Aqueous Biphasic Extraction for Processing of Fine Coal

Grant No. DE-FG22-96 PC96211

Semi-Annual Report

Reporting Period Start Date: 04/01/00

Reporting Period End Date: 10/01/00

**Principal Authors: K. Osseo-Asare, Professor of Metallurgy and
X. Zeng, Graduate Research Assistant**

Date Report was issued: 06/30/2001

DOE Award Number: DE-FG22-96 PC96211

**Submitting organization: Metals Science and Engineering Program
Department of Materials Science and Engineering
209 Steidle Building
Penn State University
University Park, PA 16802**

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

ABSTRACT

Ever-stringent environmental constraints dictate that future coal cleaning technologies be compatible with micron-size particles. This research program seeks to develop an advanced coal cleaning technology uniquely suited to micron-size particles, i.e., aqueous biphasic extraction. The partitioning behaviors of hematite in the dextran (Dex)/Triton X-100 (TX100) and polyethylene glycol (PEG)/dextran systems were investigated and the effects of some ionic surfactants on solid partition were studied. In both biphasic systems, the particles stayed in the bottom dextran-rich phase under all pH conditions. This behavior is attributable to the fact that the hydrophilic oxide particles prefer the more hydrophilic bottom phase. Also, the strong favorable interaction between dextran and ferric oxide facilitates the dispersion of the solids in the polysaccharide-rich phase. In the Dex/TX100 system, addition of sodium dodecylsulfate (SDS) or potassium oleate had no effect on the solid partition; on the other hand, addition of dodecyltrimethylammonium bromide (DTAB) transferred the particles to the top phase or interface at high pH values. In the PEG/Dex system, the preferred location of hematite remained the bottom phase in the presence of either SDS or DTAB. The effects of anionic surfactants on the partition behavior are attributable to the fact that they are not able to replace the strongly adsorbed polysaccharide layer on the ferric oxide surface. The results with the cationic surfactant are due to electrostatic interaction between the cationic surfactant and the charged surface of the solid particles. The difference in solids partitioning in the two systems is the result of the different distribution of DTAB in these systems. In the Dex/TX100 system, DTAB prefers the top surfactant-rich phase, while it concentrates in the bottom phase in the PEG/dextran system.

TABLE OF CONTENTS

Abstract.....	3
List of Figures.....	5
List of Tables.....	6
Executive Summary.....	7
Introduction.....	7
Results and Discussion.....	9
Conclusions.....	11
References.....	12
Publications Published/Submitted.....	13

LIST OF FIGURES

- Fig. 1 Chemical structure of Triton X-100.....14
- Fig. 2 Effect of pH on the partitioning behavior of hematite in the top phase of the Dextran/Triton X-100 system in the presence of DTAB. (Dextran: 9.0 wt%, Triton X-100: 11.0 wt%, silica: 2.0 g/L, DTAB: 1.0 g/L)..... 14

LIST OF TABLES

Table 1 Partitioning behavior of hematite in the dextran/Triton X-100 system. (Dex: 9.0 wt%, TX100: 11.0 wt%, hematite: 2.0 g/L).....	15
Table 2 Partitioning behavior of hematite in the PEG/dextran system. (PEG: 7.0 wt%, dextran: 16.8 wt%, hematite: 2.0 g/L).....	15

EXECUTIVE SUMMARY

The objective of this research project is to develop an aqueous biphasic extraction process for the treatment of fine coals. Aqueous biphasic extraction is an advanced separation technology and it relies on the ability of an aqueous system consisting of a water-soluble organic polymer and an inorganic salt to separate into two immiscible aqueous phases. Differences in the hydrophobic/hydrophilic properties of the particulates can then be exploited to effect selective transfers to either the top polymer-rich phase, or the bottom salt-rich phase. The goal of this experimental program is to identify process conditions that optimize the selective transfer of coal into the top phase while retaining the mineral matter in the bottom phase. An additional goal is to develop an improved coal-pyrite separation technique based on aqueous biphasic extraction.

The partitioning behaviors of hematite in the dextran (Dex)/Triton X-100 (TX100) and polyethylene glycol (PEG)/dextran systems were investigated and the effects of ionic surfactants on solid partition were studied. In both systems, the particles stayed in the bottom dextran-rich phase under all pH conditions. These trends are attributable to the fact that the hydrophilic oxide particles prefer the more hydrophilic bottom phase. Also, the strong interaction between dextran and ferric oxide favors the dispersion of the solids in the polysaccharide-rich phase. In the Dex/TX100 system, addition of sodium dodecylsulfate (SDS) or potassium oleate had no effect on the solid partition; on the other hand, addition of dodecyltrimethylammonium bromide (DTAB) led to transfer of the particles to the top phase or interface at high pH values. In the PEG/Dex system, the preferred location of hematite remained the bottom phase in the presence of either SDS or DTAB. Apparently, the anionic surfactants are unable to replace the strongly adsorbed polysaccharide layer on the ferric oxide surface. The results with cationic surfactant are due to electrostatic interaction between the cationic surfactant and the charged surface in solution. The difference in solids partitioning in the two systems is the result of the different distribution of DTAB in these systems. In the Dex/TX100 system, DTAB prefers the top surfactant-rich phase, while it concentrates in the bottom phase in the PEG/dextran system.

INTRODUCTION

Coal represents the largest source of fossil energy in the U.S. This resource also represents the most readily accessible and socially acceptable substitute for oil and natural gas. In response to the stipulations of the Clean Air Act (1), advanced coal cleaning technologies are needed in order to more efficiently eliminate unacceptable levels of ash and sulfur from the run-of-mine coal prior to combustion. The ability to achieve mineral matter liberation from coal is fundamental to all separation techniques that seek to produce super-clean coal. It has been concluded from the microscopic examination of a wide variety of U.S. coals that, in many cases, grinding to 10 μm or below may be necessary in order to achieve the necessary liberation (2). It is clear, therefore, that future advanced coal cleaning technologies must be capable of accommodating micron size particles.

This project seeks to investigate the feasibility of separating pyrite and mineral materials from fine coal by using aqueous biphasic extraction. Although aqueous biphasic systems have been known for more than 100 years, it was only in the mid 50s that their potential use as separation media was recognized. Albertsson, who pioneered the separation of microbial cells, cell organelles, and virus performed the initial work (3). In recent years, interest in aqueous biphasic extraction has broadened to applications in the commercial-scale separation of proteins (4-7), as well as separation of ultrafine particles (8-14), and metal ions (15-17). Chaiko et al. used aqueous biphasic extraction to remove radioactive residue from soil (9-13). Compared with conventional organic-solvent-based liquid-liquid extraction, aqueous biphasic extraction is especially attractive for waste treatment applications, because it avoids the use of an organic solvent which itself is a possible pollutant. In addition, the polymers used in aqueous biphasic systems are generally inexpensive, nontoxic, and biodegradable (9).

In our laboratory, work is in progress to apply aqueous biphasic systems as extraction media for ultrafine particle processing (18-20). The partitioning behavior of several inorganic particles, e.g., pyrite, hematite, silica, alumina, and titania, has been studied in PEG/Na₂SO₄ systems. As in conventional liquid-liquid extraction (21-23), the partition relies on the surface properties of the solids and the interfacial interactions between the particles and the surrounding liquid solution. The distribution of particles is dependent upon many factors, such as the surface hydrophilic/hydrophobic balance, solution pH, the nature and concentration of collectors (surfactants), and specific interaction between the polymer and the oxides.

Previous work in the literature has mainly focused on the partition of solids in polymer/salt aqueous biphasic systems; little work has been reported for other systems. The only available result of solid partition in polymer/polymer biphasic systems concerns the work of Baxter et al (14) who studied the partition of dispersed TiO₂ pigment and latex particles in the PEG/ poly(N-vinylpyrrolidone) (PVP) system. The results were greatly dependent upon the surface chemistry of the solid, i.e., the functional group on the particle surface. Partition was attributed to the specific interaction between the functional groups on the solid surface and the polymer chain. When treated with a dispersant containing carboxylate groups, TiO₂ preferred the PEG-rich phase. On the other hand, the pigments transferred to the PVP-rich phase if the functional group on the surface was the hydroxyl group.

In the available published literature, no research has been reported yet about the partition of inorganic particles in the polymer/surfactant system, although this system has been used in bioseparation (24-26). Since hematite partition in polymer/salt systems was studied previously (17-18), it was of interest to also investigate the partitioning behavior of hematite (α -Fe₂O₃) in polymer/polymer (PEG/Dex) and polymer/surfactant (Dex/TX100) systems. First, the partitioning behavior at different pH values is presented; then, the feasibility of applying electrostatic interaction to modify particle partition is considered. In polymer/nonionic surfactant systems, electrostatic interaction can have a significant effect on the distribution of biological materials (24-26). In these systems, a

weakly charged environment develops if an ionic surfactant is added which is concentrated in the top surfactant-rich phase. Thus, coulombic attraction or repulsion is produced between the surfactant-rich phase and charged proteins; therefore, the partitioning of proteins is affected by this electrostatic interaction (24-26).

RESULTS AND DISCUSSION

Partitioning Behavior of Hematite in the Dextran/Triton X-100 System

Effect of pH on hematite partition. Table 1 shows the partitioning behavior of hematite in the Dex/TX100 system at pH 3, 7, and 11. Under all the pH conditions, hematite stayed in the bottom polymer-rich phase. Like other metal oxides, hematite surface is covered by metal hydroxyl groups (Fe-OH), which make the surface hydrophilic. According to Albertsson's scale of relative hydrophilic/hydrophobic character, PEG is at the more hydrophobic end than dextran (3). Triton X-100 is a surfactant composed of a hydrocarbon chain and a chain of about 10 oxyethylene units which is the repeating unit of PEG, as shown in Figure 1. So, the solution of Triton X-100 is more hydrophobic than that of PEG. Hence, it is reasonable to deduce that the bottom dextran-rich phase is more hydrophilic than the top surfactant-rich layer. When solid particles are dispersed in aqueous biphasic systems, the surface hydrophilic/hydrophobic properties play a dominant role in the partitioning behavior if there is no specific interaction between the phase components and the solids. Therefore, if one only considers the hydrophilic/hydrophobic properties, then hematite particles prefer the more hydrophilic bottom phase, not the more hydrophobic top one.

It is known that dextran interacts strongly with ferric oxide in aqueous solution and can even solubilize the oxide to form iron-dextran complexes (27). The complexes are pharmaceutically important as synthetic substitutes for the iron storage protein ferritin, and it is used in the treatment of iron deficiency anaemias (28). Research shows that iron-dextran complexes are composed of an iron-based core with a dextran shell (27-31). At the same time, the adsorption of nonionic surfactants on metal oxides is believed to be a physical process through hydrogen bonding and van der Waals attraction force (32). Thus, it is reasonable to conclude that dextran has stronger interaction with hematite than TX100; hence, the particles prefer to stay in the bottom dextran-rich phase. From the above discussion, it can be seen that both hydrophilic/hydrophobic properties and specific polymer-solid interaction favor the distribution of hematite into the dextran-rich phase.

Effects of surfactants on hematite partition. Table 1 lists the experimental results of hematite partition in the dextran/Triton X-100 system at pH 3, 7, 11 in the presence of SDS, potassium oleate, and DTAB. Figure 2 shows the partitioning behavior of ferric oxide from pH 2 to 12 in the presence of DTAB. From Table 1, it can be seen that at all the pH values, SDS and oleate had no effect on hematite partition. A similar result was obtained with low concentration of DTAB (0.2-0.8 g/L). However, at higher concentrations (1.0 g/L), DTAB could modify the distribution of hematite particles. At high pH (pH 5, 8-11), the solids mainly stayed in the top TX100-rich phase, although

some material remained at the interface. It was very difficult to accurately separate solids at the interface from those in either the top phase or the bottom phase. Therefore, for convenience, the interfacial portion of the solids was generally combined with the solids in the top phase. At pH 4, the oxide particles mainly concentrated at the interface. In acidic solution (pH 2 and 3), the particles resided in the bottom phase, similar to the DTAB-free system. It needs to be noticed that at pH 6, 7, and 12, the system formed only one phase, not two phases. For these three pH values, no partition results are available.

The pH_{PZC} of ferric oxides is known to occur in the pH range from 5 to 8.6 (33). Below the pzc, the hematite surface is positively charged; the surface acquires a net negative charge above this pH. The uptake of SDS by hematite is believed to be a physical adsorption process (34-35), while oleate can chemisorb on this oxide (36-39). Although both of these surfactants can modify the surface chemistry of ferric oxide at certain pH values in conventional aqueous solutions, neither one changed the partitioning behavior of hematite in this polymer/surfactant system. Since dextran strongly interacts with ferric oxide (27-31), it appears that SDS or oleate is not able to replace the strongly adsorbed dextran layer on the hematite surface so that the particles continue to stay in the bottom phase.

In the Dex/TX100 system, ionic surfactants concentrate in the top phase and form mixed micelles with TX100 (24-26). It is known that cationic surfactants can adsorb on oxide surfaces above the pzc, through electrostatic attraction (40-42). Therefore, at high pH values, DTAB adsorbs on hematite surface through electrostatic attraction and transfers the particles from the bottom to the top phase. In acidic solution, DTAB cannot adsorb on the surface of ferric oxide due to coulombic repulsion, because both surfactant and solid surface are positively charged. Thus, the oxide surface is still covered with a dextran layer. Hence, the oxide remained in the bottom phase.

Partitioning Behavior of Hematite in the PEG/Dextran System

Effect of pH on hematite partition. Table 2 shows the partitioning behavior of hematite in the PEG/Dex system at pH 3, 7, 11. The solids stayed in the bottom dextran-rich phase under all the pH conditions.

This result is the same as that in the dextran/TX100 system, which can be explained by the same reasoning as that used in the polymer/surfactant system. From Albertsson's scale of relative hydrophilic/hydrophobic character, the bottom dextran-rich phase is more hydrophilic than the top PEG-rich layer (3). Therefore, the hydrophilic hematite particles prefer the bottom phase. At the same time, dextran interacts strongly with ferric oxide in aqueous solution (27-31). But, there is negligible adsorption of PEG on hematite (43-46). It is obvious that there is stronger interaction between dextran and hematite than between PEG and hematite, which renders the particles more compatible with the bottom dextran-rich phase. On the basis of both hydrophilicity/hydrophobicity and specific interaction, hematite is likely to stay in the bottom dextran-rich phase of the PEG/Dex system.

Effects of surfactants on hematite partition. Table 2 lists the results of hematite partition in the dextran/Triton X-100 system at pH 3, 7, 11 in the presence of SDS and DTAB. In all the experiments, the particles stayed in the bottom phase. The effect of SDS on the hematite partition in the PEG/dextran is the same as that in the dextran/Triton X-100 system. Like the polymer/surfactant system, it is difficult for SDS to replace the adsorbed dextran layer since dextran interacts with ferric oxide strongly (27-31) and SDS only adsorbs on the solid surface physically (34-35).

However, compared to the results in the dextran/Triton X-100 system, the presence of DTAB in the PEG/Dex system has a different effect. In the latter, the distribution of particles remains unchanged, i.e. the solids still occupied the bottom dextran-rich phase. The results from Save and Pangarkar (47) showed that when introduced into the PEG/dextran system, cationic surfactants preferred the dextran-rich phase, and anionic surfactants went into the PEG-rich phase. As discussed above, at high pH DTAB adsorbs on the oxide surface through attractive coulombic interaction. However, unlike the case of the Dex/TX100 system, the solids still stay in the bottom phase because DTAB also prefers the dextran-rich phase. At low pH, there is no DTAB adsorption due to electrostatic repulsion, and the surfaces are surrounded with a polysaccharide layer. As a result, the particles also stay in the bottom phase.

CONCLUSIONS

The principle behind the partition of inorganic particles in aqueous biphasic systems is the physicochemical interaction between the solid surface and the surrounding liquid solution. This study demonstrates that many factors, such as hydrophilic/hydrophobic properties, polymer-solid specific interaction, adsorption of surfactant on the solid surface, may influence the partition of metal oxides in aqueous biphasic systems.

The experimental results show that in both the dextran/Triton X-100 and PEG/dextran systems, hematite stays in the bottom dextran-rich phase under all pH conditions. In both systems, the bottom phase is more hydrophilic than the top layer; hence, the hydrophilic oxide particles prefer the dextran-rich phase. Also, the strong favorable interaction between dextran and ferric oxide favors the dispersion of the solids in the polysaccharide-rich phase.

In the Dex/TX100 system, addition of SDS or oleate has no effect on the solid partition; on the other hand, DTAB can transfer the particles to the top phase or interface at high pH values. In the PEG/Dex system, the preferred location of hematite remains the bottom phase in the presence of either SDS or DTAB. The effects of anionic surfactants on the partition behavior are attributable to the fact that they are not able to replace the strongly adsorbed polysaccharide layer on the ferric oxide surface. The results with cationic surfactant are due to electrostatic interaction between the cationic surfactant and the charged surface in solution. The difference in solids partitioning in the two systems is the result of the different distribution of DTAB in these systems. In the Dex/TX100

system, DTAB prefers the top surfactant-rich phase, while it concentrates in the bottom phase in the PEG/dextran system.

REFERENCES

1. Asst. Sec. of State for Fossil Energy, *Clean Coal Technology: The New Coal Era*, U. S. Department of Energy, June, **1990**
2. M. J. Mankosa, G. F. Adel, and R. H. Yoon, *Powder Tech.*, **1986**, 49: 75
3. P. A. Albertsson, *Partition of Cell Particles and Macromolecules*, 3rd. ed., Wiley-Interscience: New York, **1986**
4. H. Walter, D. E. Brooks, and D. Fisher (Eds.), *Partitioning in Aqueous Two-Phase Systems*, Academic Press: New York, **1985**
5. B. Y. Zaslavsky, *Aqueous Two-Phase Partitioning*, Marcel Dekker Inc., New York, **1995**
6. R. D. Rogers, and M. A. Eiteman Eds., *Aqueous Biphasic Separations*, Plenum Press, New York, **1995**
7. H.-K. Rajni Eds., *Aqueous Two-Phase Systems*, Humana Press, New Jersey, **2000**
8. K. P. Ananthapadmanabhan, and E. D. Goddard, *U. S. Patent* 47,225,358, **1987**
9. D. J. Chaiko, R. Mensah-Biney, C. J. Mertz, and A. Rollins, *Sep. Sci. Technol.*, **1993**, 28: 765
10. D. J. Chaiko, and R. Mensah-Biney, *U. S. Patent* 5,411,149, **1995**
11. D. J. Chaiko, and R. Mensah-Biney, *U. S. Patent* 5,625,862, **1997**
12. D. J. Chaiko, Deepak, J. Gartelmann, Y. Vojta, E. Thuillet, and C. J. Mertz, in: K. L. Nash, and G. R. Choppin (Eds.), *Separation of f-Elements*, Plenum Press, NY, **1995**: 225
13. D. J. Chaiko, R. Mensah-Biney, and E. Van Deventer, *Report ORNL-6762*, Oak Ridge National Laboratory, Oak Ridge, TN, **1993**
14. S. M. Baxter, P. R. Sperry, and Z. Fu, *Langmuir*, **1997**, 13: 3948
15. R. D. Rogers, A. H. Bord, C. B. Bauer, *Sep. Sci. Technol.*, **1993**, 28: 1091
16. D. J. Chaiko, T. A. Hatton, B. Zaslavsky, in: K. C. Liddell and D. J. Chaiko (Eds.), *Metal Separation Technology Beyond 2000*, The Minerals, Metals, and Materials Soc., Warrendale, PA, **1999**: 167
17. E. Visser, S. T. Griffin, C. C. Ingenito, D. H. Hartman, J. G. Huddleson, R. D. Rogers, in: K. C. Liddell and D. J. Chaiko (Eds.), *Metal Separation Technology Beyond 2000*, The Minerals, Metals, and Materials Soc., Warrendale, PA, **1999**: 119
18. K. Osseo-Asare and X. Zeng, *Intern. J. Miner. Proc.*, **2000**, 58: 319
19. K. Osseo-Asare and X. Zeng, in: K. C. Liddell and D. J. Chaiko (Eds.), *Metal Separation Technology Beyond 2000*, The Minerals, Metals, and Materials Soc., Warrendale, PA, **1999**: 347
20. X. Zeng and K. Osseo-Asare, *Coll. Surf. A*, **2001**, 177: 247
21. R. W. M. Lai, D. W. Fuerstenau, *Trans. AIME*, **1968**, 241: 549
22. E. Kusaka, Y. Kamata, Y. Fukunaka, and Y. Nakahiro, *Coll. Surf. A*, **1998**, 139: 155
23. C.-A. Ku, J. D. Henry Jr., R. Siriwardane, and L. Roberts, *J. Coll. Interf. Sci.*, **1985**, 106: 377
24. U. Sivars, K. Bergfeldt, L. Piculell, and F. Tjerneld, *J. Chrom. B*, **1996**, 680: 43

25. U. Sivars, and F. Tjerneld, *Biochim. Biophys. Acta*, **2000**, 1474: 133
26. U. Sivars, J. Abramson, S. Iwata, and F. Tjerneld, *J. Chrom. B*, **2000**, 743: 307
27. M. I. Oshtrakh, V. A. Semionkin, O. B. Milder, A. B. Livshits, and A. A. Kozlov, *Z. Naturforsch.*, **2000**, 55a: 186
28. S. H. Kilcoyne, and J. L. Lawrence, *Z. Kristallogr.*, **1999**, 214: 666
29. S. H. Kilcoyne, and B. Webster, *Magn. Reson. Chem.*, **2000**, 38: S20
30. S. H. Kilcoyne, and A. Gorisek, *J. Magn. Magn. Mater.*, **1998**, 177-181: 1457
31. B. Knight, L. H. Bowen, R. D. Bereman, S. Huang, and E. D. Grave, *J. Inorg. Biochem.*, **1999**, 73: 227
32. W. Kwok, H. A. Nasr-El-Din, R. E. Hayes, and D. Sethi, *Coll. Surf. A*, **1993**, 78: 193
33. G. A. Parks, *Chem. Rev.*, **1965**, 65: 177
34. H. L. Shergold and O. Mellgren, *Trans. Inst. Min. Metall.*, **1968**, 78: C121
35. D. W. Fuerstenau and M. Colic, *Coll. Surf. A*, **1999**, 146: 33
36. M. C. Fuerstenau, R. W. Harper, and J. D. Miller, *Trans. AIME*, **1970**, 247: 69
37. O. Ofor, *J. Coll. Interf. Sci.*, **1996**, 179: 323
38. R. D. Pasco and E. Doherty, *Intern. J. Miner. Proc.*, **1997**, 51: 269
39. K. N. Han, T. W. Healy, and D. W. Fuerstenau, *J. Coll. Interf. Sci.*, **1973**, 44: 407
40. D. W. Fuerstenau, in: P. Somasundaran (Eds.), *Fine Particles Processing*, AIME, New York, **1980**: 669
41. R. Sivamohan, *Int. J. Miner. Process.*, **1990**, 28: 247
42. D. W. Fuerstenau, S. Chander, and A. M. Abouzeid, in *Beneficiation of Mineral Fines*, P. Somasundaran and N. Arbiter Eds., AIME, **1979**: 3
43. S. Mathur, and B. M. Moudgil, *Miner. Metall. Proc.*, **1998**, 15:24
44. S. Mathur, and B. M. Moudgil, *J. Coll. Interface Sci.*, **1997**, 196:92
45. E. Koksai, R. Ramachandran, P. Somasundaran, and C. Maltesh, *Powder Tech.*, **1990**, 62:253
46. Z. Sadowski, and R. W. Smith, *Miner. Metall. Proc.*, **1985**, 2:217
47. S. V. Save, and V. G. Pangarkar, *Bioseparation*, **1995**, 5: 27

PUBLICATIONS PUBLISHED/SUBMITTED

1. K. Osseo-Asare and X. Zeng, "Aqueous Biphasic Extraction of Particulates: Controlling the Hydrophilic-Hydrophobic Balance for Separation", in: K. C. Liddell and D. J. Chaiko (Eds.), *Metal Separation Technologies Beyond 2000*, The Minerals, Metals, and Materials Soc., Warrendale, PA, **1999**, p. 347-356
2. K. Osseo-Asare and X. Zeng, "Partition of Pyrite in Aqueous Biphasic Systems", *Intern. J. Miner. Proc.*, **2000**, 58: 319-330
3. X. Zeng and K. Osseo-Asare, "Partition of Pyrite and Hematite in Aqueous Biphasic Systems: Effects of pH and Surfactants", *Coll. Surf. A*, **2001**, 177: 247

Figure 1. Chemical structure of Triton X-100.

Figure 2. Effect of pH on the partitioning behavior of hematite in the top phase of the Dextran/Triton X-100 system in the presence of DTAB.
(Dextran, 9.0 wt%; Triton X-100, 11.0 wt%; silica, 2.0 g/L; DTAB, 1.0 g/L)

Table 1. Partitioning behavior of hematite in the dextran/Triton X-100 system.
(Dex: 9.0 wt%, TX100: 11.0 wt%, hematite: 2.0 g/L)

Surfactant	pH 3	pH 7	pH 11
No surfactant	Bottom phase	Bottom phase	Bottom phase
1.0 g/L SDS	Bottom phase	Bottom phase	Bottom phase
1.0 g/L Oleate	Bottom phase	Bottom phase	Bottom phase
0.2 g/L DTAB	-	-	Bottom phase
0.4 g/L DTAB	-	-	Bottom phase
0.8 g/L DTAB	-	-	Bottom phase
1.0 g/L DTAB	Bottom phase	-	Mainly top phase, some at interface

Table 2. Partitioning behavior of hematite in the PEG/dextran system.
(PEG: 7.0 wt%, dextran: 16.8 wt%, hematite: 2.0 g/L)

Surfactant	pH 3	pH 7	pH 11
No surfactant	Bottom phase	Bottom phase	Bottom phase
1.0 g/L SDS	Bottom phase	Bottom phase	Bottom phase
1.0 g/L DTAB	Bottom phase	Bottom phase	Bottom phase