USING LINEAR PROGRAMMING TO MINIMISE COSTS IN WET PROCESSING OF TRIAXIAL CERAMIC BODIES

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ABSTRACT

Mixture design experiments and response surfaces were used to describe and simulate the behaviour of ceramic suspensions as a function of triaxial components quartz, feldspar and clay mineral. Furthermore, linear programming was used to find a composition which minimizes materials cost, subjected to restrictions imposed by the optimum deflocculant amount and the relative sedimentation height of the suspensions.

1. INTRODUCTION

Optimisation has become a major interesting area in process systems engineering[1,2]. It has evolved from a methodology of academic interest into a technology that has and continues to make significant impact in industry. Basically, optimisation problems can be classified in terms of continuous and of discrete variables. The major problems for continuous optimisation include linear programming (LP) and non-linear programming, (NLP)[3]. Since 1950, advances in LP are remarkable. In the last years, LP has been considered a fundamental tool to optimise cost in business companies all over the world. Some papers also report the use of linear programming to reformulation problems, particularly in ceramics field[4,5]. The aim of the present work is to minimise the costs of ceramic bodies as a function of the raw materials, considering rheological properties, as optimum amount of deflocculant and settling stabilization, using linear programming.

2. MATERIALS AND METHODS

Potash feldspar, quartz sand, and a mixture of two clays (77 wt.% A-39 and 23 wt.% A-12) were used as raw materials in suspensions with 60 wt.% solids. As deflocculant, sodium tripolyphosphate powder (Na-TPP, mass ratio P_2O_5/Na_2O=1.5, Manchester) was used, added before the ball milling process. The crystalline phases present were identified by X-ray diffraction (XRD) and quantified by rational analysis[6]. Rheological measurements were carried out using a viscometer (ThermoHaake, VT550), with concentric cylinder geometry, at 25.0 ± 0.1ºC, and the apparent viscosities were determined in a shear rate of 42 s^{-1}. The optimum deflocculant amount (ODA)[7] was used to calculate the coefficients of regression equations that represent a model related to the weight fractions of clay mineral, feldspar and quartz. The ratio between the suspension initial settling height (h_0) and the height (h_1) measured after 1 day, called relative sedimentation height (RSH) was determined[8]. A mathematical model relating the RSH and the weight fractions of the mixture was found. An optimisation using linear programming was performed.

Figure 1. The ternary system clay-quartz-feldspar (independent components) showing the raw materials triangle and the intersection area containing only compositions that fulfil viscosity restrictions.

3. RESULTS AND DISCUSSION

The bound limits used were 20 wt.% of clay mineral, 15 wt.% of potash feldspar and 15 wt.% of quartz[9]. Figure 1 represents a restricted composition triangle of pseudocomponents on which a {3,2} simplex lattice (six points) was set. To these original six points, a central point was first added (centroid simplex), followed by three more (augmented {3,2} simplex lattice). Compositions with higher clay mineral weight fraction (M1 and M8) could not be tested due to restrictions in the viscometer work range.

Table 1 presents only 8 compositions, of those 10 mixtures (M_i, i = 1, 2,…,10), in terms of independent components as well as its correspondent values of ODA and RSH.

Mixtures	Compositions			ODA (wt.%)	RSH
	Clay mineral	Feldspar	Quartz		
M2	0.200	0.650	0.150	0.05	0.08
M3	0.200	0.150	0.650	0.07	0.40
M4	0.450	0.400	0.150	0.30	0.00
M5	0.450	0.150	0.400	0.50	0.00
M6	0.200	0.400	0.400	0.06	0.23
M7	0.367	0.317	0.316	0.20	0.00
M9	0.283	0.483	0.234	0.15	0.00
M10	0.283	0.233	0.484	0.20	0.00

Table 1. Triaxial compositions of the mixtures created by the augmented {3,2} simplex and measured values of ODA and RSH.

Two linear regression polynomials were obtained:

$$\text{ODA (wt.\%)} = 1.0897X_C - 0.2982X_F - 0.1048X_Q \quad (1)$$

$$\text{RSH} = - 0.5538X_C + 0.1538X_F + 0.5846X_Q \quad (2)$$

where X_C is the clay mineral, X_F is the feldspar and X_Q is the quartz fraction, respectively, in original components.

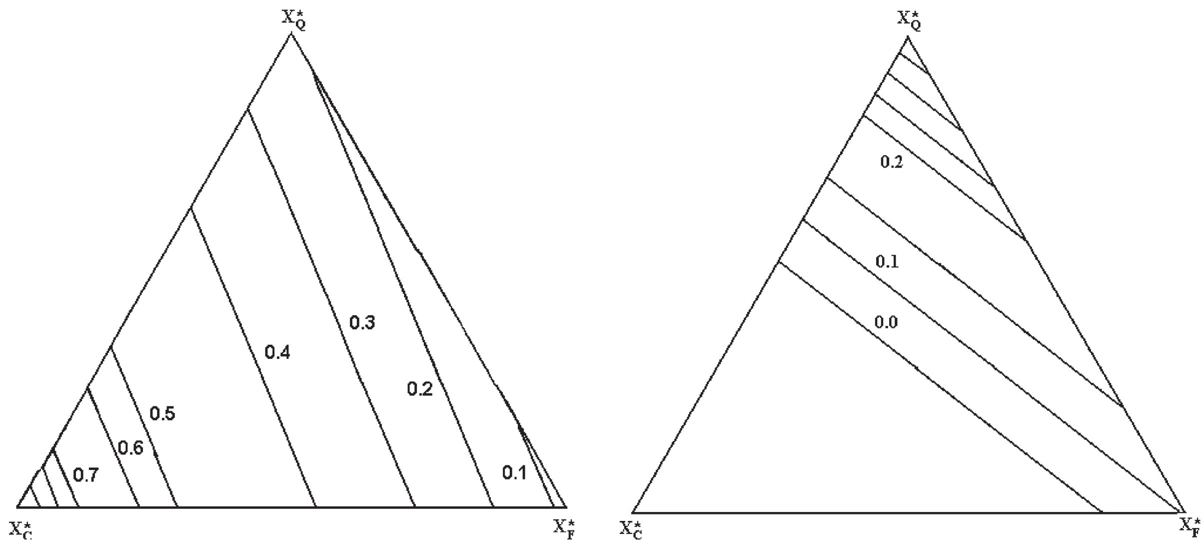
Table 2 shows that the regressions were significant to a confidence level of 5%.

Response property	Model adjusted	$SS_{Effec.t}$	df_{Effect}	MS_{Effect}	SS_{Error}	df_{Errpr}	MS_{Error}	F	p value
ODA (wt.%)	Linear	0.1402	2	0.0700	0.0207	5	0.0041	4.7853	0.0689
RSH		0.1028	2	0.0514	0.0537	5	0.0107	16.918	0.0059

Table 2. Variance analysis for the linear polynomials models for ODA and RSH.

Clay mineral fraction increases the deflocculant consumption, while both feldspar and quartz weight fractions acts in an antagonistic way. According to the literature[10,11], clay mineral crystals are characterised by the presence of cationic exchange due to unsaturated areas proceeding from broken valence bonds. These characteristics influence directly in the amount of dispersant agent necessary to stabilize a ceramic suspension. On the other hand, from the RSH regression, feldspar and quartz weight fractions increase the sedimentation height, due to their higher density, about 2.55 and 2.65 g/cm^3, respectively[12].

Figures 2 (a) and (b) show the projections of the calculated constant surfaces (in pseudocomponents) onto the composition triangle, as constant ODA and RSH contour plots.



a) **b)**

Figure 2. Content (a) ODA and (b) RSH plots vs. composition, expressed in terms of pseudocomponents.

It can be seen that lower amounts of deflocculant (ODA < 0.2 wt.%) can be reached with clay mineral contents below 20 wt.% (as raw material). Nevertheless, no sedimentation is observed with clay mineral contents above 50 wt.%. In addition, quartz fraction has the major influence on the sedimentation height compared to feldspar.

Assuming that the raw materials studied in this work were to be used in a wet processing, a set of constraints can be placed on the values of ODA (≤ 0.2 wt.%) and RSH (≤ 0.0). This optimisation problem aims to find a vector of optimisation variables, X_C, X_F and X_Q in order to minimize the objective function, which is the cost:

$$Cost = 9.74X_C + 77.89X_F + 32.65X_Q \quad (3)$$

By solving the linear problem, the vector found that minimizes the function Cost followed by constraints system was:

Minimize (Cost, X_C, X_F, X_Q) = [0.33, 0.48, 0.19]

In terms of original components, this result can be expressed as 33.3 wt.% clay mineral, 47.8 wt.% feldspar and 18.9 wt.% quartz, presenting the smallest cost in ceramic bodies production ($46.64/ton) followed by rheological constraints.

4. CONCLUSIONS

Mixture design experiments and the use of response surface methodologies enabled the calculation of regression models relating rheological properties to the initial composition. Furthermore, the use of linear programming shows that, for the particular raw materials under consideration, an optimised composition can be found, in order to minimize materials cost, subjected to restrictions imposed by specification standards.

REFERENCES

[1] DEGEN, A., KOSEC, M., ROCAK, D., Ceramic suspension optimization using factorial design of experiments, Journal of the European Ceramic Society, n. 22, p. 391-395, 2001.

[2] FERNANDEZ, C., VERNÉ, E., VOGEL, J., CARL, G., Optimisation of the synthesis of glass-ceramic matrix bicomposites by the "response surface methodology", Journal of the European Ceramic Society, n. 23, p. 1031-1038, 2002.

[3] BIEGLER, L.T., GROSSMANN, I.E., Retrospective on optimization, Computers and Chemical Engineering, n. 28, p. 1169–1192, 2004.

[4] ADAMS, K.V. et al., Reformulation of whiteware bodies using characterization and linear programming methods and techniques, Ceramic Bulletin, n. 8, v. 63, p. 1039-1050, 1984.

[5] PHELPS, G.W., Reformulation of whiteware bodies, American Ceramic Society Bulletin, n. 5, v. 55, p. 528-532, 1976.

[6] COELHO, C., ROQUEIRO, N., HOTZA, D., Materials Letters, v. 52, p. 394, 2002.

[7] GOMES, C.M., DE NONI JR., A., REIS, J.P., OLIVEIRA, A.P.N., HOTZA, D., American Ceramic Society Bulletin, november, p. 9301-9304, 2004.

[8] PANDOLFELLI et al. Dispersão e empacotamento de partículas – Princípios e aplicações em processamento cerâmico, São Paulo: Fazendo Arte, 2000.

[9] CORREIA, S.L., CURTO, K.A.S., HOTZA, D., SEGADÃES, A.M., Journal of the European Ceramic Society, v. 24, 2813-2818, 2003.

[10] POZZI, P. et al., La reologia dei materiali ceramici tradizionali, Faenza: Gruppo Editoriale Edritice, 1994.

[11] YILDIZ, N., EROL, M., BARAN, B., SARIKAYA, Y., CALIMLI, A., Applied Clay Science, v.13, p. 65, 1998.

[12] STEFANOV, S., BATSCHWAROV, S., Smalti Ceramici, Faenza Editrici, 1991.