

SELECTIVE FLOCCULATION OF PYRITE AND/OR SILICA IN THE PRESENCE OF COAL

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Abstract

Two cationic surfactants, Arquad T-50 and Duomac T, were investigated as possible selective flocculants or coagulants for iron pyrite or silica particles in the presence of particles of eastern bituminous coal. Although these surfactants were adsorbed by all three materials, they were found to promote the flocculation of pyrite and silica much more than the flocculation of coal when the solid materials were flocculated separately. In subsequent selective flocculation tests involving binary mixtures of the solid components, a good separation of coal and silica was achieved with Duomac T by agitating the flocculating suspension for a prolonged time. However, the separation of coal and pyrite proved more elusive. While some separation was achieved with Arquad T-50 because pyrite was flocculated more extensively than coal, the separation was marginal at best.

Introduction

There is an increasing need for industry to clean ultrafine-size coal, and one of the more promising methods for cleaning such coal is selective flocculation of either the organic material or the mineral matter (1). The principles and various applications of selective flocculation have been reviewed extensively (1-3). Much of the earlier work on this method as well as some of the recent work (4,5) has been based on the use of very long-chain, water-soluble organic polymers which act as bridging flocculants. Examples of such flocculants are polyacrylamide and polyethylene oxide polymers having a molecular weight of 10^6 or more. Recently some success has been achieved with completely hydrophobic, water-insoluble polymers which have a greater affinity for the organic portion of coal than have the water-soluble polymers (6-8). Another class of reagents, which may act as selective flocculants or coagulants, is comprised of ionic surfactants of much lower molecular weight than the polymeric flocculants. When the surfactants are adsorbed, they produce a hydrophobic coating on the coal or mineral particles (2). If the treated particles are brought into very close contact, they can stick together because of hydrophobic interaction. However, since this interaction involves very short-range forces, the effect of longer-range electrostatic repulsive forces may need to be minimized. Achieving rapid flocculation or coagulation of hydrophobic particles smaller than $10 \mu\text{m}$ in size may require the application of very high shear rates; hence, the term "shear flocculation" has been used to describe such a method (9).

In the work described below an attempt was made to selectively flocculate iron pyrite or silica in the presence of an eastern high volatile bituminous coal by employing a cationic surfactant. Pyrite and silica are two of the most common mineral impurities in coal and their removal has been difficult to achieve when they are finely disseminated. Of the two commercial surfactants selected for this study, Arquad T-50 is an alkyltrimethylammonium chloride in which the alkyl group is derived from tallow, and Duomac T is N-tallow derivative of 1,3-propanediamine diacetate. These surfactants were selected because long-chain amines are widely used as selective flotation collectors for quartz and silicate minerals due to their ability to render these materials hydrophobic (10-12). Unfortunately various amines

are also known to be adsorbed by coal, and some have been used as coal flocculants or coagulants (13-16). Therefore, it remained to be seen whether the chosen surfactants would be selective.

In order to see if the flocculants are adsorbed by the different materials, the zeta potential of coal, pyrite, and silica was measured in both the presence and absence of the surfactants. Flocculation tests were conducted with the materials individually using various surfactant concentrations and pH levels. Based on the flocculation characteristics of the individual materials, promising conditions for the selective flocculation of pyrite or silica in the presence of coal were selected and tested.

Experimental

Materials

Materials used in coagulation and flocculation experiments included a specially selected high volatile bituminous coal, iron pyrite, and silica. The coal sample was from the No. 2 gas seam in Raleigh County, West Virginia, and on a dry basis it had a fixed carbon content of 65%, volatile matter content of 33%, ash content of 2-3%, a total sulfur content of 1.0-1.5%, and a pyritic sulfur content of 0.2-0.3%. The coal appeared to be highly hydrophobic and was difficult to wet or disperse in water.

Floated silica powder was obtained from Fisher Scientific Company, and iron pyrite which originated in Huanzala, Peru, was obtained from Ward's Natural Science Establishment. X-ray diffraction analysis showed the silica to be pure quartz with no detectable impurities, and it showed the pyrite to be over 99.5% pure with only traces of silica, calcite, and alumina.

Coarse lumps of coal or pyrite were crushed and then ground. A ball mill containing stainless steel balls was used to grind the pyrite in a dry state. The ground pyrite was analyzed with a Leeds and Northrup Microtrac particle size analyzer which showed that 90% of the material was smaller than 16.6 μm . The coal and silica were ground separately with a high speed impact mill, and the products which passed through a screen with 38 μm openings were used for flocculation.

Arquad T-50 and Duomac T Diacetate were supplied by Armaq Chemicals and used as cationic flocculants. Arquad T-50 is a quaternary ammonium compound with the formula $\text{RN}(\text{CH}_2)_3\text{Cl}$ in which R represents alkyl groups of 14 to 18 carbon atoms derived from tallow. Duomac T is an acetic acid salt of an aliphatic diamine and has the formula $\text{RNH}(\text{CH}_2)_3\text{NH}_2 \cdot (\text{HOOCCH}_3)_2$ in which R represents alkyl groups of 12 to 18 carbon atoms also derived from tallow. The typical molecular weight of Arquad T-50 is 340 and that of Duomac T is 480. Deionized water having a resistivity of 18 megohm-cm was used in the experimental work; it was prepared by passing steam condensate through a Barnstead NANOpure II deionization system. The pH of the particle suspensions was adjusted by adding either reagent grade ammonium hydroxide or hydrochloric acid.

Methods

A cylindrical Plexiglas vessel having an inside diameter of 6 cm and height of 10 cm was used for coagulation and flocculation tests. The volume of the vessel was 250 ml, and the vessel was fitted with four vertical baffles which projected 0.7 cm into the vessel. An agitator with a variable-speed drive motor and a two-blade impeller having a diameter of 2.8 cm was used for stirring the contents of the vessel.

Flocculation tests were conducted by first dispersing either 1.0 or 2.0 g of material in 200 ml of water. If a single component was to be flocculated, 1.0 g was

used whereas if a two-component mixture was to be flocculated, 2.0 g were used. The slurry was stirred at 1700 rpm for 30 s to obtain a uniform suspension. The pH of the suspension was adjusted with either ammonium hydroxide or hydrochloric acid, and then the particles were redispersed by stirring at 1700 rpm for an additional 10 s. While stirring was continued at 1700 rpm, a dilute solution of the organic flocculant was added rapidly, whereupon the agitator speed was immediately reduced to 300 rpm and stirring was continued for 60 s. After stirring was stopped and the suspension had settled for 60 s, the clear supernatant liquid was decanted, and the remaining solids were recovered by filtration, dried, and weighed to determine the recovery or mass yield of flocculated material.

After treating a two-component mixture by the above procedure, the recovered solids were analyzed to determine the mass recovery of each component. For a coal/pyrite mixture this involved determining the total sulfur content of the flocculated product by means of a Fisher Sulfur Analyzer, and using a sulfur material balance to estimate the distribution of coal and pyrite in the product. For a coal/silica mixture, the ash content of the product was determined and used to estimate the distribution of coal and silica in the product.

For measuring the zeta potential of particles, a concentrated suspension was prepared first by mixing 1 g of material with 50 ml of 0.01 M potassium nitrate and stirring for 1 hr. Twenty drops of the concentrated suspension were subsequently diluted to 100 ml with 0.01 M potassium nitrate. The pH of the suspension was adjusted with either ammonium hydroxide or hydrochloric acid, and the suspension was stirred vigorously for 10 min. If the zeta potential of the material in the presence of a surfactant was to be determined, the requisite amount of surfactant was added and stirring was continued for 1 min. The suspension was allowed to sit overnight without stirring. The particles were resuspended by placing the mixture in an ultrasonic bath and then 20 readings of the zeta potential were made with a Zeta-Meter, system 3.0. The readings were averaged to obtain the reported value. Also the pH of the remaining suspension was redetermined and reported.

The surface of silica was characterized by measuring the induction time or time required for attachment of one or more particles of silica to a small gas bubble when brought into contact. The apparatus and procedure described by Yordan and Yoon (17) were used for this purpose. A short induction time is indicative of a hydrophobic surface, whereas a longer induction time is indicative of a hydrophilic surface.

Results and Discussion

Electrokinetic Properties

The measured zeta potentials of different materials in 0.01 M potassium nitrate are shown as a function of pH in Figure 1. For the bituminous coal the variation in zeta potential with pH was similar in general to that observed for other coals (18-21), and this variation has been attributed to the adsorption of positively charged hydronium ions at low pH and negatively charged hydroxyl ions at high pH (18). The nature of the zeta potential curve for pyrite suggests that the surface of the pyrite was oxidized, since similar curves were reported for oxidized pyrite by others (19,21). The zeta potential curve for unoxidized pyrite was reported to be monotonic with a single isoelectric point between pH 2 and 4. The zeta potential curve for silica was similar to that reported for quartz by Pugh (22).

When the zeta potential of the different materials was determined in a solution containing 20 ppm Arquad T-50, the results shown in Figure 2 were obtained. The large positive values of the zeta potential for coal and silica indicate that surfactant cations were adsorbed strongly by these materials over the pH range from 2 to 10. While results for pyrite were not as dramatic, they still confirm adsorption of the surfactant at both high and low pH where the zeta potential was

reversed because of adsorption. In the pH range from 3 to 10, the zeta potential of pyrite may not have been as high as that of the other materials because of competition for adsorption sites by potassium ions. Since sodium ions are known to be adsorbed by pyrite (23), it is anticipated that potassium ions would be adsorbed as well.

The results in Figure 3 indicate that Duomac T was also adsorbed strongly by the various materials over a wide pH range. The decline in zeta potential of the materials between pH 8 and 10 was probably due to a reduction in the dissociation of the diamine. The dissociation of amines is known to decrease between pH 8 and 10 whereas the dissociation of quaternary ammonium compounds remains high over the entire pH range. This would explain why the zeta potential of the materials declined at high pH in the presence of Duomac T but not in the presence of Arquad T-50.

The zeta potential of silica was found to be greatly affected by the concentration of Duomac T in the suspending medium (see Figure 4). The measurements were made at the natural pH of the suspension and showed that the zeta potential increased markedly as the concentration of Duomac T increased. These results again reflect adsorption of surfactant cations.

Flocculation of Individual Materials

The results of flocculating silica suspensions with different concentrations of Duomac T are presented in Figure 4. The recovery or yield of flocculated product increased with increasing concentrations of Duomac T until a concentration of 3 ppm was employed. At this point the silica recovery was 87% and further increases in flocculant concentration had little effect on the recovery. Interestingly, the zeta potential data for silica in Figure 4 show that silica was close to its isoelectric point when suspended in 3 ppm Duomac T. The correspondence between silica recovery and zeta potential for Duomac T concentrations up to 3 ppm suggest that a charge neutralization mechanism may have accounted for the type of flocculation which took place. On the other hand, when Duomac T concentrations of 20 ppm or more were applied, the zeta potential of silica was so high that electrostatic repulsion would create a formidable barrier to flocculation or coagulation. Nevertheless, a high recovery of silica was achieved which apparently was due to the hydrophobic coating imparted by the surfactant. The hydrophobicity of the treated silica was verified by measuring the induction time of both the treated and untreated material. Thus, the induction time of silica in water was 27.7 ms whereas in 20 ppm Duomac T it was 1.3 ms. This decrease in induction time indicates a large increase in hydrophobicity (17).

The hydrodynamics of the flocculation system may have been such that shear flocculation prevailed, since an increase in agitation time after the surfactant was added produced an increase in silica recovery. Thus with 0.5 ppm Duomac T the recovery increased from 54% for 1 min of agitation to 83% for 5 min of agitation and remained the same for up to 20 min of agitation. This type of behavior is not observed with electrolytic coagulation or polymeric flocculation where the flocs break up with prolonged agitation (9).

The effect of Duomac T concentration on silica recovery is further illustrated by the results presented in Figure 5 which show that the recovery decreased when the concentration was raised above 100 ppm. The same diagram also indicates the effect of Duomac T concentration on the recovery of pyrite and coal when these materials were treated separately at the natural pH of their respective suspensions. The maximum recovery of pyrite was achieved with a surfactant concentration of 20 ppm. Since the recovery of coal never exceeded 10%, little or no flocculation or coagulation of this material took place over the surfactant concentration range of 5 to 80 ppm. The results with coal suggest that adsorption of the surfactant cations may have reduced the hydrophobicity of the coal. This could have occurred if the

hydrophobic tails of the adsorbed cations were directed towards the surface and the hydrophilic head groups were directed away from the surface.

The effect of pH on the recovery of the different materials with 20 ppm Duomac T is shown in Figure 6. Again the materials were treated separately. While the recovery of silica remained high over the entire pH range, the recovery of pyrite was exceptionally large only between pH 4.5 and pH 10 and coal recovery peaked at pH 8-9. The maximum coal recovery was only 53% compared to a maximum recovery of about 90% for the other materials. The results indicated that it might be possible to selectively flocculate either silica or pyrite in the presence of the coal within the pH range from 2 to 6.

Flocculation results achieved when the different materials were flocculated individually with various concentrations of Arquad T-50 are presented in Figure 7. The maximum recovery of silica was obtained with 10-20 ppm Arquad T-50 and the maximum recovery of pyrite with 80 ppm at the natural pH of the suspension. The coal did not appear to be flocculated at any concentration of the surfactant within the range from 10 to 150 ppm.

The effect of pH on the recovery of the materials with 80 ppm Arquad T-50 is indicated by Figure 8. The recovery of silica and pyrite was high above pH 5, and while the recovery of coal never exceeded 25%, the best coal recovery was observed above pH 8. The results indicated that it might be possible to selectively flocculate either silica or pyrite in the presence of coal at pH 5-6.

Flocculation of Binary Mixtures

Mixtures of coal and either pyrite or silica were flocculated using conditions which would favor the selective flocculation of the inorganic material based on the preceding work. In some cases the coal constituted 90% of the mixture by weight whereas in other cases it constituted 50%. The mass recovery or yield of each component which was recovered in the settled material is given in Table 1. The separation efficiency as defined below is also indicated for each test.

$$\text{Separation Eff. (\%)} = \text{Mineral Recovery (\%)} - \text{Coal Recovery (\%)}$$

Although the percentage recovery of pyrite or silica was generally greater than the percentage recovery of coal, the difference in recovery was small so that the separation efficiency was low. The largest separation efficiency for a mixture of pyrite and coal was 26-27% which was achieved with 80 ppm Arquad T-50 at pH 4.6. Also, the highest separation efficiency for a mixture of silica and coal was only 9.7% which was obtained with 10 ppm Arquad T-50 at pH 4.9. Generally the recovery of one component of a binary mixture went hand in hand with the recovery of the other component, suggesting that the two materials underwent a process of mutual coagulation. Furthermore, in the case of silica/coal mixtures it appeared that the overall recovery was controlled by the relative amount of silica present. Thus, when a mixture containing 10% silica was flocculated, the recovery of either silica or coal was only 25-30%, whereas the recovery of each of these was generally over 80% when the initial mixture contained 50% silica. It is unlikely that electrostatic interaction would cause mutual coagulation of the particles since all of the solid components were charged positively in the presence of the cationic surfactants. On the other hand, the coal particles may have been physically entrapped in the pyrite or silica flocs (2). Also, the different solids may have been held together by hydrophobic association.

An interesting result was achieved when the time of agitation was extended after adding Duomac T to a suspension of silica and coal. As the data in Table 2 indicate, the recovery of silica increased while the recovery of coal decreased. Consequently by agitating the suspension for 20 min it was possible to obtain a separation efficiency of over 84%. However, when the same procedure was applied to

Table 1. Results of flocculating binary mixtures of particles with cationic surfactants

Particle mixture		Slurry pH	Surfactant		Recovery, %		Sepn. Eff., %
Materials	Ratio		Type	ppm	Mineral	Coal	
pyrite/coal	10/90	4.5	Duomac	20	76.0	64.9	11.1
pyrite/coal	50/50	4.5	Duomac	20	87.1	78.9	8.2
pyrite/coal	10/90	5.4	Arquad	10	53.0	36.3	16.7
pyrite/coal	10/90	4.6	Arquad	80	49.7	23.4	26.3
pyrite/coal	50/50	4.6	Arquad	80	54.9	28.1	26.8
pyrite/coal	50/50	6.0	Arquad	10	82.8	73.2	9.6
pyrite/coal	50/50	9.4	Arquad	10	82.0	78.0	4.0
silica/coal	10/90	4.5	Duomac	20	31.5	32.0	-0.5
silica/coal	10/90	1.5	Duomac	20	25.1	29.3	-4.2
silica/coal	50/50	1.5	Duomac	20	83.8	87.6	-4.8
silica/coal	50/50	4.9	Arquad	10	88.3	78.6	9.7
silica/coal	50/50	9.6	Arquad	10	76.0	72.8	3.2
silica/coal	50/50	6.0	Arquad	80	86.3	81.5	4.8
silica/coal	10/90	6.0	Arquad	80	29.6	25.5	4.1

Table 2. Results of flocculating binary mixtures of particles at pH 4-5 with 20 ppm Duomac T

Particle mixture		Agitation time, min.	Recovery, %		Sepn. Eff., %
Materials	Ratio		Mineral	Coal	
silica/coal	50/50	1	80.0	79.1	0.9
silica/coal	50/50	5	98.8	45.2	53.6
silica/coal	50/50	20	95.7	11.3	84.4
pyrite/coal	50/50	1	87.1	78.9	8.2
pyrite/coal	50/50	5	92.0	82.0	10.0
pyrite/coal	50/50	20	80.2	75.7	4.5

a suspension of pyrite and coal, no benefit was realized. Apparently the interaction between coal and silica particles was weaker than that between coal and pyrite particles. Further work is needed to explain these divergent results and to see whether the method can be extended to the separation of clay or shale and coal.

Conclusions

Two cationic surfactants, Arquad T-50 and Duomac T, were found to strongly promote the flocculation or coagulation of iron pyrite and silica particles while showing only a moderate tendency to promote the flocculation of an eastern bituminous coal. Selective flocculation tests showed that it is possible to achieve a good separation of coal and silica with Duomac T providing the particle suspension is agitated for a prolonged time after introducing the surfactant. However, an

extended treatment time did not benefit the separation of coal and pyrite, and the separation of these materials proved more elusive.

By observing the effect on the zeta potential it was shown that the surfactants were adsorbed by all three solid materials. Adsorption of Duomac T by silica greatly increased the hydrophobicity of this solid as indicated by a corresponding decrease in measured induction time. While charge neutralization could account for coagulation of silica in the presence of small concentrations of Duomac T, it is likely that in the presence of high concentrations hydrophobic interaction between particles plays a leading role in flocculation. The increased silica recovery achieved by prolonging the time of agitation is indicative of shear flocculation of hydrophobic particles. Further research is needed to account for the interaction between coal and silica or between coal and pyrite in the presence of the surfactants.

Acknowledgments

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Literature Cited

1. S. V. Krishnan, "Selective Flocculation of Fine Coal", in: Fine Coal Processing, S. K. Mishra and R. R. Klimpel (eds.), Noyes Publications, Park Ridge, New Jersey, 1987, pp. 160-178.
2. J. A. Kitchener, "Flocculation in Mineral Processing", in: The Scientific Basis of Flocculation, K. J. Ives (ed.), Sijthoff & Noordhoff, Aphen aan den Rijn, The Netherlands, 1978, pp. 283-328.
3. Shaning Yu and Y. A. Attia, "Review of Selective Flocculation in Mineral Separations", in: Flocculation in Biotechnology and Separation Systems, Y. A. Attia (ed.), Elsevier, Amsterdam, 1987, pp. 601-637.
4. L. Spencer and G. F. Brookes, "Polyacrylamides and Selective Flocculation of Coal/Shale Mixtures", Coal Preparation, 4, 133-159 (1987).
5. G. Barbery and P. Dauphin, "Selective Flocculation of Coal Fines", in: Flocculation in Biotechnology and Separation Systems, Y. A. Attia (ed.), Elsevier, Amsterdam, 1987, pp. 535-546.
6. Y. A. Attia, "Cleaning and Desulfurization of Coal Suspensions by Selective Flocculation", in: Processing and Utilization of High Sulfur Coals, Y. A. Attia (ed.); Elsevier, Amsterdam, 1985, pp. 267-285.
7. Y. A. Attia, Shaning Yu, and S. Vecchi, "Selective Flocculation Cleaning of Upper Freeport Coal with a Totally Hydrophobic Polymeric Flocculant", in: Flocculation in Biotechnology and Separation Systems, Y. A. Attia (ed.), Elsevier, Amsterdam, 1987, pp. 547-564.
8. L. Spencer, S. Thompson, and G. F. Brookes, "Hydrophobic Polymers in Coal Preparation", Proceedings of International Symposium on Innovative Plant and Processes for Minerals Engineering, Doncaster, UK, March 31-April 2, 1987, (The Minerals Engineering Society), pp. 173-193.
9. L. J. Warren, "Shear Flocculation", Chemtech, 11, 180-185 (1981).
10. J. Leja, Surface Chemistry of Froth Flotation, Plenum Press, New York, 1982.

11. R. W. Smith and S. Akhtar, "Cationic Flotation of Oxides and Silicates", in: Flotation, A. M. Gaudin Memorial Volume, Vol. 1, M. C. Fuerstenau (ed.), AIME, New York, 1976, pp. 87-116.
12. A. Bleier, E. D. Goddard, and R. D. Kulkarni, "The Structural Effects of Amine Collectors on the Flotation of Quartz", in: Flotation, A. M. Gaudin Memorial Volume, Vol. 1, M. C. Fuerstenau (ed.), AIME, New York, 1976, pp. 117-147.
13. P. J. Bethel and G. F. Brookes, "Reversibility of Long-chain Alkyl Amine Adsorption at the Coal Surface", Transactions of the Institution of Mining and Metallurgy, Sec. C, 86, C164-C165 (1977).
14. N. J. Miles, "Amines and their Applicability to Coal Flotation", Ph.D. Thesis, University of Nottingham, Nottingham, England, 1983.
15. G. F. Brookes and P. J. Bethel, "Zeta Potential, Contact Angle and the Use of Amines in the Chemical Dewatering of Froth-Floated Coal", Powder Technology, 40, 207-214 (1984).
16. J. R. Field, "Some Development Associated with Flocculants during the Last Decade", Coal Preparation, 4, 79-107 (1987).
17. J. L. Yordan and R. H. Yoon, "Induction Time Measurements for the Quartz-amine Flotation System", Preprint No. 86-105 for SME Annual Meeting, New Orleans, LA, March 2-6, 1986.
18. J. A. L. Campbell and S. C. Sun, "Bituminous Coal Electrokinetics", Transactions of the Society of Mining Engineers of AIME, 247, 111-122 (1970).
19. W. W. Wen and S. C. Sun, "An Electrokinetic Study on the Oil Flotation of Oxidized Coal", Separation Science and Technology, 16, 1491-1521 (1981).
20. D. W. Fuerstenau, J. M. Rosenbaum, and J. Laskowski, "Effect of Surface Functional Groups on the Flotation of Coal", Colloids and Surfaces, 8, 153-173 (1983).
21. S. Kelebek, T. Salman, and G. W. Smith, "An Electrokinetic Study of Three Coals", Canadian Metallurgical Quarterly, 21(2), 205-209 (1982).
22. R. J. Pugh, "Selective Coagulation in Quartz-Hematite and Quartz-Rutile Suspensions", Colloid & Polymer Science, 252, 400-406 (1974).
23. A. M. Gaudin and W. D. Charles, "Adsorption of Calcium and Sodium on Pyrite", Transactions AIME, 196, 195-200 (1953).

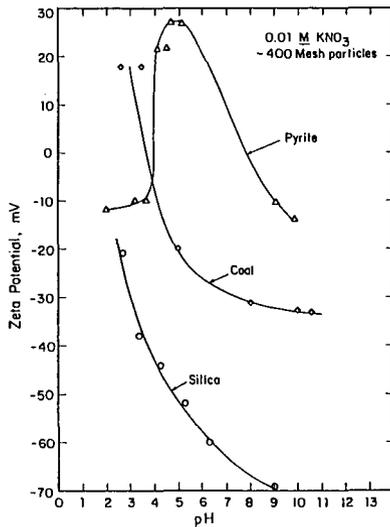


Figure 1. Zeta potential of coal, pyrite, and silica.

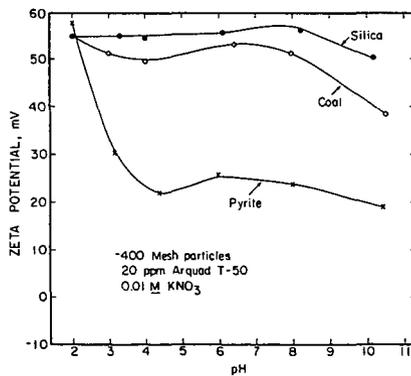


Figure 2. Zeta potential of different materials in the presence of Arquad T-50.

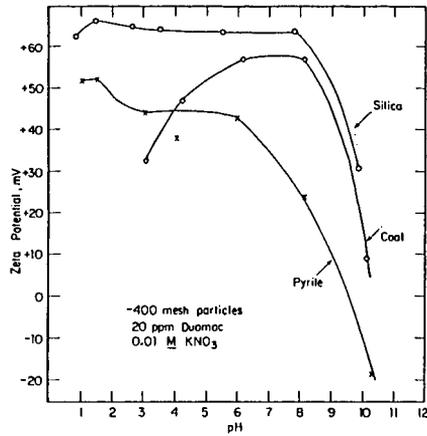


Figure 3. Zeta potential of different materials in the presence of Duomac T.

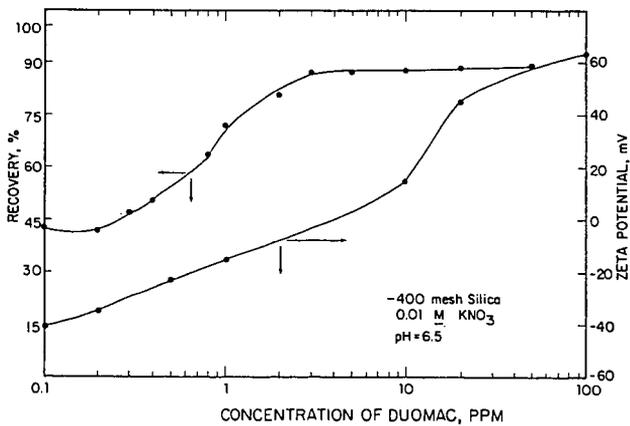


Figure 4. Effect of Duomac T concentration on the zeta potential and recovery of silica.

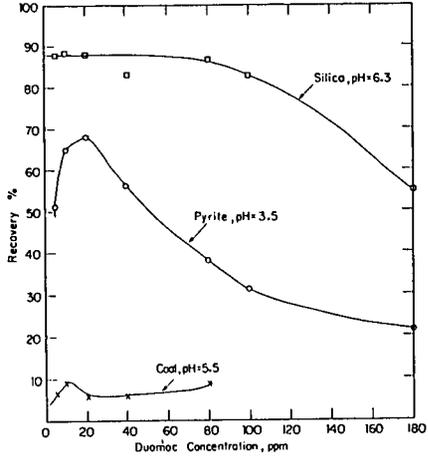


Figure 5. Effect of Duomac T concentration on the flocculation recovery.

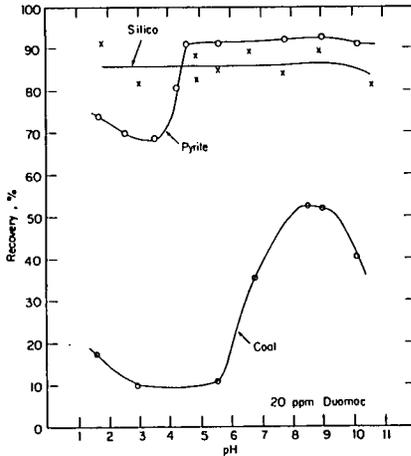


Figure 6. Effect of pH on the recovery of different materials with Duomac T.

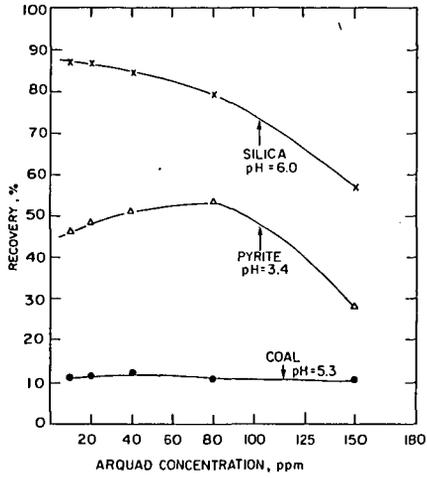


Figure 7. Effect of Arquad T-50 concentration on the flocculation recovery.

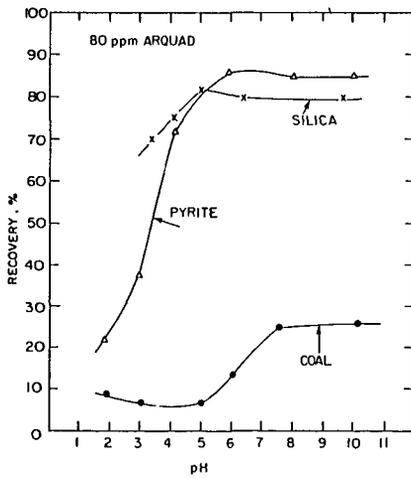


Figure 8. Effect of pH on the recovery of different materials with Arquad T-50.