

DESIGNED EXPERIMENT FOR EFFECTS OF NORMAL QI, CARRY-OVER QI, AND BETA RESIN IN PITCH ON PREBAKED ANODE PROPERTIES

Part II - Statistical Evaluation of Anode Properties

C. R. Manganaro
Aristech Chemical Corporation
Research Laboratory
1000 Tech Center Drive
Monroeville, PA 15146

Abstract

Properties determined for anodes made from all eight experimental pitches of a factorially-designed experiment included maximum baked apparent density, pitch level producing maximum density, electrical resistivity of a maximum density anode, and coke yield from the pitch. The design model comprising terms for three main effects and three two-factor interactions was fitted to each of the four measured responses. Statistically insignificant terms were removed from the design model by regression analysis leading to models for all responses showing no significant lacks-of-fit and exhibiting excellent predictive qualities. Additional properties, e.g., reactivities and strength properties, were measured on anodes made from the first block of four pitches using half the experimental pitches; however, these additional properties were so highly correlated with either baked apparent density or resistivity, it was not deemed economically expedient to determine these properties for the second block of four pitches. These properties would be at their optimum at maximum density.

Introduction

Part I of this paper presented 1) the statistical experimental design strategy, 2) the preparation and analysis of experimental pitches, and 3) the fabrication and testing of anodes. Part II presents a detailed statistical evaluation of the various test-anode properties.

Design

The experimental points, i.e., the eight treatment combinations of the three variables are shown graphically in Figure 1. Each point, represented by either a square for centrifuged, low-carry-over-QI (CQI) pitch or a circle for non-centrifuged, high-CQI pitch, is shown on the grid at its intersection of beta resin (BRS) and normal QI (NQI) concentrations. Ideally, a two-by-three factorial design would exhibit both a square and a circle at the same point on each corner of a rectangle on the BRS-by-NQI grid (a cube in three-dimensional space). Given the formidable nature of the task of producing identical low and high levels (four each) of the three studied factors (CQI, NQI, BRS), overall, the theoretical design space (a cube with a treatment at each of the eight corners) was adequately represented by the eight experimental pitches. The adequacy of the resultant combinations of variable levels was supported by the low condition numbers of all the derived models - an indication that there was no colinearity in the predictor terms of the models. Also, curvature effects could be examined for the variables

since the number of test levels was greater than two for each variable.

Statistical Evaluation Software and Routines Used

The RS/Series of statistical software, available from BBN, Inc. [1], was used to analyze the data. The specific statistical routines utilized included:

- 1) Polynomial curve fitting to relate baked anode properties (e.g., apparent density and resistivity) to pitch percent;
- 2) Principal component regression, a multivariate analytical technique, to reduce the dimensionality of the anode test results to two groups of responses, each group comprising those responses highly correlated with each other;
- 3) One-way analysis of variance to test the effect of pitch treatment on test results and to graphically illustrate pitch differences;
- 4) Multiple stepwise regression to develop second- order fitted models of the statistically significant terms;
- 5) Contourplotting to graphically interpret the fitted models.

Polynomial Curve Fitting

Second-order polynomial functions for baked apparent density (BAD) and resistivity versus weight percent pitch were derived for each of the three replicates of the eight experimental pitches (24 total) and for each replicate of the production pitch (10 total). Typical examples are shown in Figures 2 and 3 for BAD and resistivity of Pitch A, respectively. Since experimental pitch contents were varied in whole percentage points, and since the optimum pitch content (OBC) for a given pitch did not necessarily fall on an even percentile, the optima (i.e., maximum BAD, wt% pitch to achieve maximum BAD, and the resistivity of a maximum density anode) had to be interpolated from the polynomial equations. This was accomplished by determining the point of the polynomial where the slope of the tangent line (the first derivative of BAD with respect to X, the wt% pitch) equaled zero. Setting the first derivative to zero and solving for X, the wt% pitch, and then using this value of X in the polynomials for BAD and resistivity to solve for BAD and resistivity gave the three desired response parameters, namely, 1) the pitch concentration for maximum BAD, i.e. OBC, 2) the BAD at OBC, and 3) the resistivity (RES) of a maximum density anode at the OBC. A fourth derived parameter, the Kg pitch requirement for a one-metric-ton baked anode (MTP), was

calculated with the following equation:

$$MTP = (1000 * OBC) / [(ICV * OBC / 100) + 100 - OBC]$$

where ICV is the in-situ coking value of the pitch observed from the anode-baking operation, and OBC is defined above.

The descriptive statistics for these four derived responses are shown in Table I. The relationship between MTP and OBC, grouped by low - and high-CQI, is shown in Figure 4. Values range from a low of 17.5% OBC and 185.8 MTP with a low-CQI pitch to a high of 20.0% OBC and 214 MTP with a high-CQI pitch. The relationship between resistivity (RES) of a maximum density anode and maximum BAD is shown in Figure 5. A trend toward lower resistivities at higher BAD's with low-CQI pitches is evident from the scatter diagram in Figure 5, e.g., densities from 1.515 to 1.534 g/cm³ and resistivities (RES) from 68 to 64 μΩ·m.

Table I Descriptive Statistics:
Baked Anode Properties; N = 24

	OBC wt%	BAD g/cm ³	RES μΩ·m	MTP
Mean	18.5	1.5271	66.1	197.2
Std. Dev.	0.86	.0049	1.0	9.6
Min.	17.5	1.515	64.4	185.8
Q1*	17.7	1.524	65.4	187.9
Median	18.3	1.527	66.1	195.2
Q3*	19.2	1.531	66.8	204.9
Max.	20.0	1.534	68.2	214.0
IQR**	1.5	0.007	1.4	17.0
Range***	2.5	0.019	3.8	28.2

- * Quartiles
- ** Inner Quartile Range: Q3 - Q1
- *** Range: max. minus min.

Principal Component Regression

As cited in Part I of this paper, many additional response determinations were made on selected baked specimens from the first half of the experiment, e.g., air and CO₂ reactivity, air permeability, flexural strength, crushing strength and Young's modulus. To determine if all these tests were really needed, multivariate principal component regression (MPCR) was applied to the data. MPCR performs a variance-weighted, linear combination on the original response variables to reduce the dimensionality and to separate the responses into components (or groups) of highly correlated responses. The MPCR results are illustrated in the bargraph in Figure 6, where two components are shown to explain at least 90% of the variability in six baked-anode properties. The highly correlated properties of the two component groupings are defined in Table II by the correlation coefficients between the two components and the various anode properties.

Table II Correlation Coefficients Between Baked Anode Properties and Principal Component (PC)

	1 st PC	2 nd PC
BAD	-0.292	+0.919*
RES	-0.967*	-0.104
Air Perm.	+0.455	-0.846*
Young's Mod., Sonic	+0.977*	+0.108
Flex Strength	+0.934*	+0.074
Comp. Strength	+0.727*	+0.520

* Very Highly Correlated Groups of Responses within PC

The first component comprises the responses resistivity (RES), Young's modulus, flexural strength and compressive (or crushing) strength. The second component includes baked apparent density (BAD) and air permeability. Correlations are further evident in Figures 7 through 10 showing:

- 1) minimum permeability with maximum BAD, Fig. 7
- 2) decreasing reactivity (air or CO₂) with increasing BAD, Fig. 8
- 3) maximum Young's modulus with minimum RES, Fig. 9
- 4) decreasing strengths (flexural and crushing) with increasing RES, Fig. 10.

Because of these statistically significant correlations between either BAD or RES with the rest of the responses, responses other than BAD and RES were not determined on the second half of the experiment. The overriding criterion for producing the best baked anodes with respect to all properties from a specific pitch appears to be the utilization of that pitch at its optimum pitch concentration (OBC) for maximum baked anode density (BAD).

One-Way Analysis Of Variance Of Derived Responses: Overview Of Experimental Pitches

The purpose of this routine was to determine how the derived responses were affected by the experimental pitches. Tests for significant differences between the pitches (without regard to the controlled-factor treatment combinations initially) were made by comparing the variation between pitches to the residual error estimated from the three-replicate anode sets. The results are interpreted in the four multiple comparisons graphs of Figures 11 through 14 for OBC, MTP, maximum BAD and RES, respectively. Each graph shows a horizontal line representing the grand average, a confidence bar on each pitch mean and two horizontal lines representing a range of uncertainty about the grand average. If error bars on the pitch means overlap, the pitches can be assumed to be not significantly different. If the error bars do not overlap, the means can be assumed to be significantly different. Likewise, pitch means exhibiting error bars outside the range of uncertainty for the grand average are significantly different from the grand average for all groups. Considering the pitch percent to achieve maximum density (OBC), Figure 11, and MTP, Figure 12, it is evident that significantly less pitch (17.6 to 18.1 wt% or 187 to 192 Kg/MT) is required to achieve maximum BAD with pitches A, C, D, and E than with pitches B, F, and G (19.0 to 19.8 wt% or 204 to 212 Kg/MT). However, provided that the OBC is used, less variability is seen in BAD's, Figure 13, and the only pitches showing a significant difference are pitches F (1.534 g/cm³) and H (1.522 g/cm³) and pitches F and A (1.522 g/cm³). Also, pitches F and H are the only ones showing a difference in resistivity, Figure 14 (65 μΩ·m for pitch F and 67.5 μΩ·m for pitch H); this at the 90 to 95 percent confidence level since there is a slight overlap of the confidence bars on these two.

Modeling Of Second-Order Models By Multiple Stepwise Regression

Since the experimental pitches did exhibit significant effects on measured baked-anode responses, the next step was to develop models relating these responses to second-order models including main effects, two-factor interactions and square terms of the predictor variables CQI, NQI and BRS. This was done for the four derived responses (OBC, MTP, BAD, RES) and for two pitch coking values, i.e., the Conradson coking values (CCV) of the experimental pitch and the in-situ

coking value (ICV) of the experimental pitch measured during anode fabrication.

Table III Orthogonal Transformations for Predictors (Controlled Factors)

Coarse QI and Natural QI Models

~CQI, wt%	=	(CQI - 2.245)/1.965
~NQI, wt%	=	(NQI - 15.14)/3.74
~BRS, wt%	=	(BRS - 15.6)/4.5

Total QI and Ash Models

~TQI, wt% (without Prodn. Pitch Data)	=	(TQI - 16.455)/4.765
~TQI, (with Prodn. Pitch Data)	=	(TQI - 16.005)/5.215
~A, wt%	=	(A - 0.215)/0.175
~BRS, wt%	=	(BRS - 15.6)/4.5

The three main predictor factors (CQI, NQI, and BRS) were first orthogonally transformed to a plus-one, minus-one scale, Table III, and then, a full second-order model of main effects, two-factor interactions and square terms of these transformed predictors was fitted to each of the responses. Non-significant terms were removed from the models by stepwise regression. The refined models were used to predict performance of the production pitch which was run along side of the experimental pitches but whose data were not included in the modeling. Predictions from the models were then compared with actual observations for the production pitch.

The criteria used to assess goodness-of-fit (model adequacy) were: 1) R-square adjusted which is the percent of response variability explained by the model, the higher the better; 2) RMS Error (root mean square error) which is a measure of the differences between predicted observations and actual observations for all observations used in the regression, the smaller the better; and 3) the difference between the predicted response and the actual response for the production pitch, the smaller the better. [Note: Plus or minus approximately twice the RMS Error (depending on residual error degrees of freedom) is the ninety-five percent confidence interval on model predictions.]

CQI-NQI-BRS Models

Model coefficients for the orthogonally transformed predictor terms and goodness-of-fit criteria are shown in Table IV for six models—one each for each of the coking values (CCV & ICV) and one for each of the derived responses (OBC, MTP, BAD, RES). Figures 15 through 20 show fitted values against actual values for each of the six models. [Note: The coefficients are the response changes associated with changes in the predictor from their midpoints to either their lowest or highest level on an orthogonal scale, i.e., to either minus one or plus one.]

Conradson Coking Value of Pitch (CCV)

The model for CCV had an adjusted R-square of 0.95, indicating an excellent fit, and an RMS Error of 0.32. CQI, NQI and NQI squared were the only significant terms in the model. The coefficient for NQI was twice that of CQI, 1.6 versus 0.7. However, the model prediction for CCV for the production pitch was 2.1 percentage units higher than actual, 59.4 versus 57.3 wt%, Table IV. This is not surprising since the NQI of the production pitch, not used in fitting the model, was far less than

the lowest NQI of the experimental pitches, 8.2 versus 11.4. A plot of fitted versus actual for CCV, Figure 15, shows a tight distribution of points around a one-to-one correspondence line for data used in fitting the model.

In-Situ Coking Value (ICV)

The model for ICV, with an adjusted R-square of 0.53 and an RMS Error of 0.77, was not nearly as good as that for CCV. NQI was the only significant term, and an increase in NQI across its range (-1 to +1) increased ICV by 2.1 (twice the coefficient). This model predicted an ICV for the production pitch that was 2.1 lower than actual (64.7 versus 66.8) Table IV. A plot of fitted versus actual, Figure 16, showed three values (those of pitches D, H and F) to be considerably removed from the one-to-one correspondence line for data used in fitting the model. The poor model for this response is probably due in part to the variability in removing packing coke from the baked anodes which would affect the apparent weight, and thus the apparent in-situ coking value of the pitch.

Optimum Binder Concentration (OBC)
For Maximum Baked Anode Density

The model for OBC had an adjusted R-square of 0.94 and an RMS Error of 0.21. When considering simple linear effects of going from the lowest to the highest levels of the three predictor variables, the largest effect (twice the coefficient value shown in Table IV for the OBC model) is that of CQI (+3.1), or + 0.8 for every percentage point increase in CQI, followed by BRS (+2.0), or + 0.22 for every percentage point increase in BRS, and then NQI (+0.6), or + 0.08 for every percentage point increase in NQI. However, there are also significant second-order interaction and square terms present in this model, as shown in Table IV, for (NQI * BRS), (CQI**2), and (BRS**2). Therefore, in the presence of these interactions, linear effects have little practical value. This model predicted a 17.7 OBC for the production pitch compared with an actual 17.8, a very good prediction. A plot of fitted versus actual for OBC, Figure 17, with this model shows a good distribution of points around the one-to-one correspondence line.

Kg Pitch Per Metric Ton Baked Anode (MTP)

The model for predicting the pitch requirement for a one-metric-ton baked anode, MTP, a parameter calculated from the OBC, would be expected to give a model as good as that for OBC, and that was found to be the case. This model gave an adjusted R-square of 0.94, the same as that for OBC, and an RMS Error of 2.38. The significant predictor terms were the same ones found significant for the OBC model. Again, considering only linear effects, MTP was affected most by CQI and least by NQI, with coefficients of 18.2, 11.59 and 2.99 for CQI, BRS and NQI, respectively. This model predicted an MTP of 188.7 for the production pitch, compared with an actual value of 189.6, a difference of only 0.9, Figure 18. However, as was the case for the OBC model, because of significant second-order terms in this model, consideration of only simple linear effects should be avoided. Interpretation of this model as well as the OBC model above is best accomplished with contourplots as will be shown below.

Maximum Baked Apparent Density
And Electrical Resistivity

It was shown earlier, by analysis-of-variance methods, that there was considerably less variation in BAD's and RES's of maximum density anodes than there was with OBC's and MTP's to produce the maximum-density anodes. Models for BAD and

RES did not exhibit adjusted R-squares as good as those of OBC and MTP, only 0.60 and 0.46 for the BAD and RES models, respectively. The pitch-to-pitch variability with respect to BAD or RES is greatly diminished when the optimum pitch concentration is used in anode fabrication. Predictions for the production pitch based on these models were off, by 0.002 g/cm³ for BAD and by 1.1 μΩ•m for resistivity, as shown in Table IV and Figures 19 and 20.

Ash-TQI-BRS Models

Since NQI and CQI are not normally measured independently, but instead are measured together as total QI (TQI), a model including TQI and BRS was evaluated for fitting the OBC data. Also, so that the contributions of the CQI fraction would not be completely compromised as a result of combining it with NQI in the TQI parameter, the ash content of the pitch was used in the model to estimate the contribution of CQI. As evidenced in Figure 21 for these experimental pitches and one production pitch, there is a direct relationship between the CQI and ash contents of the pitches. Ash content is shown to increase with increasing CQI concentration of the pitch independently of whether the tar source is low or high in NQI. The correlation appeared strong enough from the graphic of Figure 21 to allow utilization of ash concentration in the model to measure the contribution of CQI. A model including the TQI, BRS and ash contents of the pitch as well as the second- and third-order interactions of these terms was fitted to the OBC values. Two models were developed - one without and one with the production pitch data. Coefficients are shown in Table V for both models. Adjusted R-squares were 0.94 and 0.91, and RMS Error's were 0.215 and 0.210, without and with the production pitch data, respectively. However, as might be expected, the production pitch prediction is identical to actual when the production pitch data are used in fitting the model. Without the production pitch data in the model, the model predicts an OBC 1.9 units higher than actual, 19.7 versus 17.8. Fitted-versus-actual plots for both models are shown in Figures 22 and 23.

Graphical Interpretation Of Models

The presence of higher-order terms in the developed models prevents simple comparisons between the main predictors for their relative effects on the various responses. This is because the effect of one factor, say NQI, depends on the level of the other factors, say CQI or BRS. A good way to interpret these models is through the use of contourplots.

A contourplot is read the same as a topographical map. Contour lines define levels of a surface viewed from above. The lines, representing portions of the surface at the same height, show the relationship of a dependent variable (the response, e.g., OBC, BAD, RES, MTP) to two independent factors (e.g., BRS and NQI, or ASH and TQI). If more than two independent variables are present in the model, e.g., three, the third variable can be fixed at any desired level for the generation of the contourplot, or the third variable can be varied over different levels to generate a family of contourplots at various levels of the fixed third variable. The following contourplots are included for interpretation of the models described above:

CQI-NQI-BRS Models	Surface or Response		Y-Axis	X-Axis	Fixed
FIG. 24	OBC	vs.	BRS	NQI	CQI=2.6
FIG. 25	BAD	vs.	BRS	NQI	CQI=2.6
FIG. 26	RES	vs.	BRS	NQI	CQI=2.6
FIG. 27	MTP	vs.	BRS	NQI	CQI=2.6

ASH-TQI-BRS Models

FIG. 28	OBC	vs.	ASH	TQI	BRS=11.3
FIG. 29	OBC	vs.	ASH	TQI	BRS=15.0

The utility of a contourplot can be discussed in reference to Figure 27, showing the relationship between MTP (the response) and predictors (BRS and NQI) for a fixed level of CQI of 2.6 (uncentrifuged tar). The largest MTP (215 Kg/MT anode) is seen at 19 to 20 wt% NQI and 18 to 20 wt% BRS. There is a wide shallow upward slope in MTP (pitch demand) ascending a ridge defined by 8 wt% NQI and 12 to 17 wt% BRS upward to the maximum at 19 to 20 wt% NQI and 18 to 20 wt% BRS. Pitch demands drop going down either side of the ridge at a fixed level of NQI (variable BRS), but the slopes are steeper (more sensitive to BRS) at high NQI levels than at low NQI levels. Figure 25 shows a similar plot for BAD. Note in Figure 25 that BAD's are highest atop that same ridge defined above for MTP.

Part II Summary And Conclusions

Baked-anode properties obtained from experimental pitches produced in a statistically-designed experiment to determine the effects of normal and carry-over QI and beta resin were statistically evaluated. Second-order models for derived response parameters, e.g., optimum pitch concentration and pitch demand for a one-metric ton baked anode, gave excellent models capable of predicting those same parameters for a production pitch not used in fitting the models. A model employing total QI and ash contents of the pitch, readily available measurements used in place of the more formidable CQI and NQI measurements, also gave an excellent model for predicting pitch demand. However, this model had to include the production pitch data to adequately predict the production pitch.

Because of the presence of significant two-factor interactions in the derived models, linear estimates of the effects of the predictors (i.e., linear effects of CQI, NQI, BRS) have little practical value [2]. For this reason, contourplots were provided to interpret the associated interactions of the derived models. An example is the interpretation of the NQI*BRS interactions in the OBC and BAD models. For example, from the contourplots for OBC and BAD, Figures 24 and 25, an increase in NQI from 8 to 20 wt% at a BRS of 12 wt% shows a decrease in OBC of 0.5 wt% (down from 18.0 wt% to 17.5 wt%) and a decrease in BAD of 0.004 g/cm³ (down from about 1.524 g/cm³ to 1.520 g/cm³). However, the opposite is true at a higher BRS, e.g., at 20 wt% BRS. In this case, a similar increase in NQI from 8 to 20 wt% shows an increase in OBC of 3.0 wt% (up from 17.0 wt% to 20 wt%) and an increase in BAD of 0.014 g/cm³ (up from 1.510 g/cm³ to 1.524 g/cm³). [Note: A result of the

interaction is that the effect of NQI going from low to high NQI on the responses OBC and BAD is reversed depending on the level of BRS.] Another noteworthy item from the two contourplots is that in the BRS range 13 to 15 wt% both the OBC and BAD are essentially unaffected by increasing NQI. OBC follows in a trough of 18 to 18.5 wt% going from 8 to 20 wt% NQI, while BAD is relatively constant at 1.524 to 1.525 g/cm³ and MTP is relatively constant at 195 to 200 Kg/MT. A suggestion that follows from this is that if a user finds that pitching demand is increasing because of increasing QI, an adjustment in BRS might be considered to make the system more robust, i.e., less sensitive, to QI fluctuations.

The effect of CQI on OBC is evident from the contourplot relating OBC to wt% ash (a measure of CQI) and wt% TQI, Figure 29. At a BRS of 15 wt%, an increase in wt% ash from 0.0 to 0.4 (equivalent to a CQI increase of 4 wt%) increases OBC by 0.6 wt% equivalent to a 0.15 wt% increase in OBC for every 1 wt% increase in CQI. At a lower BRS, i.e., 11.3 wt%,

Figure 28, the effect of increasing ash (or CQI) on OBC is very sensitive to wt% TQI. For example, at 11 to 12 wt% TQI there is only a 0.5 wt% increase in OBC (up from 17.5 at low ash to 18.0 wt% at high ash) equivalent to an increase of 0.12 wt% in OBC for every 1 wt% increase in CQI. However at 20 to 21 wt% TQI, an increase of about 3 wt% in OBC is evident across the ash range translating to an 0.75 wt% increase in OBC for every 1 wt% increase in CQI. Here again, interactions with BRS very dramatically alter the effects of NQI or TQI as each is raised from a low to a high level; this information would otherwise be lost with a linear interpretation of the main effects.

Acknowledgments

D. L. Belitskus, L. A. Hartley, K. C. Krupinski, R. W. Smith, and B. M. Triko made significant contributions to the review of the results. Also, permission to publish these results by Alcoa and Aristech management is greatly appreciated.

Table IV Model coefficients for orthogonally transformed predictors* for CQI-NQI-BRS models

Response = Constant + (a * ~ CQI) + (b * ~ NQI) + (c * ~ BRS) + (ab * ~ CQI * ~ NQI) + (ac * ~ CQI * ~ BRS) + (bc * ~ NQI * ~ BRS) + (aa * ~ CQI * ~ CQI) + (bb * ~ NQI * ~ NQI) + (cc * ~ BRS * ~ BRS)						
Response	Conradson Coking Value of Pitch wt%; CCV	In-Situ Coking Value of Pitch, wt%; ICV	Optimum Binder Conc., wt%; OBC	Kg Pitch per MTON Baked Anode; MTP	Baked Apparent Density, g/cm ³ @ OBC; BAD	Baked Anode Resistivity, μΩ-M @ Max. BAD; RES
Constant	59.3	66.6	18.81	201	1.521	67
a	+0.697	0.0	+1.564	+18.2	+0.0016	+0.243
b	+1.616	+1.035	+0.318	+2.99	+0.0011	-0.336
c	0.0	0.0	+0.991	+11.59	-0.0004	-0.294
ab	0.0	0.0	0.0	0.0	0.0	0.0
ac	0.0	0.0	0.0	0.0	0.0	0.0
bc	0.0	0.0	+0.723	+8.21	+0.0035	-0.788
aa	0.0	0.0	+1.471	+17.35	+0.0089	-1.323
bb	+0.874	0.0	0.0	0.0	0.0	0.0
cc	0.0	0.0	-1.223	-14.99	-0.006	0.0
R ^{adj}	0.95	0.53	0.94	0.94	0.60	0.46
RMS Error	0.32	0.77	0.21	2.38	0.003	0.73
Production Pitch						
Y, Predicted	59.4	64.7	17.7 ± 0.84	188.7 ± 9.6	1.525 ± 0.013	66.5 ± 2.7
Actual**	57.3	66.8	17.8 ± 0.15	189.6 ± 0.4	1.527 ± 0.003	65.4 ± 0.6
Y Minus Actual	+2.1	-2.1	-0.1	-0.9	-0.002	+1.1

* See Table III for transformations.

** One value for coking values; avg. of ten values otherwise.

Table V Model coefficients for orthogonally transformed predictors* for Ash-TQI-BRS models

Response = Constant + (a *~ A) + (b *~ TQI) + (c *~ BRS) + (ab *~ A *~ TQI) + (ac *~ A *~ BRS) + (bc *~ TQI *~ BRS) + (aa *~ A *~ A) + (abc *~ A *~ TQI *~ BRS)		
Response	Optimum Binder Conc., wt%; OBC (without Production Pitch Data)	Optimum Binder Conc., wt%; OBC (with Production Pitch Data)
Constant	16.67	18.54
Coefficients		
a	+3.16	+0.25
b	-0.997	+0.832
c	+1.151	+0.718
ab	-3.097	-0.205
ac	+0.539	-0.565
bc	+1.233	+0.800
aa	+6.391	0.0
abc	0.0	-0.926
R ² adjusted	0.94	0.91
RMS Error	0.215	0.21
Production Pitch Y, Predicted	19.7 ± 1.9	17.8 ± 0.3
Actual**	17.8 ± 0.15	17.8 ± 0.15
Y Minus Actual *	+1.9	0.0

* See Table III for transformations.
** Avg. of ten values.

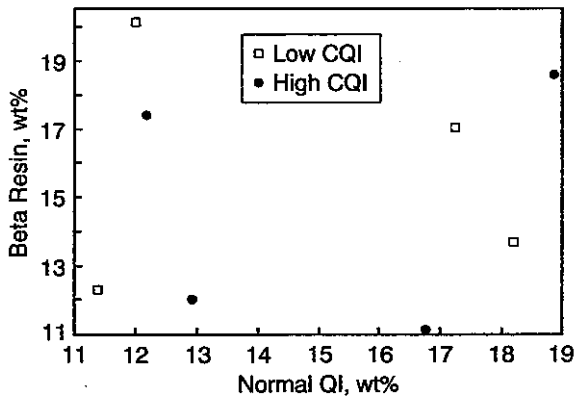


Fig. 1: Experimental treatment combinations.

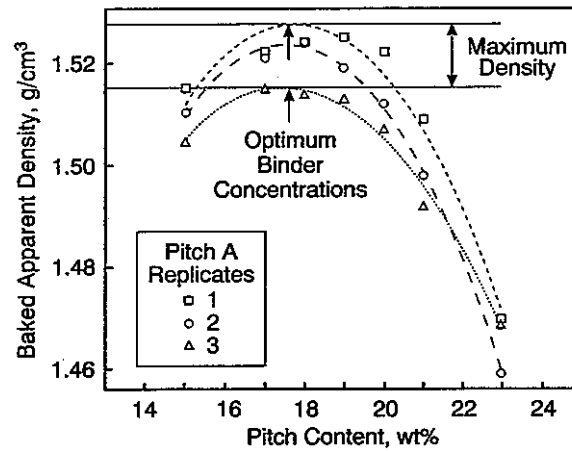


Fig. 2: BAD vs. % binder pitch for pitch A.

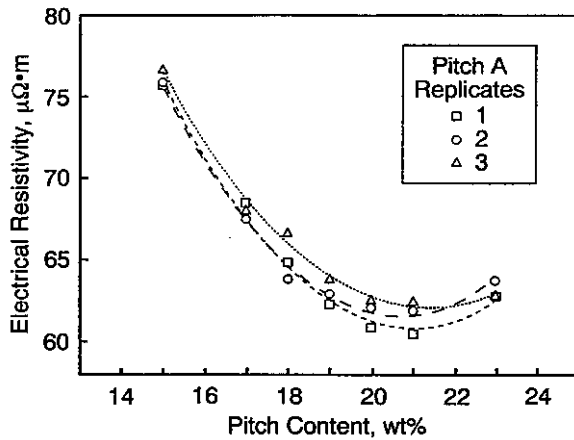


Fig. 3: Electrical RES vs. % binder pitch for pitch A.

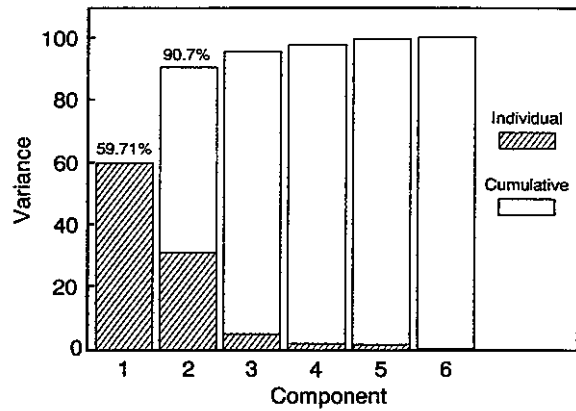


Fig. 6: Bargraph showing %age of variance explained by principal components one and two.

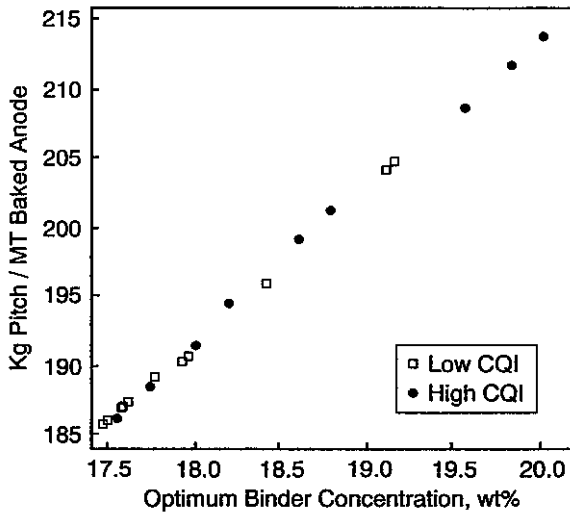


Fig. 4: Pitch requirement, Kg/MT, vs. wt%, OBC.

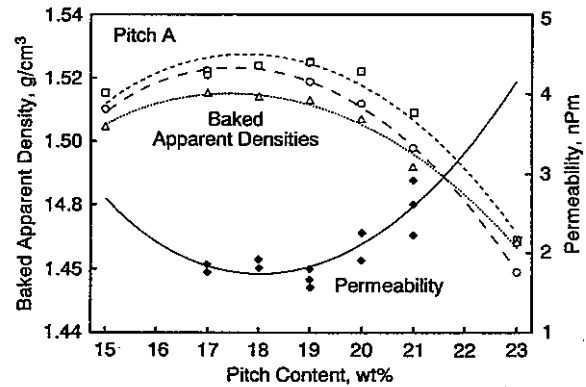


Fig. 7: BAD and air permeability vs. % binder for pitch A.

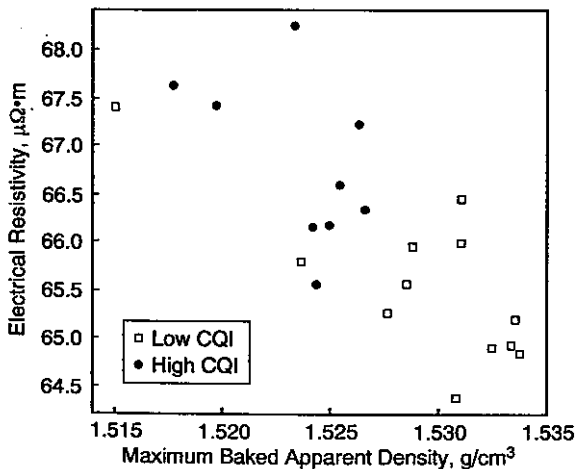


Fig. 5: Electrical RES vs. max BAD for a maximum-density anode.

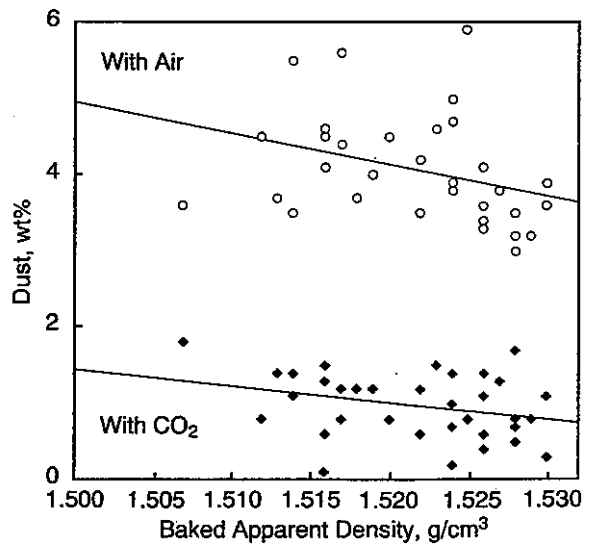


Fig. 8: Air and CO2 dust reactivity vs. BAD.

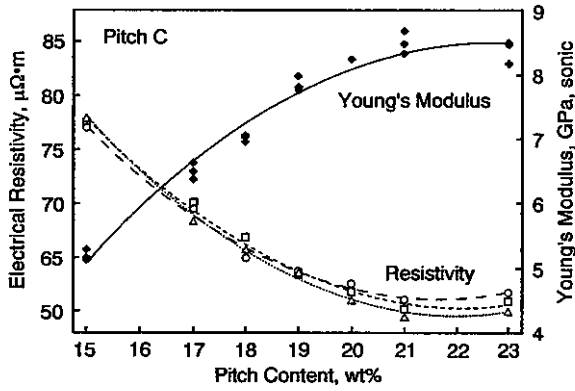


Fig. 9: Young's modulus and electrical RES vs. % binder.

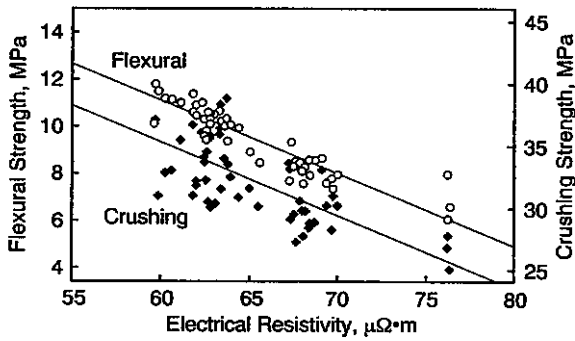


Fig. 10: Flexural and crushing strength vs. electrical RES.

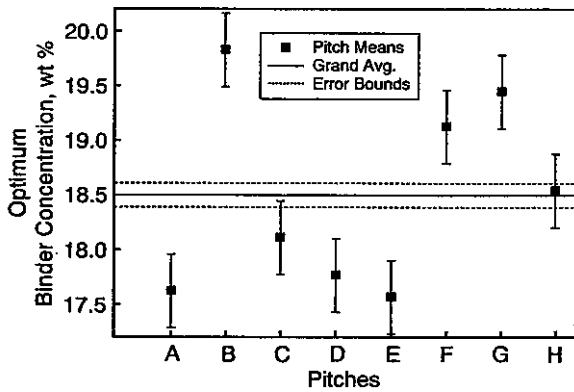


Fig. 11: Multiple comparisons graph relating OBC to pitches.

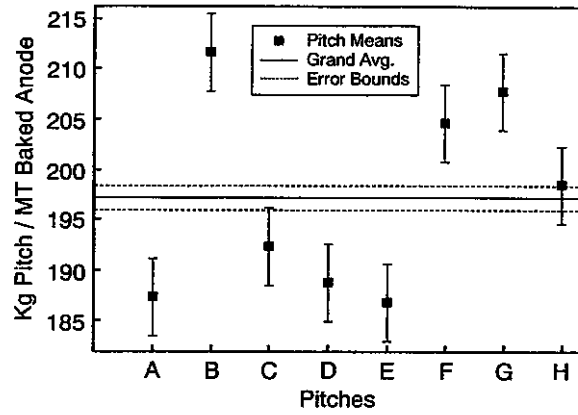


Fig. 12: Multiple comparisons graph relating pitching requirement to pitches.

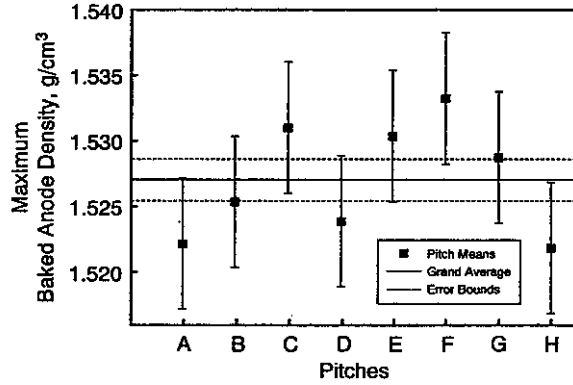


Fig. 13: Multiple comparisons graph relating maximum BAD to pitches.

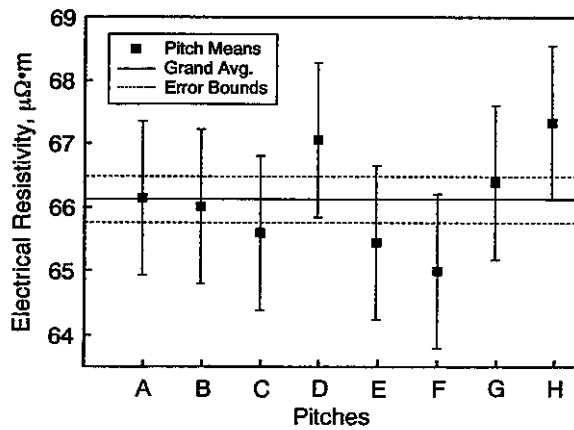


Fig. 14: Multiple comparisons graph relating electrical RES of maximum density anode to pitches.

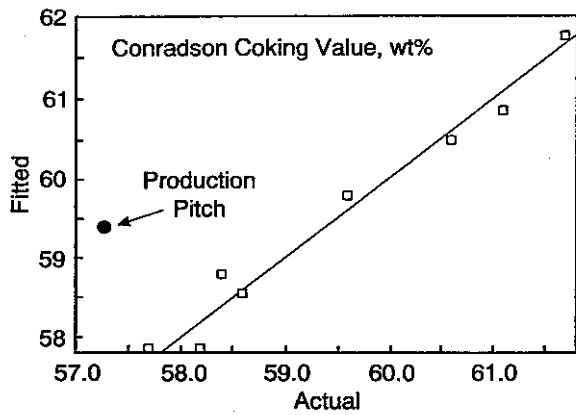


Fig. 15: Model for Conradson coking value of pitch: fitted values vs. actual observations.

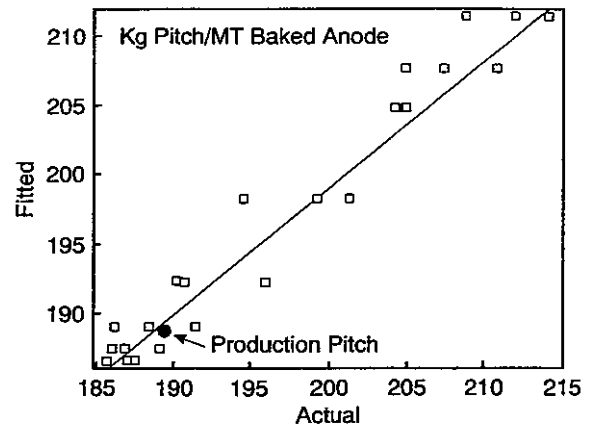


Fig. 18: Model for pitching requirement: fitted values vs. actual observations.

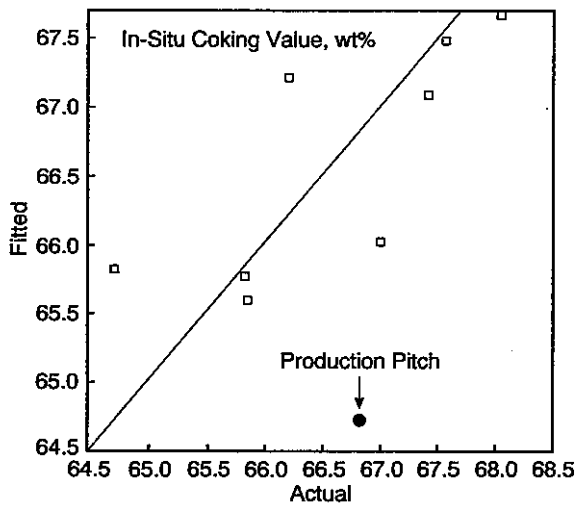


Fig. 16: Model for in-situ coking value of pitch: fitted values vs. actual observations.

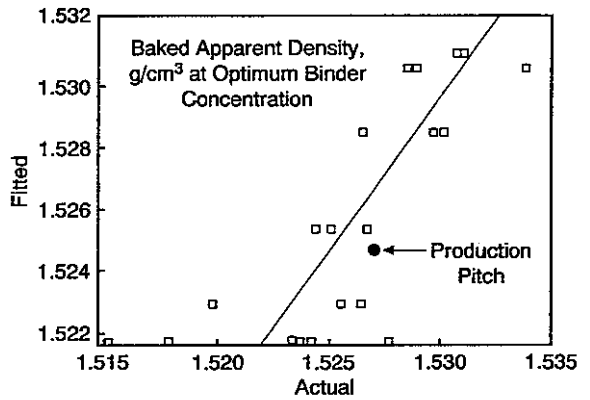


Fig. 19: Model for maximum BAD at OBC: fitted values vs. actual observations.

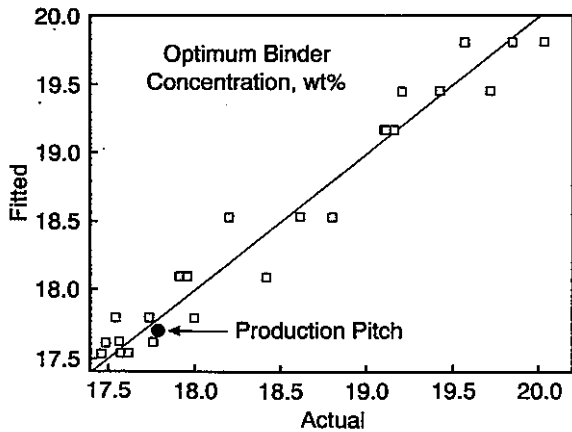


Fig. 17: Model for OBC: fitted values vs. actual observations.

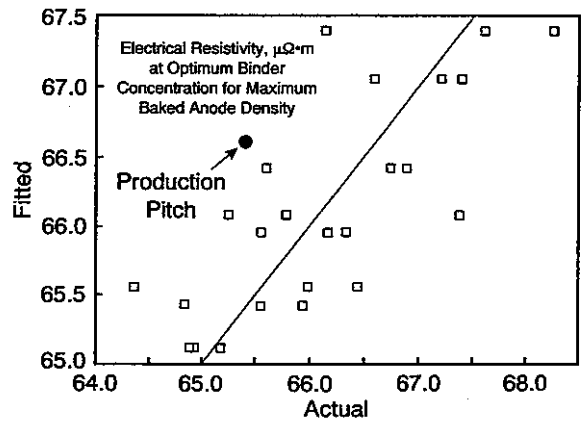


Fig. 20: Model for electrical RES of maximum density anode: fitted values vs. actual observations.

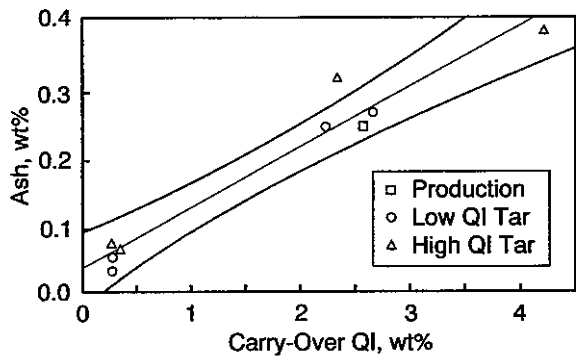


Fig. 21: Scatter plot with least squares line showing relationship between ash and CQI contents.

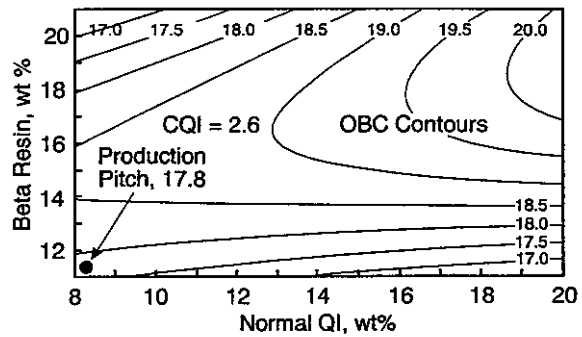


Fig. 24: Contourplot relating OBC to BRS and NQI at a fixed CQI level of 2.6 wt% (pitch from non-centrifuged tar).

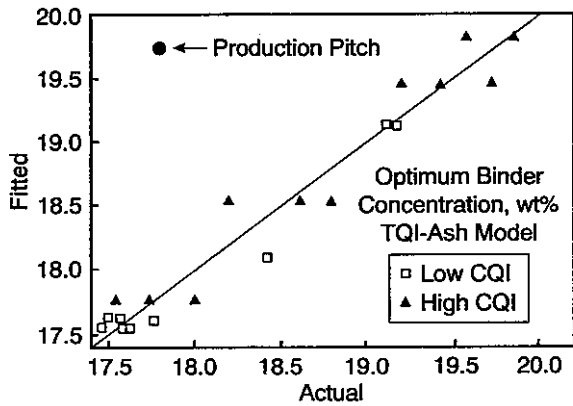


Fig. 22: TQI-ash model without production-pitch observations for OBC: fitted vs. actual.

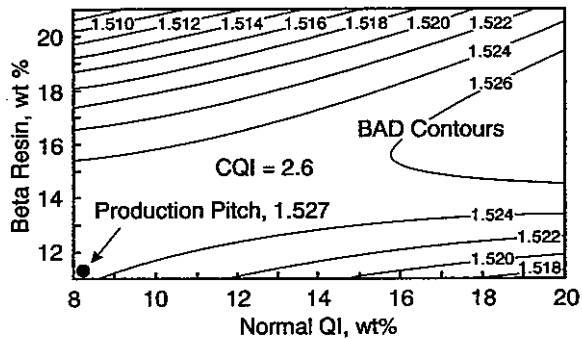


Fig. 25: Contourplot relating maximum BAD to BRS and NQI at a fixed CQI level of 2.6 wt% (pitch from non-centrifuged tar).

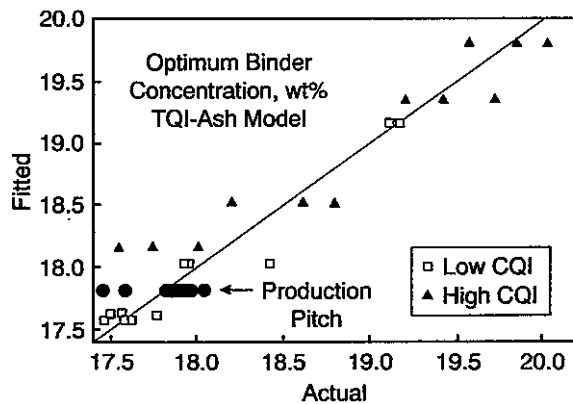


Fig. 23: TQI-ash model with production-pitch observations for OBC: fitted vs. actual.

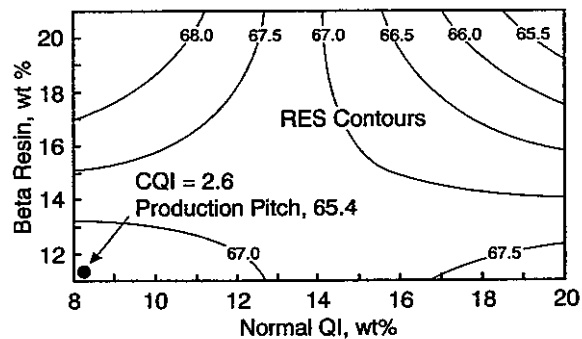


Fig. 26: Contourplot relating electrical RES of maximum density anode to BRS and NQI at a fixed CQI level of 2.6 wt% (pitch from non-centrifuged tar).

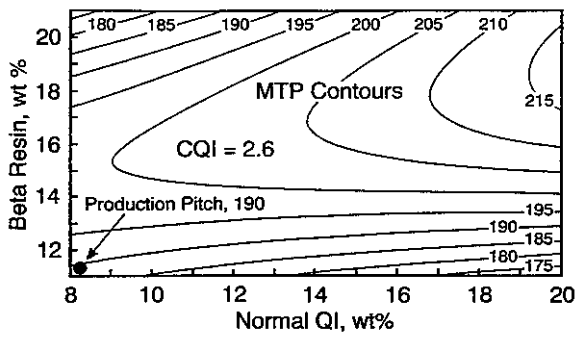


Fig. 27: Contourplot relating pitching requirement for one-metric-ton baked anode to BRS and NQI at a fixed CQI level of 2.6 wt% (pitch from non-centrifuged tar).

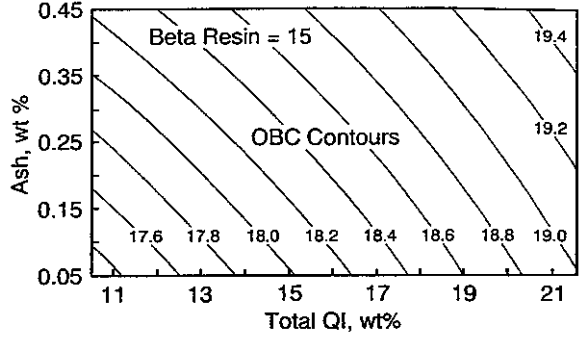


Fig. 29: Contourplot relating OBC to ash and TQI concentrations at a fixed BRS level of 15 wt%.

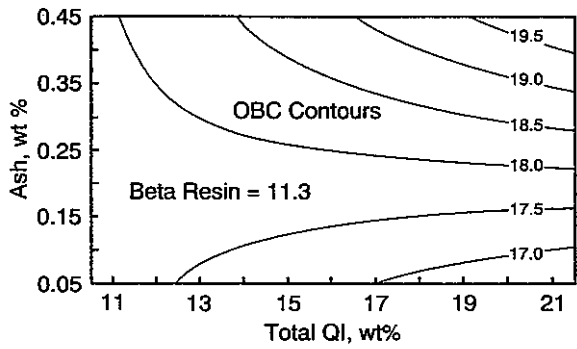


Fig. 28: Contourplot relating OBC to ash and TQI concentrations at a fixed BRS level of 11.3 wt%.

References

1. BBN Software Products, Software for Technical Data Analysis and Graphics, RS/1 Documentation, Cambridge, MA (1992).
2. Design-Ease, Stat-Ease, Inc., Minneapolis, MN (1991).