Separation Science and Technology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713708471

Improved Phosphate Flotation Using Clay Binder

Daniel Tao[a]; Xiaohua Zhou[a]; Dennis Kennedy[b]; Pablo Dopico[b]; John Hines[b]
[a] Department of Mining Engineering, University of Kentucky, Lexington, KY, USA [b] Georgia-Pacific Chemicals, Decatur, GA, USA

Online publication date: 04 March 2010

To cite this Article Tao, Daniel , Zhou, Xiaohua , Kennedy, Dennis , Dopico, Pablo and Hines, John(2010) 'Improved Phosphate Flotation Using Clay Binder', Separation Science and Technology, 45: 5, 604 — 609
To link to this Article: DOI: 10.1080/01496390903566788
URL: http://dx.doi.org/10.1080/01496390903566788

Separation Science and Technology, 45: 604–609, 2010

ISSN: 0149-6395 print/1520-5754 online
DOI: 10.1080/01496390903566788

Taylor & Francis
Taylor & Francis Group

Improved Phosphate Flotation Using Clay Binder

Daniel Tao,[1] Xiaohua Zhou,[1] Dennis Kennedy,[2] Pablo Dopico,[2] and John Hines[2]
[1]*Department of Mining Engineering, University of Kentucky, Lexington, KY, USA*
[2]*Georgia-Pacific Chemicals, Decatur, GA, USA*

The presence of insoluble clay slimes in phosphate ore adversely affect phosphate flotation performance. In this study, the feasibility of using a clay binder as slime depressant for phosphate flotation was investigated by conducting batch mechanical flotation tests using a 16-200 mesh phosphate sample under various operating conditions. The flotation process parameters examined for their impacts on clay binder performance included collector dosage, binder dosage and conditioning time, flotation time, etc. Results have shown that use of 0.1 lb/t clay binder increased phosphate yield and recovery by 1.7% and 5.5% respectively with a two min. flotation time. The concentrate grade was essentially constant at about 24%. The highest yield of 16.09% and the highest recovery of 91.01% were obtained with 0.25 lb/t clay binder.

Keywords agglomeration; flocculation; flotation depressant; flotation kinetics; industrial minerals

INTRODUCTION

Phosphate is a vital non-renewable mineral and the increased need for world food production assures long-term growth in world phosphate demand. The United States is the world's largest producer and consumer of phosphate rock and the leader in fertilizer production and exports (9).

Phosphate rock requires upgrading, or beneficiation, to reduce the content of gangue minerals mainly composed of quartz, clay, calcite, dolomite, etc. A variety of concentration processes may be used for phosphate beneficiation, but froth flotation is the most widely practiced method (5). It is estimated that more than two-thirds of the phosphate ore produced in Florida and more than half of the world's marketable phosphate is processed by froth flotation (8). Other beneficiation methods include calcinations, acid leaching, and magnetic separation which have certain limitations and disadvantages compared to flotation and are not widely employed in the phosphate industry (8).

Received 15 July 2009; accepted 6 December 2009.
Address correspondence to Daniel Tao, Department of Mining Engineering, University of Kentucky, Rose Street, 234 MMRB, Lexington, KY 40506-0107, USA. E-mail: dtao@engr.uky.edu.

The presence of clay slimes poses a serious problem in the flotation of many minerals including phosphate. The slimes may attach to coarse particles and prevent originally hydrophobic value minerals from being floated (10). Slimes also result in higher reagent consumption in flotation due to their large specific surface area, which means sufficient reagent may not be available for the flotation of larger concentrate particles, resulting in decreased recovery Gaudin et al. (3) have shown that slime coating occurs as a result of the electrostatic attraction between particles of opposite charges. To minimize the adverse effect of clay slimes on flotation, numerous research efforts have been devoted to this issue. Nevertheless, this is still a serious problem that needs to be addressed due to the extremely complicated physicochemical conditions involved in the flotation process.

In this investigation a new reagent developed by Georgia-Pacific (Decatur, GA), referred to as Georgia-Pacific clay binder, was introduced as a depressant for phosphate flotation. The Georgia-Pacific clay binder is a low molecular weight polymer which is a condensation product of urea and formaldehyde reacted under acidic conditions. The Georgia-Pacific clay binder functions as a slime depressant by agglomerating insoluble slimes to reduce their surface area and minimize their adsorption of flotation reagents. The successful applications of clay binders in coal and potash flotation have been reported elsewhere (11). In this study, mechanical flotation tests were performed to study the effects of Georgia-Pacific clay binder on phosphate flotation efficiency.

EXPERIMENTAL

Materials

The phosphate ore sample used in this study was flotation feed provided by the Mosaic Company. The moisture in the as-received sample was 17.32%. Screening was conducted with the sample and the particle size distribution data for this particular phosphate sample is shown in Table 1. The sample consisted of only 1.64% + 40 mesh materials and less than 2% of the sample was smaller than 200 mesh. The dominant size fractions were −60 + 100 mesh and −100 + 150 mesh which accounted for 49.78%

TABLE 1
Particle size distribution of phosphate sample

Size (mesh number)	Wt. (%)	Grade (%)	A.I. (%)	Cumulative Overscreen (%)	Cumulative Overscreen Grade (%)	Cumulative Overscreen A.I. (%)
>16	0.14	10.50	50.53	0.14	10.50	50.53
16–30	0.43	15.11	39.61	0.58	13.97	42.30
30–40	1.06	13.17	52.53	1.64	13.45	48.94
40–60	17.24	5.34	82.75	18.88	6.05	79.82
60–100	49.78	3.70	88.01	68.66	4.35	85.76
100–150	24.06	3.09	89.98	92.72	4.02	86.85
150–200	5.86	4.76	83.32	98.58	4.06	86.64
<200	1.42	5.27	70.85	100.00	4.08	86.42

and 24.06% of the total sample, respectively. The as-received sample was assayed and its grade (P_2O_5%) was found to be 4.08%.

Flotation Tests

Flotation tests were performed using a Denver D-12 lab flotation machine equipped with a five-liter tank and a 2–7/8″ diameter impeller. To evaluate the binder's performance and optimize the process parameters, flotation tests were carried out under various operating conditions including different collector dosage, binder dosage and conditioning time. In each test, the slurry (70% solids by weight, pH 9.3) was first conditioned in a two-liter cell at a speed of 400 rpm before the addition of binder and collector. After that the conditioned slurry was transferred to the flotation cell, and water was added to dilute it to 20% solids by weight before flotation was initiated. The P_2O_5 recovery for each experiment was calculated from the weight and grade of dry flotation concentrate and tailings using Eq. (1)

$$\text{Recovery} = \frac{Cc}{Cc + Tt} 100 \tag{1}$$

C and T are weight % of dry concentrate and tailings respectively. c and t are P_2O_5 grades of concentrate and tailings in %, respectively.

For all the flotation tests, a clay binder, GP374G41, was added to the pulp before the addition of a collector made of 60% (vol.) CUSTOFLOAT (FCO) and 40% (vol.) #5 fuel oil (FO). No depressant is currently used in the industry, which was the baseline test in this study. Unless otherwise specified, flotation time was kept at two min. and tap water was used in all the tests.

Analysis of P_2O_5 and Insolubles

The phosphate samples to be assayed were prepared by the acid digestion method proposed by Zhang and Bogan (13). In this method, one gram of solid was digested with 30 ml of digestion acid composed of 40% (vol) HNO_3, 20% (vol) HCI, and 40% (vol) H_2O. Digestion consisted of bringing the digestion acid and solid in a 250 ml volumetric flask to boiling until the colored fumes dissipated in approximately 10 min. Flask and contents were cooled to room temperature and deionized water was added to bring the solution to the final volume of 250 ml. A 20 to one dilution was made to the digested solution for P_2O_5 analysis using the Inductively Coupled Plasma (ICP) instrument (Vista-Pro) made by Varian, Inc. (Palo Alto, Calif.).

Acid insolubles (A.I.) were determined from a separate one gram sample. The solid was placed in a 400 ml beaker with 30 ml digestion acid which was then boiled as above. When the digestion was completed the solution was cooled to the room temperature and then filtered through Whatman 41 filter paper. The filter paper with the undissolved solid was transferred to a tarred 30 ml porcelain crucible. The crucible with the filter paper was placed in a 600°C muffle furnace for 10 min. The temperature was then increased to 900°C for one hour. The crucible was cooled to the room temperature in a desiccator and then weighed again. The % insoluble was calculated from the weight difference.

RESULTS AND DISCUSSION

Effect of Collector Dosage on Flotation Performance

Baseline flotation tests were conducted to investigate the effect of collector dosage on flotation performance in the absence of Georgia-Pacific clay binder. The collector was made of 60% fatty acid and 40% fuel oil. Figure 1 shows the effect of collector dosage on flotation when no frother was added and impeller speed was maintained at 1200 rpm. The product yield, recovery and concentrate A.I. increased with increasing the collector dosage from 1 lb/t to 3 lb/t, which is in agreement with studies by other researchers

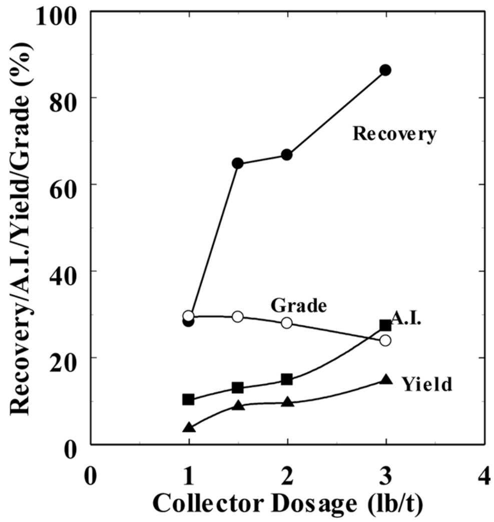

FIG. 1. Effect of collector dosage on flotation performance.

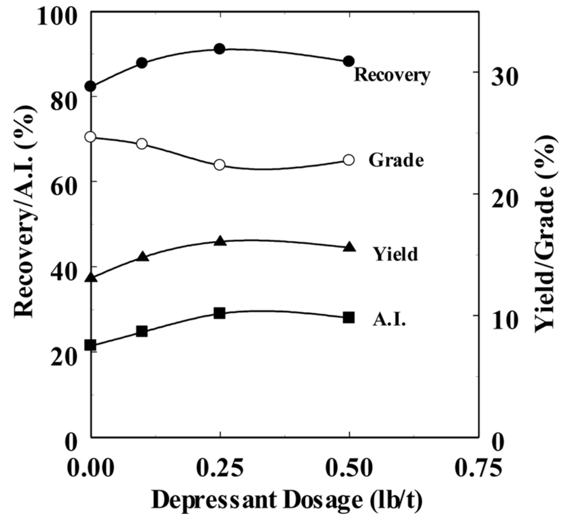

FIG. 2. Effect of depressant dosage on flotation performance.

(2, 5) that reported enhanced flotation recovery with an increase in collector concentration. However, the concentrate grade slightly decreased with increasing the collector dosage. Similar observations have been made by Tao et al. (11) in a phosphate flotation study using column flotation and similar mineral. The data shown in Fig. 1 also suggests that 3 lb/t collector dosage was needed to get the highest recovery and the suitable concentrate grade in the absence of Georgia-Pacific clay binder.

Effect of Binder Dosage on Flotation Performance

Since the purpose of this study was to investigate the effect of Georgia-Pacific binder as a depressant for phosphate flotation, binder dosage was evaluated as a major parameter. A series of flotation tests were performed where Georgia-Pacific binder 374G41 was used as depressant and its dosage varied from 0 to 0.5 lb/t. It should be noted that at a binder dosage of higher than 0.5 lb/t, e.g., 1 lb/t, pronounced depression of phosphate was observed and thus the binder was not employed at dosages higher than 0.5 lb/t in the study. For all these tests, the impeller speed was kept at 1200 rpm and binder conditioning time was maintained at 1 min. unless otherwise specified. Figure 2 shows the data obtained in the presence of 3 lb/t collector and no frother. It indicates that the yield, recovery, and A.I. increased significantly with the depressant dosage increasing from 0 to 0.25 lb/t, but the grade decreased slightly. Yield, recovery, and A.I. showed a decrease when the binder dosage increased from 0.25 lb/t to 0.5 lb/t, but they were still higher than for the control with no depressant. The highest yield and recovery of 16.09% and 91.01%, respectively were generated with a concentrate grade of 22.34% at 0.25 lb/t binder.

In phosphate beneficiation plants, −150 mesh slimes were removed by cyclone or other processes before the flotation of phosphate. However, as shown in Table 1, the as-received phosphate sample contains 5.86% 150–200 mesh and 1.42% -200 mesh materials which will severely reduce the process efficiency of froth flotation. According to Klassen and Morkrousov (7), slimes armor-coat bubbles, hindering bubble attachment to valuable mineral particles and reducing flotation recovery. The introduction of clay binders can agglomerate the slimes and reduce the slime coating and adsorption of collector by slime particles, resulting in a higher recovery with an acceptable grade.

Effect of Binder Conditioning Time

To investigate the effect of binder conditioning time on phosphate flotation performance, four flotation tests were performed using 0.25 lb/t GP374G41 at 1200 rpm impeller rotation speed. The collector dosage was 3.0 lb/t and no frother was added. The binder conditioning time varied from 0.5 min., 1.0 min., 2.0 min. to 4.0 min. As shown in Fig. 3, the P_2O_5 recovery increased, but the yield and A.I. decreased with increasing the binder conditioning time from 0.5 min. to 1.0 min. whereas the grade showed no change. However, when the conditioning time further increased to 2.0 min., the recovery, the yield and A.I. decreased and the grade increased slightly. The decrease in yield and recovery at 2 min. conditioning time was probably because the slime flocs formed in the slurry broke down with extended conditioning time, which diminished the binder depressing effect. No significant change was observed when the conditioning time longer than 2 min. was applied. The highest recovery of 91.01% was achieved

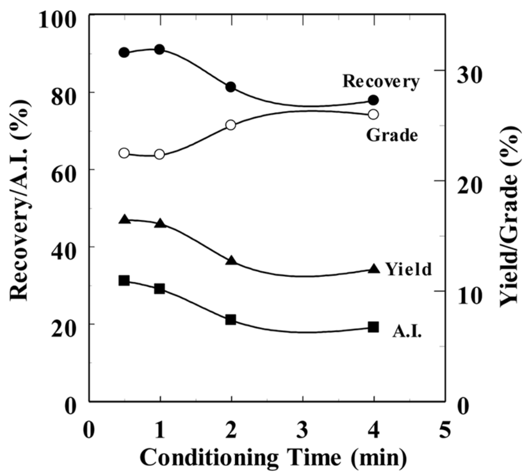

FIG. 3. Effect of binder conditioning time at 1200 rpm.

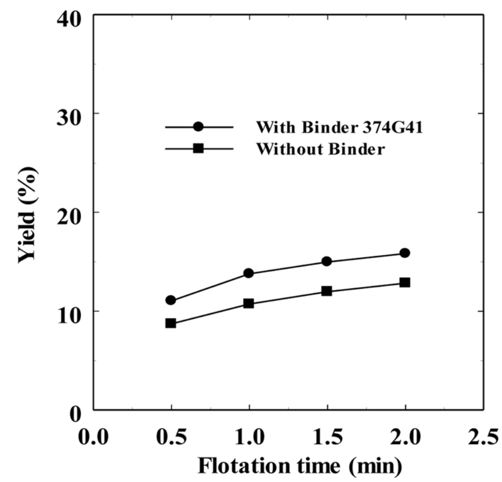

FIG. 5. Yield versus flotation time.

with a grade of 22.34% at 1.0 min. depressant conditioning time.

Flotation Separation Performance Curve Comparison

Figure 4 provides a comparison of the flotation separation performance curves obtained under different operating conditions with and without the clay binder. The data points that are closer to the upper right corner represent more efficient separations. One can see that use of binder generally provided higher recovery values (open symbols in Fig. 4) compared with the results achieved without the addition of the binder (solid symbols). Based on the difference in the best fitting lines, it can be concluded that the use of the clay binder improved the recovery by about 5–7% at a given concentrate grade.

Kinetic Flotation Tests with and without Georgia-Pacific Binder

To determine the effect of clay binders on the kinetic flotation performance curve, yield and recovery versus flotation time, kinetic flotation tests were performed with and without the clay binder. The results obtained with 0.25 lb/t clay binder and 3 lb/t collector are shown in Figs. 5 and 6 for a flotation period of 2 min.. It can be seen that the product yield and recovery obtained with and without the clay binder GP374G41 were higher with longer flotation time, which is in agreement with known flotation kinetics (more materials can be recovered with longer flotation time). It is more important to point out that the yield and recovery curves with the clay binder are always above those obtained without the clay binder. This clearly

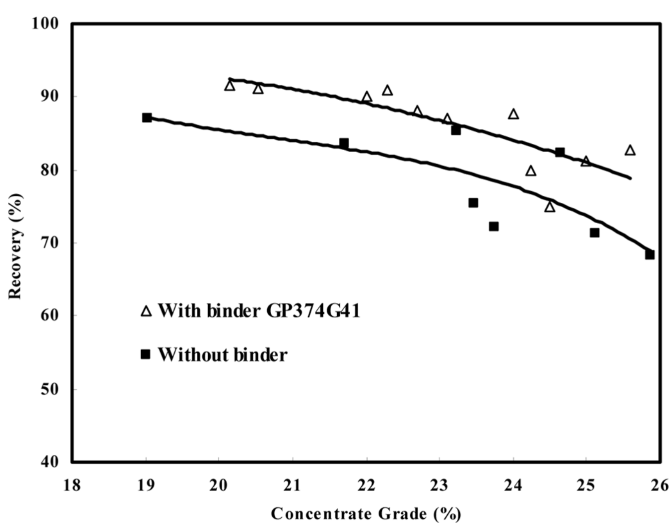

FIG. 4. Result comparison with and without clay binder.

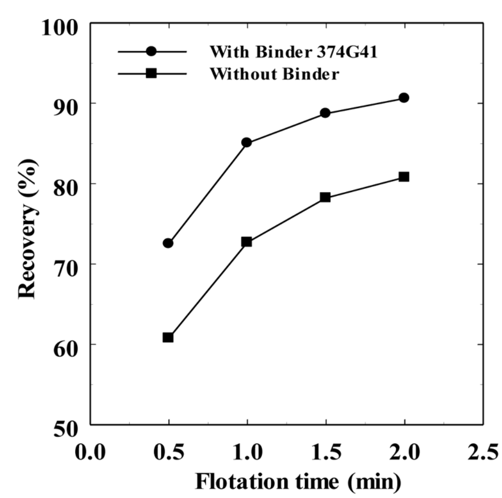

FIG. 6. Recovery versus flotation time.

indicates that the use of the clay binder increased the concentrate yield and P_2O_5 recovery at any given flotation time. The increase was about 2 to 3 absolute % points for yield and ten absolute % points for recovery. In other words, addition of the clay binder made the flotation process faster. It is believed that the removal of clay slime from phosphate surface increased phosphate hydrophobicity by exposing phosphate surface and agglomeration of clay particles in slurry-reduced clay surface area. This made more collector molecules available for adsorption on phosphate.

To quantify the improvement on flotation kinetics by the clay binder, the following data analyses were carried out with the above kinetic flotation data. Since flotation kinetics studies the variation in floated mineral mass as a function of flotation time, the algebraic relationship between floated mass and flotation time is a flotation rate equation when all other operational variables are kept constant during the test (1) proposed that the equation representing flotation kinetics can be expressed by analogy with chemical reaction kinetics as follows:

$$\frac{dC}{dt} = -k \cdot C^n$$

where C is the concentration of solids, t the flotation time, n the reaction order, and k is the flotation rate constant that depends on process variables such as particle hydrophobicity, aeration, reagent concentration, particle size, etc. Generally, flotation rate equation can be expressed as three different forms which are first-order equation (n = 1), second-order equation (n = 2) and a non-integral-order equation. Each of these three scenarios was studied by (4). The three equations are listed in Table 2.

In the present investigation, the flotation rate constants for the three models above were calculated and the results are shown in Table 3. It can be seen that although the first and second order models fit the data reasonably well, the non-integral order model best fits the experimental data since its correlation coefficient, r^2, is above 0.99 for both kinetic tests. These results are consistent with findings reported by other researchers such as Hernainz and Calero (6). Comparison of k values in Table 3 indicate that the use of the clay binder increased the flotation rate constant by 17.1%, 21.4%, and 13.2% for three different models.

TABLE 2
Equations for flotation kinetics

Order	Equation
First order (n = 1)	$\ln\frac{C_0}{C} = k_1 \cdot t$
Second order (n = 2)	$\frac{C_0}{C} = 1 + C_0 \cdot k_2 \cdot t$
Non-integral order	$\ln\frac{1}{1-\frac{R_q}{R_\infty}} = k_q \cdot t$

Where C_0: initial mass of mineral in the flotation cell; Rq: recovery % of mineral at time t; R_∞: recovery % of mineral at infinite time.

TABLE 3
Three models for flotation kinetics

	n = 1		n = 2		Non-integral	
Tests	k_1 (min^{-1})	R^2	k_2 (min^{-1})	r^2	k_q (min^{-1})	r^2
Without binder	0.0304	0.9681	0.0341	0.9704	1.5413	1
With binder	0.0356	0.9306	0.0414	0.9344	1.7452	0.9963

CONCLUSIONS

In this study, the feasibility of using clay binder as clay depressant in phosphate flotation was evaluated by performing flotation tests under different process conditions. It has been found that GP374G41 clay binder was an effective depressant for clay particles in phosphate flotation, and its addition to flotation slurry significantly improved phosphate flotation performance. For example, use of 0.1 lb/t GP374G41 clay binder increased P_2O_5 recovery from 82.25% to 87.75% while the concentrate grade was kept essentially constant. It was established that the clay binder dosage and conditioning time were two major parameters for the clay binder performance. With 1200 rpm impeller rotation speed, 2-min. flotation time, 2-min. depressant conditioning time and 0.25 lb/t dosage gave rise to optimum flotation performance of 16.09% yield, 91.01% recovery and 22.34% concentrate grade. A comparison of the flotation separation performance curves obtained with and without the clay binder indicates that use of the clay binder improved the recovery by about 5–7% at a given concentrate grade. It can also be concluded from the kinetic flotation studies that the flotation rate constant was increased considerably with the use of the clay binder and the non-integral order flotation model best fit the kinetic flotation data.

ACKNOWLEDGEMENTS

This study was supported financially by the Georgia Pacific Chemicals, LLC. Special thanks are given to Mosaic Company for providing phosphate samples, flotation reagents, and technical advice.

REFERENCES

1. Arbiter, N.; Harris, C.C. (1962) In: *Froth Flotation 50th Anniversary Volume*, Fuerstenau, D.W., ed.; AIME: Am Arloz, MI, pp. 215–246.

2. EI-Shall, H.; Sharma, R. (2001) Column flotation of Florida phosphate: An optimization study. *Minerals & Metallurgical Processing*, 18 (3): 142–146.
3. Gaudin, A.M.; Miaw, H.L. (1960) Slime coatings in galena flotation. *Transactions Canadian Inst. of Mining and Metallurgy*, 63: 668–671.
4. Hernainz, F.; Calero, M. (1996) Flotation rate of celestite and calcite. *Chem. Engr. Sci.*, 51: 119–125.
5. Hernainz, F.; Calero, M.; Blazquez, G. (2004) Flotation of low-grade phosphate ore. *Advanced Powder Technology*, 15 (4): 421–433.
6. Hernainz, F.; Calero, M.; Blazquez, G. (2005) Kinetic considerations in the flotation of phosphate ore. *Advanced Powder Technology*, 16 (4): 347–361.
7. Klassen, V.I.; Morkrousov, V.A. (1963) *An introduction to the theory of flotation*, Translated by Leja, J. Poling, G.W. Butterworth, London.
8. Sis, H.; Chander, S. (2003) Reagents used in the flotation of phosphate ores: a critical review. *Minerals Engineering*, 16: 577–585.
9. Stephen, M. Jasinski. (2003) Phosphate Rock, U.S. Geological Survey. *Mineral Commodity Summaries*.
10. Taggart, A.F.; Taylor, T.C.; Ince, C.R. (1930) *Transactions AIME*, 87: 285.
11. Tao, D.; Honaker, R.; Parekh, B.K. Development of picbubble flotation for enhanced recovery of coasrse phosphate particles. *FIPR Report*, 2006.
12. Tao, D.; Chen, G.; Fan, M.M. Enhanced coal and mineral flotation by selective clay agglomeration, *45th International Conference of Metallurgists*, Montreal, Canada, Oct 1–4, 2006.
13. Zhang, P.; Bogan, M. (1995) Recovery of phosphate from Florida beneficiation slimes I. re-identifying the problem. *Minerals Engineering*, 8 (4/5): 523–534.