full factorial experimentation is possible. We are passing through a crisis in availability of woody fibre raw materials due to ecological constraints, and Pollution problem restriction. India has abundant source of non-wood fibres examples, Rice Straw, Wheat Straw, Bagasse etc. These are being used to compensate the unavailability of woody fibres and also to accomplish the requisite prevailing economic returns. Apart from the conventional pulping and paper making processes the treatise on optimizations of the part of specific operations will also give an impetus to the overall economics of the plant, to get specific grades of paper. In this particular problem an attempt has been made to investigate the behavior of the products to produce from blends of short fibre pulp (rice straw) and coniferous wood a long fibre pulp, with a view to develop specific equations for some particular properties like surface, strength and optical properties for specific grades of paper. In fact both pulps long fibre and short fibre pulps have their unique and distinct properties and the furnish values are also different. The moment they will be mixed there will be different type of characteristics developed radically different from the individual ones.

Full - Factorial Design (An off - Line Quality Control Technique) : No correlation is available at present to evaluate the parameters, which can be of help to the design engineer, Here a statistical model has been developed and verified by empirical data to predict and use the process design. Thus the equation to be developed appears to be a unified one, using Full - Factorial Experimental Design Technique. Keeping in View of the above philosophy in mind the following stepwise investigation has been carried out.

Step 1 : The Number of factors chosen was three (3) with three number of levels. The total number of trials came out to be 27. Tables of different properties were generated designating the trials for Burst Strength, Porosity, Scattering Coefficient, and Cobb 60 i.e. Table 1.

Step 2 : The basic level of factors is the unit or variation of interval on Zj axis and has been transformed into a

Table 1

Long Fibre %	Filler $CaCO_3$ % Wt/Wt.	Size % Wt./Wt.	Burst Strength Kg/cm²		Porosity sec/300ml		Scattering Coefficient		Cobb 60	
50	25	25	0.45	0.50	7.00	8.00	52.00	51.00	22.90	22.80
50	25	50	0.55	0.50	10.00	8.0	49.00	49.00	15.13	15.20
50	25	100	0.45	0.40	11.00	11.00	48.00	49.00	17.57	17.56
50	50	25	0.40	0.40	11.00	9.00	47.00	48.00	24.05	23.12
50	50	50	0.50	0.50	13.00	10.00	54.00	52.00	18.49	18.96
50	50	100	0.50	0.45	15.00	15.00	53.00	53.00	15.85	15.97
50	100	25	0.30	0.20	14.00	15.00	41.00	50.00	26.65	25.63
50	100	50	0.40	0.40	16.00	10.50	58.00	59.00	25.00	25.03
50	100	100	0.30	0.30	17.00	17.00	47.00	48.00	17.45	17.89
60	25	25	0.55	0.55	6.50	6.50	57.00	58.00	29.20	29.12
60	25	50	0.75	0.75	12.50	10.00	31.00	31.00	19.35	19.83
60	25	100	0.60	0.60	9.50	9.00	61.00	60.00	22.50	22.46
60	50	25	0.50	0.50	10.00	10.00	60.00	61.00	32.45	32.54
60	50	50	0.63	0.60	14.00	14.00	49.00	50.00	16.15	16.45
60	50	100	0.50	0.45	18.50	20.50	42.00	40.00	24.00	23.50
60	100	25	0.63	0.45	12.00	12.00	36.00	35.00	23.40	23.60
60	100	50	0.50	0.50	19.50	21.00	33.00	35.00	21.60	21.10
60	100	100	0.40	0.40	19.00	20.50	35.00	36.00	20.85	20.89
75	25	25	0.90	0.90	5.00	5.00	19.00	20.00	17.89	17.58
75	25	50	1.60	1.65	10.00	11.50	28.00	28.00	16.24	16.30
75	25	100	1.45	1.35	6.50	7.50	20.00	19.00	16.29	16.25
75	50	25	0.80	0.80	10.00	10.00	21.00	21.00	22.26	22.36
75	50	50	1.50	1.50	11.00	12.00	22.00	23.00	19.32	19.31
75	50	100	1.30	1.20	10.50	10.50	18.20	19.00	10.33	10.36
75	100	25	0.45	0.50	1.00	1.00	38.00	39.00	20.44	20.45
75	100	50	0.45	0.40	3.00	3.00	37.00	36.00	16.45	16.93
75	100	100	0.30	0.30	1.00	1.00	42.00	43.00	11.69	11.78

dimensionless system of co - ordinates Xj. First the table of observations is made with each of the factor designated as Z1, Z2, Z3.

Step 3 : A design matrix is formed out of the factors on natural scale.

Step 4 : The design matrix is converted to experimental matrix which is the matrix formed out of coded factors.

Step 5 : A suitable regression equation is assumed of the form ;

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_{12}X_1X_2 + B_{13}X_1X_3 + B_{23}X_2X_3 + B_{123}X_1X_2X_3$$

Step 6 : The table of coefficient matrices were developed for each of the property and the coefficient for each of the properties was calculated. Finally regression equations for each property were obtained.

Step 7 : ANOVA analysis for each factor with three levels was carried out including analysis of all interaction effects

Table 2 : ANOVA Design for Full - Factorial Experiment with Three Levels and Three Factors Including all Interction effects Burst Factor

A	B	C	AB	BC	CA	ABC	YB1	YB2	SQRYB1	SQRYB2
1	1	1	1	1	1	1	0.45	0.5	0.2025	0.25
1	1	2	1	2	2	2	0.55	0.5	0.3025	0.25
1	1	3	1	3	3	3	0.45	0.4	0.2025	0.16
1	2	1	2	1	2	2	0.4	0.4	0.16	0.16
1	2	2	2	2	3	3	0.5	0.5	0.25	0.25
1	2	3	2	3	1	1	0.5	0.45	0.25	0.2025
1	3	1	3	1	3	3	0.3	0.2	0.09	0.04
1	3	2	3	2	1	1	0.4	0.4	0.16	0.16
1	3	3	3	3	2	2	0.3	0.3	0.09	0.09
2	1	1	2	2	1	2	0.55	0.55	0.3025	0.3025
2	1	2	2	3	2	3	0.75	0.75	0.5625	0.5625
2	1	3	2	1	3	1	0.6	0.6	0.36	0.36
2	2	1	3	2	2	3	0.5	0.5	0.25	0.25
2	2	2	3	3	3	1	0.63	0.6	0.3969	0.36
2	2	3	3	1	1	2	0.5	0.45	0.25	0.2025
2	3	1	1	2	3	1	0.63	0.45	0.3969	0.2025
2	3	2	1	3	1	2	0.5	0.5	0.25	0.25
2	3	3	1	1	2	3	0.4	0.4	0.16	0.16
3	1	1	3	3	1	3	0.9	0.9	0.81	0.81
3	1	2	3	1	2	1	1.6	1.65	2.56	2.7225
3	1	3	3	2	3	2	1.45	1.35	2.1025	1.8225
3	2	1	1	3	2	1	0.8	0.8	0.64	0.4096
3	2	2	1	1	3	2	1.5	1.5	2.25	2.25
3	2	3	1	2	1	3	1.3	1.2	1.69	1.44
3	3	1	2	3	3	2	0.45	0.5	0.2025	0.25
3	3	2	2	1	1	3	0.45	0.4	0.2025	0.16
3	3	3	2	2	2	1	0.3	0.3	0.09	0.09
							17.66	17.05	15.1838	14.1671

and significance of each factor was tested using F-Test. Table 2-9.

RESULTS AND DISCUSSIONS

The following regression equations were obtained helpful to the design engineer on the basis of experimental data collected applying full - factorial experimental design with three levels and three factors and using ANOVA Analysis

1. $Y_{BURST} = 0.613037 + 0.1144\, X_1 - 0.2088 + 0.0317593\, x X_1 X_2$.
2. $Y_{COBB} = 0.2265 + 0.07207 X_1 + 0.0248\, X_2$.
3. $Y_{SCATTER} = 4.1 - 7.2 X_1 + 2.9 X_1 X_2$.

Here,

X_1 = A = Long Fibre %

X_2 = B = Filler %

X_3 = C = Sizing Chemical %.

$X_1 X_2$ = AB = Long Fibre % * Filler %.

Table 3 : ANOVA Table for Burst Strength (Kg/cm²)

SS	df	MSS	F-Ratio	
SSA = 2.93875	dfA = 2	1.469375	112.8119002	Significant
SSB = 1.66604	dfB = 2	0.83302	51.9825273	Significant
SSC = 0.44355	dfC = 2	0.221775	13.839331357	Significant
SSAB = 1.30454	dfAB =4	0.326135	20.35163807	Significant
SSBC = 0.09264	dfBC = 4	0.02316	1.778119002	Insignificant
SSAC = 0.10282	dfAC = 4	0.025705	1.973512476	Insignificant
SSABC = 0.05908	dfABC = 8	0.007385	0.460842434	Insignificant
Sse = 0.43267	dfe = 27	0.016024815		
Sstot = 7.04009	dfTOT = 53			

Table 4 : ANOVA Design for Full - Factorial Experiment with Three Factors and Three levels including all Interaction Effects Porosity

A	B	C	AB	AC	BC	ABC	YP1	YP2	SQRYP1	SQRYP2
1	1	1	1	1	1	1	7	8	49	64
1	1	2	1	2	2	2	10	8	100	64
1	1	3	1	3	3	3	11	11	121	121
1	2	1	2	1	2	2	11	9	121	81
1	2	2	2	2	3	3	13	10	169	100
1	2	3	2	3	1	1	15	15	225	225
1	3	1	3	1	3	3	14	15	196	225
1	3	2	3	2	1	1	16	10.5	256	110.25
1	3	3	3	3	2	2	17	17	289	289
2	1	1	2	2	1	2	6.5	6.5	42.25	42.25
2	1	2	2	3	2	3	12.5	10	156.25	100
2	1	3	2	1	3	1	9.5	9	90.25	81
2	2	1	3	2	2	3	10	10	100	100
2	2	2	3	3	3	1	14	14	196	196
2	2	3	3	1	1	2	18.5	20.5	342.25	420.25
2	3	1	1	2	3	1	12	12	144	144
2	3	2	1	3	1	2	19.5	21	380.25	441
2	3	3	1	1	2	3	19	20.5	361	420.25
3	1	1	3	3	1	3	5	5	25	25
3	1	2	3	1	2	1	10	11.5	100	132.25
3	1	3	3	2	3	2	6.5	7.5	42.25	56.25
3	2	1	1	3	2	1	10	10	100	100
3	2	2	1	1	3	2	11	12	121	144
3	2	3	1	2	1	3	10.5	10.8	15.75	116.64
3	3	1	2	3	3	2	1	1	1	1
3	3	2	2	1	1	3	3	3	9	9
3	3	3	2	2	2	1	1	1	1	1

Table 5 : ANOVA Table for Porosity (sec/300ml)

CF = 6279.135				
SS	df	MSS	F-Ratio	
SSA = 121.559	dfA = 2	MSSA = 60.7795	0.7631003	Insignificant
SSB = -84.274	dfB = 2	MSSB = -42.137	- 0.52904	Insignificant
SSC = -840.788	dfC = 2	MSSC = -420.394	- 5.278142	Insignificant
SSAB = 45.809	dfAB =4	MSSAB = 11.45225	0.1437856	Insignificant
SSBC = -193.441	dfBC = 4	MSSBC = -48.36025	- 0.607174	Insignificant
SSAC = 81.726	dfAC = 4	MSSAC = 20.4315	0.2565221	Insignificant
SSABC = 2.165	dfABC = 8	MSSABC = 0.270625	0.0033978	Insignificant
Sse = 2150.499	dfe = 27	MSSe = 79.64811		
SS tot = 1283.255	dfTOT = 53			

Table 6 : ANOVA Design for Full - Factorial Experiment with Three Factors and Three levels including all Interaction Effects Scattering Coefficient

A	B	C	AB	BC	CA	ABC	YS1	YS2	SQRYS1	SQRYS2
1	1	1	1	1	1	1	52	51	2704	2601
1	1	2	1	2	2	2	49	49	2401	2401
1	1	3	1	3	3	3	48	49	2304	2401
1	2	1	2	1	2	2	47	48	2209	2304
1	2	2	2	2	3	3	54	52	2916	2704
1	2	3	2	3	1	1	53	53	2809	2809
1	3	1	3	1	3	3	41	50	1681	2500
1	3	2	3	2	1	1	58	59	3364	3481
1	3	3	3	3	2	2	47	48	2209	2304
2	1	1	2	2	1	2	57	58	3249	3364
2	1	2	2	3	2	3	31	31	961	961
2	1	3	2	1	3	1	61	60	3721	3600
2	2	1	3	2	2	3	60	61	3600	3721
2	2	2	3	3	3	1	49	50	2401	2500
2	2	3	3	1	1	2	42	40	1764	1600
2	3	1	1	2	3	1	36	35	1296	1225
2	3	2	1	3	1	2	33	35	1089	1225
2	3	3	1	1	2	3	35	36	1225	1296
3	1	1	3	3	1	3	19	20	361	400
3	1	2	3	1	2	1	28	28	784	784
3	1	3	3	2	3	2	20	19	400	361
3	2	1	1	3	2	1	21	21	441	441
3	2	2	1	1	3	2	22	23	484	529
3	2	3	1	2	1	3	18.2	19	331.24	361
3	3	1	2	3	3	2	38	39	1444	1521
3	3	2	2	1	1	3	37	36	1369	1296
3	3	3	2	2	2	1	42	43	1764	1849

Table 7 : ANOVA Table for Scattering Coefficient

CF = 90544.54

SS	df	MSS	F-Ratio	
SSA = 5222.68	dfA = 2	2611.34	31.67920123	Significant
SSB = 1.24	dfB = 2	0.62	0.007521466	Insignificant
SSC = -26.24	dfC = 2	-13.12	- 0.159163924	Insignificant
SSAB = 1199.79	dfAB =4	299.9475	3.638782085	Significant
SSBC = - 13.07	dfBC = 4	3.2675	0.158557354	Insignificant
SSAC = 301.63	dfAC = 4	75.4075	0.91479829	Insignificant
SSABC = 337.9	dfABC = 8	42.2375	0.512399864	Insignificant
Sse = 2225.63	dfe = 27	82.43074074		
SS tot = 9275.7	dfTOT = 53			

Table 8 : ANOVA Design Table for Full Factorial Design with Three Factors and Three Levels Including All Interaction Effects COBB 60

A	B	C	AB	BC	CA	ABC	YC1	YC2	SQRYC1	SQRYC2
1	1	1	1	1	1	1	22.9	22.8	524.41	519.84
1	1	2	1	2	2	2	15.13	15.2	228.9169	231.04
1	1	3	1	3	3	3	17.57	17.56	308.7049	308.3536
1	2	1	2	1	2	2	24.05	23.12	578.4025	534.5344
1	2	2	2	2	3	3	18.49	18.96	341.8801	359.4816
1	2	3	2	3	1	1	15.85	15.97	251.2225	255.0409
1	3	1	3	1	3	3	26.65	25.63	710.2225	656.8969
1	3	2	3	2	1	1	25	25.03	625	626.5009
1	3	3	3	3	2	2	17.45	17.89	304.5025	320.0521
2	1	1	2	2	1	2	29.2	29.12	852.64	847.9744
2	1	2	2	3	2	3	19.35	19.83	374.4225	393.2289
2	1	3	2	1	3	1	22.5	22.46	506.25	504.4516
2	2	1	3	2	2	3	32.45	32.54	1053.003	1058.852
2	2	2	3	3	3	1	16.15	16.45	260.8225	270.6025
2	2	3	3	1	1	2	24	23.5	576	552.25
2	3	1	1	2	3	1	23.4	23.6	547.56	556.96
2	3	2	1	3	1	2	21.6	21.1	466.56	445.21
2	3	3	1	1	2	3	20.85	20.89	434.7225	436.3921
3	1	1	3	3	1	3	17.89	17.58	320.0521	309.0564
3	1	2	3	1	2	1	16.24	16.3	263.7376	265.69
3	1	3	3	2	3	2	16.29	16.25	265.3641	264.0625
3	2	1	1	3	2	1	22.26	22.36	495.5076	499.9696
3	2	2	1	1	3	2	19.32	19.31	373.2624	372.8761
3	2	3	1	2	1	3	10.33	10.36	106.7089	107.3296
3	3	1	2	3	3	2	20.44	20.45	417.7936	286.6249
3	3	2	2	1	1	3	16.44	16.93	270.2736	286.6249
3	3	3	2	2	2	1	549.49	542.97	11770.88	11540.24

X_1X_3 = AC = Long Fibre % * Sizing Chemical %

X_2X_3 = BC = Filler % * Sizing Chemical %

$X_1X_2X_3$ = ABC = Long Fibre % * Filler % * Sizing Chemical %

Where A, B, C, AB, AC, BC, ABC are the factors and interaction effects in the ANOVA Table.

From the ANOVA analysis it can be observed that the Burst Factor is dependent on the Long Fibre %, Filler % and the interaction effect of Long Fibre and Filler%. The Cobb Value is dependent on Long Fibre % and the Size %. Porosity in a blend of rice straw and coniferous wood is not affected significantly by any of the three factors. Finally the Scattering Coefficient is dependent on Long Fibre % and interaction effect of Long Fibre and Filler %.

From the ANOVA Analysis and the ANOVA Tables the following Table for response data can be obtained for each factor. (Table 10)

From Table 10 evidently, for Cobb - 60 values tne response is maximum at level 2 of the significant factors - Long Fibre % and Level 3 of Sizing %. Therefore the optimum setting at plant level should be 60% Imported Long Fibre from Coniferous Woods & 40% Rice Straw and 100% Wt/Wt of sizing (Rosin / Alum) for achieving the Optimum value of Cobb in a blend of Coniferous Wood Pulp and Rice Straw Pulp.

For Scattering Coefficient evidently, the response is maximum at Level 1 of the significant factors - Long Fibre % and Level 2 of the interaction effect of Long Fibre% and Filler %. Therefore the optimum setting at plant level should be 50% Imported Long Fibre from Coniferous

Table 9 : ANOVA Table for COBB VALUE (gm/m²)

CF = 22101.28				
SS	df	MSS	F-Ratio	
SSA = 340.93	dfA = 2	MSSA = 170.465	3.573246	Significant
SSB = (-404.93)	dfB = 2	MSSAB = -202.465	-4.24402	Insignificant
SSC = 444.09	dfC = 2	MSSC = 222.045	4.654453	Significant
SSAB = 37.7	dfAB =4	MSSAB = 9.425	0.197565	Insignificant
SSBC = (- 667.06)	dfBC = 4	MSSAC = -166.765	-3.49569	Insignificant
SSAC = 163.831	dfAC = 4	MSSBC = 40.95775	0.858546	Insignificant
SSABC = 7.218556	dfABC = 8	MSSABC = 0.90232	0.018914	Insignificant
Sse = 1288.06	dfe = 27	MSSe = 47.70593		
SS tot = 1209.84	dfTOT = 53			

Table 10

FACTORS	**LEVEL AVERAGES**		
	1	2	3
COBB - 60	Factor (A) – 20.3	Factor (A) – 23.3	Factor (A) – 17.1
	Factor (C) – 24.2	Factor (C) – 18.7	Factor (C) – 17.7
Scattering	Factor (A) – 50.4	Factor (A)45	Factor (A)–27.4
Coefficient	Factor (AB) 35.7	Factor (AB) – 46.6	Factor (AB) – 41.0
Burst Factor	Factor (A) – 0.42	Factor (A) – 0.55	Factor (A) – 0.96
	Factor (B) – 0.80	Factor (B) – 0.68	Factor (B) – 0.43
	Factor (C) – 0.59	Factor (C) – 0.76	Factor (C) – 0.63
Porosity	NA	NA	NA

Woods & 50% Rice Straw pulp with 100% Wt./Wt of Filler Dose ($CaCO_3$).

For Burst Strength evidently, the response is maxim a at Level 3 of the significant factors - Long Fibre % and Level 1 of Filler %. Therefore in a blend of Coniferous Wood Pulp and Rice Straw Pulp, the response for Burst Strength is maximum at Level 3 of the significant factors - Long Fibre % and Level 1 of Filler %. Therefore the optimum setting at the plant level should be 75% Imported Long Fibre from coniferous wood & 25% Rice Straw Pulp with 25% Wt/Wt Filler Dose ($CaCO_3$).

For Porosity none of the factors seem to be significant from the ANOVA analysis.

CONCLUSION

Therefore application of off - line quality control techniques can lead to significant conclusions and optimizing process parameters. A judicious selection of these techniques at laboratory level can help in controlling the process at plant scale. Selection of proper statistical model will result in developing specific model equations leading to optimization of process parameters at plant level.

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