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POC-SCALE TESTING OF AN ADVANCED FINE COAL DEWATERING EQUIPMENT/TECHNIQUE

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EXECUTIVE SUMMARY

Economical dewatering of an ultra-fine clean coal product to a 20 percent or lower level moisture will be an important step in successful implementation of the advanced fine coal cleaning processes. This project is a step in the Department of Energy's program to show that ultra-clean coal could be effectively dewatered to 20 percent or lower moisture using either conventional or advanced dewatering techniques.

The cost-sharing contract effort is for 36 months beginning September 30, 1994. This report discusses technical progress made during the quarter from April 1 to June 30, 1995.

OBJECTIVES AND SCOPE OF THE PROJECT

The main objective of the proposed program is to evaluate a novel surface modification technique, which utilizes the synergistic effect of metal ions-surfactant combination, for dewatering of ultra-fine clean coal on a proof-of-concept scale of 1 to 2 tph. The novel surface modification technique developed at the UKCAER will be evaluated using vacuum, centrifuge, and hyperbaric filtration equipment. Dewatering tests will be conducted using the fine clean coal froth produced by the column flotation units at the Powell Mountain Coal Company, Mayflower Preparation Plant in St. Charles, Virginia. The POC-scale studies will be conducted on two different types of clean coal, namely, high sulfur and low sulfur clean coal. The Mayflower Plant processes coals from five different seams, thus the dewatering studies results could be generalized for most of the bituminous coals.

APPROACH

The project team consist of the University of Kentucky Center for Applied Energy Research (UKCAER), Powell Mountain Coal Company (PMCC) and Andritz Ruthner Inc.

The UKCAER is the prime contractor of the project which has been divided into nine (9) tasks. The clean coal froth generated by the 'Ken-Flote' columns at the PMCC Mayflower Preparation Plant will be utilized for dewatering studies using hyperbaric, centrifuge and vacuum dewatering techniques.

ACCOMPLISHMENTS DURING THE QUARTER

During this quarter, addition of reagents such as ferric ions and a novel concept of in-situ polymerization (ISP) was studied in the laboratory. Using the ISP approach with vacuum filtration provided 25% moisture filter cake compared to 65.5% moisture obtained conventionally without using the ISP.

A series of dewatering tests were conducted using the Andritz hyperbaric pilot filter unit with high sulfur clean coal slurry. The test identified that using 3 bar (43.5 psi) pressure at 1.5 rpm filter speed and 165° cake formation angle, a filter cake of 18 mm thick with 23.6 percent moisture could be obtained. Under these conditions, the solids throughput was 165 lb/ft^2/hr and air consumption was 460 scfm/ton. In the POC-Scale testing, dewatering tests conducted using flocculants provided higher moisture content than that obtained without addition of flocculants. Among the surfactants only the cationic and non-ionic lowered the filter cake moisture; about 1.5 Kg/t of anionic surfactant lowered filter cake moisture from 21% to 16%, and 0.5 Kg/t of the cationic surfactant lowered moisture from 22.5% to 19.5%. Addition of 25 ppm copper ions lowered filter cake moisture from 23% to 21%. Addition of surfactant along with metal ions did not provide a significant reduction in moisture content of filter cakes.

INTRODUCTION

For cleaning of coal finer than 0.5 mm (28 mesh) processes based on surface chemical technique such as froth flotation and oil agglomeration are the most effective. However, froth flotation process, which is commercially used, produces a product containing 80 percent moisture. Column flotation technique, which provides higher recovery of low ash product, also produces a high moisture product. Dewatering of the fine coal to a low (~20 percent) moisture level using conventional filtration equipment has not been possible. This project offers a novel surface-modification approach to modify coal surface so it could dewater to a low moisture level using either conventional or advanced dewatering equipment. The surface modification approach has provided significant reduction in filter cake moisture in laboratory studies at University of Kentucky Center for Applied Energy Research.

The aim of this program is to test the UKCAER-developed novel coal surface modification approach on a pilot scale at the rate of 1-2 tph of solids using vacuum, centrifuge and hyperbaric filtration technique. This proof-of-concept testing is being performed at the Powell Mountain Coal Company Mayflower Plant located in Lee County, St. Charles, Virginia.

The project involves a teaming arrangement between the University of Kentucky for Applied Energy Research (CAER), the Powell Mountain Coal Company (PMCC), and the Andritz Ruthner Inc. (ARI). The project will extend for a period of 36 months.

APPROACH

A team of scientists and engineers from the Center for Applied Energy Research, Powell Mountain Coal Company, and Andritz Ruthner Inc. has been formed to accomplish the objectives of the program. Each team member brings fine particle dewatering knowledge and experience to the project. The UKCAER, who is the prime contractor, will manage the project and will conduct the major part of the study. The PMCC will provide assistance and facility in conducting the pilot scale tests, and ARI will conduct laboratory dewatering tests and also pilot scale tests using the hyperbaric pressure filtration unit at the PMCC. Figure 1 shows the project organization chart. The up-to-date project schedule for the first two years of the program is shown in Figure 2.

The CAER collected clean coal froth samples from the Mayflower plant for the laboratory studies. Samples of clean coal slurries were also sent to ARI for studies using their laboratory scale hyperbaric unit. At both organizations, emphasis will be given to identify optimum process and operating conditions using vacuum and pressure techniques to dewater the clean coal slurry to about 20 percent level moisture. It is believed that the proposed research can achieve low moisture product on a pilot scale to the same extent which has already been achieved in laboratory studies.

The basic components of the process has been tested in laboratory. The purpose of the proposed work here is to evaluate all of the component steps on a consistent basis, and, to the extent possible in laboratory studies, demonstrate the feasibility of their integration. The outcome of this program will be to identify a process/technique combination which is able to achieve a 20 percent or lower moisture in the fine clean coal product and to provide technical and economic

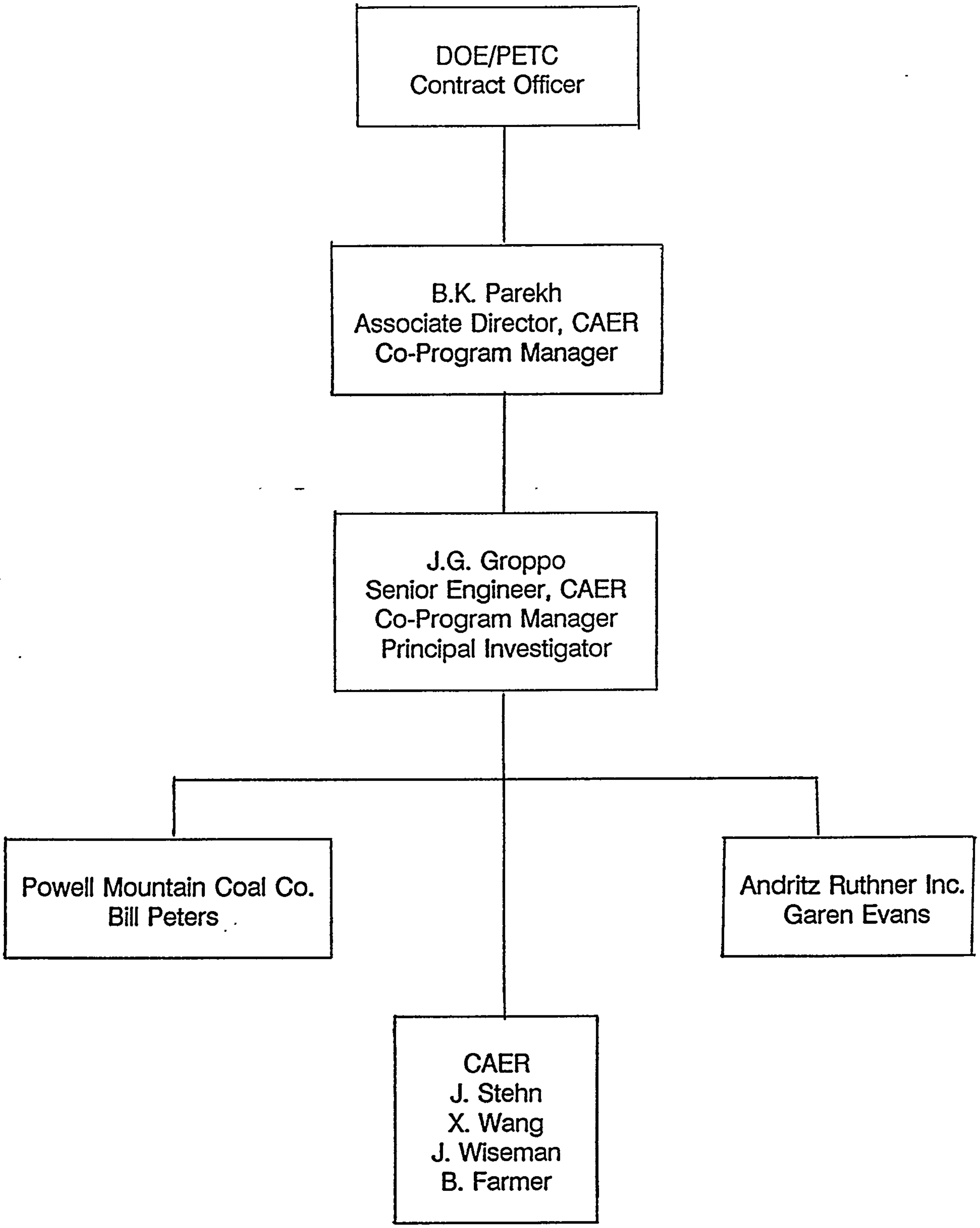

Figure 1. Project management organization chart

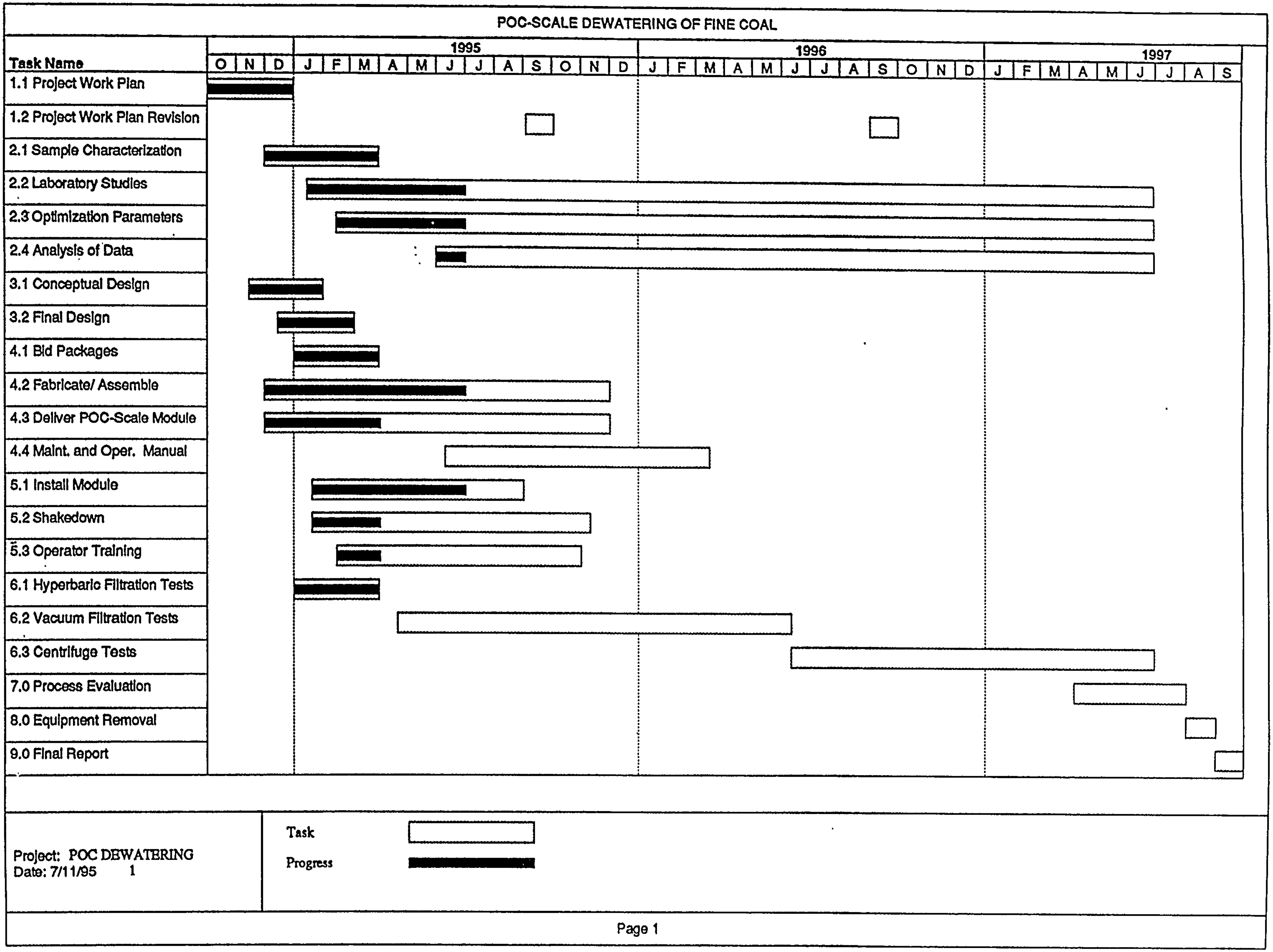

Figure 2. Up-to-date project schedule.

evaluation of the integrated concept in sufficient detail for a coal company to decide to install the dewatering process in their plant.

ACCOMPLISHMENTS DURING THE QUARTER

Table 1 lists the tasks and subtasks of the project. Each task and subtask has specific objective which can be inferred from its title. During this quarter (April 1 to June 30, 1995) work was done on Tasks 2, 4 and 6.

Task 2. Sample Analysis and Laboratory Testing:

Additional laboratory dewatering tests were conducted using the Powell Mountain clean coal slurry with average particle size of 25 μm and 32 μm for the high and low sulfur clean coal slurries, respectively.

During this period, efforts were devoted into two major aspects in the laboratory studies: (1) the effects of addition of ferric salts on the filtration behavior and final moisture content; and (2) novel concept of "in-situ polymerization" for enhancing fine coal dewatering. All the filtration tests were conducted with the PMCC compliance (low-sulfur) clean coal slurry at pre-selected pressures and natural pH. The cake thickness was kept constant at about 15 mm.

Effect of Addition of Ferric Ions on Dewatering

Ferric salts were selected in the present studies, since compared with other metal ions used in previous studies, such Cu^{+2} and Al^{3+}, ferric salts have more advantages, including less costly, more environmentally-friendly, and no pH adjustment required. Figure 3 shows the effects of addition of various dosages of $FeCl_3$ on the moisture content. The effect of filter medium on the dewatering efficiency is also compared. It can be seen that the addition of ferric chloride effectively reduces

Table 1. Outline of Work Breakdown Structure

Task 1.	Project Work Planning	
	Subtask 1.1	Project Work Plan
	Subtask 1.2	Project Work Plan Revisions
Task 2.	Samples Analysis and Laboratory Testing	
	Subtask 2.1	Acquisition and Characterization of Samples
	Subtask 2.2	Laboratory Scale Testing
	Subtask 2.3	Optimization of Parameters
	Subtask 2.4	Analysis of Data
Task 3.	Engineering Design	
	Subtask 3.1	Conceptual Design Package
	Subtask 3.2	Final Design Package
	Subtask 3.3	Construction Schedule
Task 4.	Procurement and Fabrication	
	Subtask 4.1	Bid Packages
	Subtask 4.2	Fabricate/Assemble Components
	Subtask 4.3	Deliver POC-Scale Module and Install
	Subtask 4.4	Maintenance and Operating Manual
Task 5.	Installation and Shakedown	
	Subtask 5.1	Install and Tie-in Module
	Subtask 5.2	Startup Procedures/Shakedown
	Subtask 5.3	Operators Training
Task 6.	System Operation	
	Subtask 6.1	Test Coal No. 1
	Subtask 6.2	Test Coal No. 2
Task 7.	Process Evaluation	
Task 8.	Equipment Removal	
Task 9.	Reporting	
	Subtask 9.1	Monthly Reports
	Subtask 9.2	Project Final Report

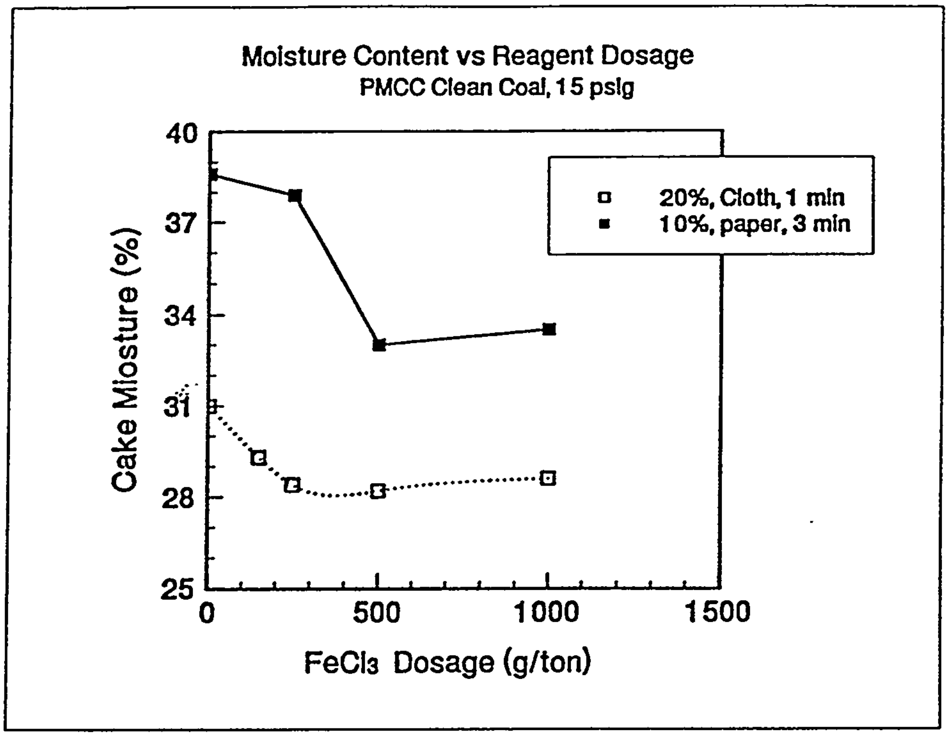

Figure 3. Effect of ferric chloride and filter medium on the moisture content of the PMCC low sulfur coal at 15 psi pressure.

the moisture content in both cases. When the Andritz filter cloth is used, the cake moisture is reduced from 31% to 28% at a dosage of 250 g/ton. When laboratory filter paper is used, the moisture content is reduced from 39% to 32% at a dosage of 500 g/ton. Compared with the results of previous studies using copper and aluminum salts, the dosage of ferric salts is considerably lower for the same amount of moisture reduction. In addition, no pH adjustment is required. Figure 4 shows the moisture content as a function of filtration time in the presence of various concentrations of ferric chloride when filter paper is used as the filter medium. It can be seen that the cake formation is about 120 seconds without adding ferric chloride. After conditioning

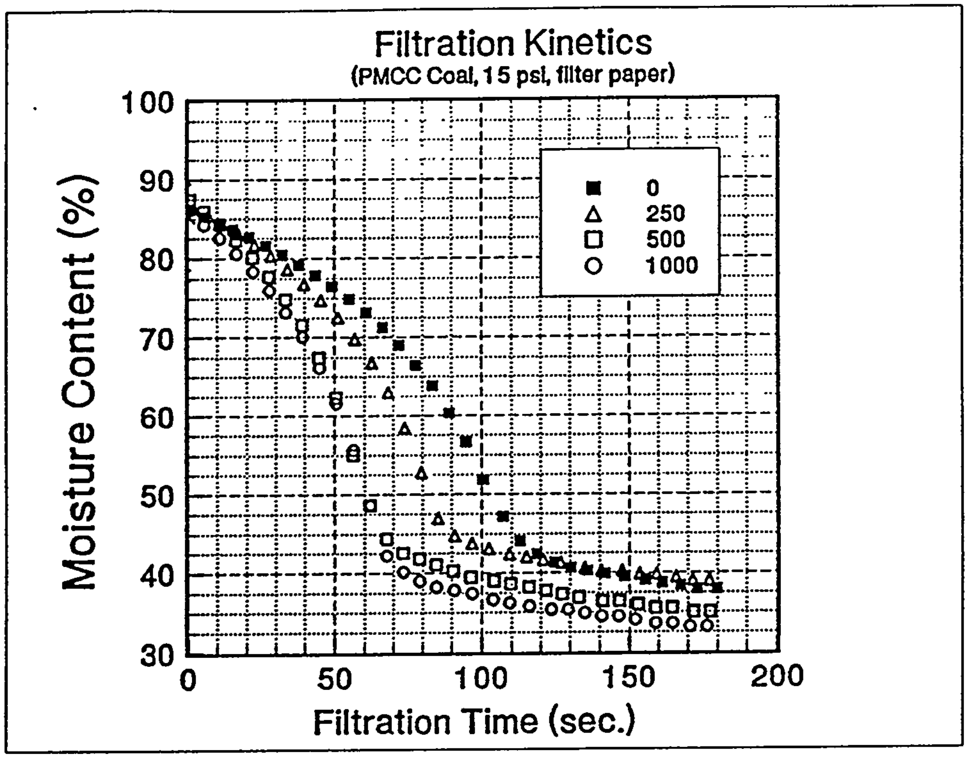

Figure 4. Moisture content as a function of filtration time in the presence of 0, 250, 500 and 1000 g/ton of ferric chloride, respectively, when filter paper is used.

with 500 g/ton $FeCl_3$, the cake formation time is reduced to 60 seconds. This indicates that ferric chloride can greatly enhance the filtration kinetics. Similar results were obtained with high pressure filtration. Figure 5 shows the moisture content as a function of ferric chloride dosage at 40 psi. Without addition of ferric chloride, the cake moisture after 2 min. filtration is about 21.5%. At a dosage of 300 g/ton ferric chloride, the moisture content is reduced to less than 19%.

The filtration kinetics have been carefully examined in order to understand the mechanisms of the enhanced coal filtration/dewatering by ferric

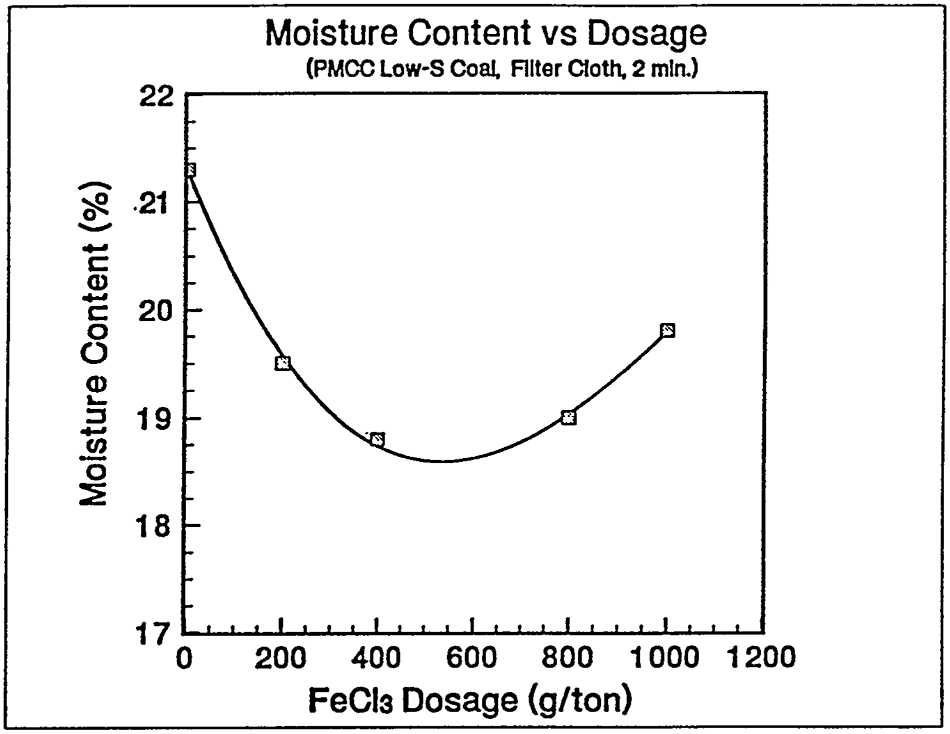

Figure 5. Moisture content as a function of ferric chloride dosage for the PMCC low-sulfur coal filtration at 40 psi. (Other conditions: 2 min. total filtration time; filter cloth)

chloride. Figures 6 and 7 show the Darcy-Konzey plot(t/V vs V) for the filtration at a pressure of 15 psi (i.e., vacuum) when the two different filter media are used. It can be seen that straight lines are obtained for all the dosages. Interestingly, all the lines are essentially parallel, that is, they have the same slope. This suggests that the specific cake resistance remains unchanged when ferric chloride is present. However, the intercept decrease with increasing the dosage of ferric chloride, indicating that the addition of ferric chloride reduces the medium resistance. As has been shown in the previous reports, the medium resistance of the studied coal plays a key role in the

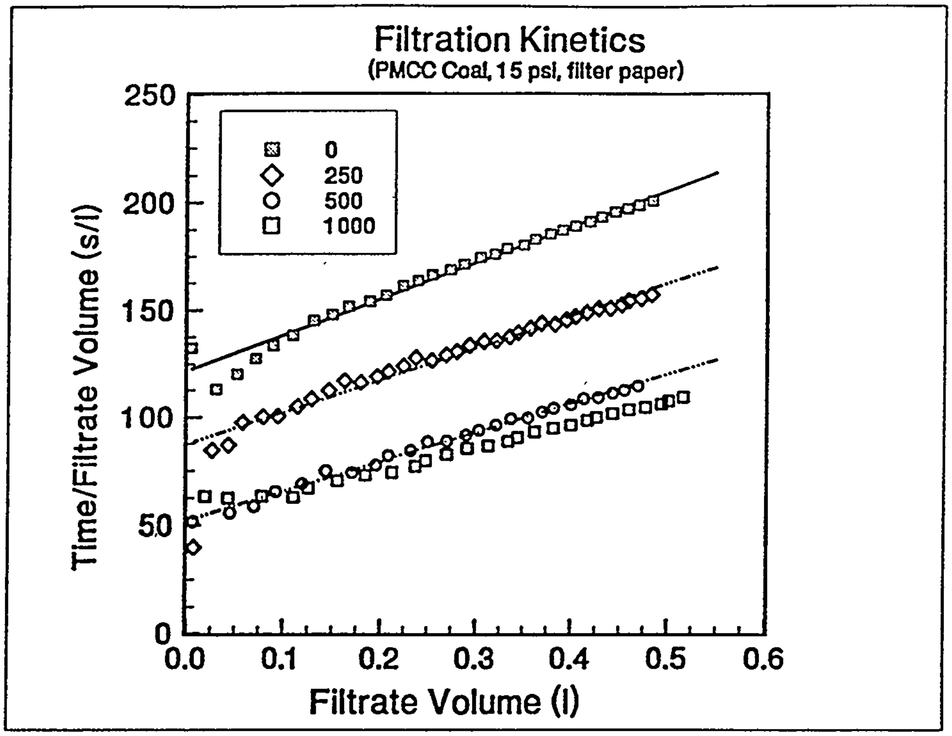

Figure 6. Darcy-Kozney Plot for PMCC low-sulfur clean coal filtration at 15 psi in the presence of different concentrations of ferric chloride when Whitman #1 paper is used.

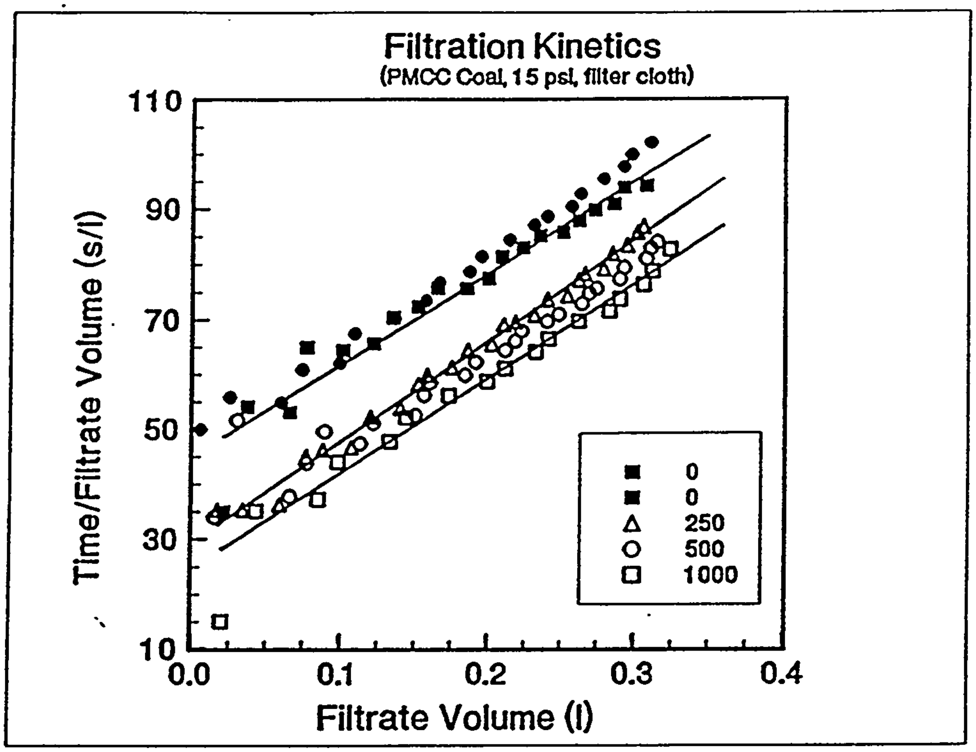

Figure 7. Darcy-Kozney Plot for PMCC low-sulfur clean coal filtration at 15 psi in the presence of various concentrations of ferric chloride when Andritz filter cloth is used.

moisture reduction of the filter cake. Therefore, a decrease of the medium resistance can effectively reduce the moisture content.

In-Situ Polymerization Enhanced Dewatering

Fine coal slurry, usually containing 1-20% solids, is considered to be highly stable dispersions. The dispersions can be destabilized by controlling the surface and colloid chemistry of the system. Common approaches for destabilization include aggregation, coagulation and flocculation which are summarized in Table 2. The approaches described above involve the use of metal ions (like Al(III) and Fe(III) and surfactants to coagulate the fine coal particles prior to filtration. There are limitations with conventional coagulation and flocculation methods. When metal ions are used as coagulants, although the formed aggregates are dense, their shear strength is low and they have poor filterability in the filtration. When organic polymers are used as flocculants, the flocs have high filterability (i.e., fast filtration kinetics) due to their loose, three-dimensional structure. However, only moderate moisture reduction can be obtained. In some cases, when high molecular weight flocculants are used, the moisture content is even higher, because water is entrapped in the flocs.

Based on the previous studies, a novel concept, "in-situ polymerization" (ISP) is being investigated to enhance fine coal dewatering. The new approach involves two steps. First, the coal slurry is conditioned with polyvalent short-chain cationic organic chemicals. This step alone causes the fine coal particles' coagulation. Subsequently, novel chemicals are added to the slurry. The chemicals specifically react with the adsorbed cationic organic chemicals by opening the double bonds and

Table 2. Modes of destabilization of colloid dispersions

Phenomena	Electrolyte Aggregation	Chemical Coagulation	Polymer Flocculation
Electrostatic interaction	Predominant	Important	Subordinate
Chemical interaction & adsorption	Mostly absent	Important	Predominant
Zeta potential for optimum aggregation	Near zero	Not necessarily zero	Usually not zero
Addition of excess of destabilizing chemical	No effect	Restabilization usually accompanied by charge reversal	Restabilization due to complete surface coverage
Relation between CCC & surface area	Independent	Stoichiometric	Linear relationship between flocculant dose and surface area
Physical properties of aggregates	Dense, great shear strength, but poor filtrability in cake filtration	Flocs of widely varying shear strength and density	Flocs of three dimensional structure; low shear strength but excellent filtrability in cake filtration

initialize chain-reactions, i.e., polymerization. The dispersions are rapidly coagulated to form dense, strong and hydrophobic aggregates. This facilitates the filtration and dewatering.

Preliminary tests showed that the novel in-situ polymerization (ISP) approach can substantially increase the filtration rate and reduce the final moisture content. For example, conventional vacuum filtration of an ultrafine coal froth (<28 μm, cake thickness = 15 mm) gives a cake of 65.5% moisture content for 1.0 min. filtration. With the ISP approach, the cake moisture is reduced to 25.0% under the same filtration conditions. This moisture reduction is equivalent to that of high pressure filtration at 60 psi. There are many advantages of the ISP approach. With ISP, the degree of polymerization, i.e., the molecular weight, can be controlled by the added chemicals and their concentrations. The hydrophobicity of the flocs can also be readily controlled. Our initial tests showed that the viscosity of the suspension is essentially unchanged.

Task 4. Procurement and Fabrication

The next series of the POC-Scale tests will be conducted using a 3-ft. diameter vacuum drum filter manufactured by WesTech Engineering Inc., Salt Lake City, Utah. During the last quarter WesTech Engineering, who is also cost sharing on the project, refurbished the pilot unit to meet minimum amount of solids handling capability. The electrical circuit was upgraded to provide extra safety for the project team members. Figure 8 shows a line diagram of the 3-ft. diameter vacuum filtration unit. Figure 9 shows the proposed layout for the vacuum filter installation at the PMCC. All the other necessary equipment needed for the POC-Scale tests have already been installed at the Powell Mountain Coal Company and used in the last tests using the hyperbaric filter.

Task 6.1 Hyperbaric Filtration Tests

As mentioned in last quarterly report that the first system tested for the program was the Andritz hyperbaric unit and the testing has been completed. The baseline dewatering data were obtained with respect to cake formation angle (CFA), filter speed, and vessel pressure. The optimum operating conditions for providing a low moisture filter cake were found to be 3 bar (44 psi) pressure, 1.5 rpm filter cake

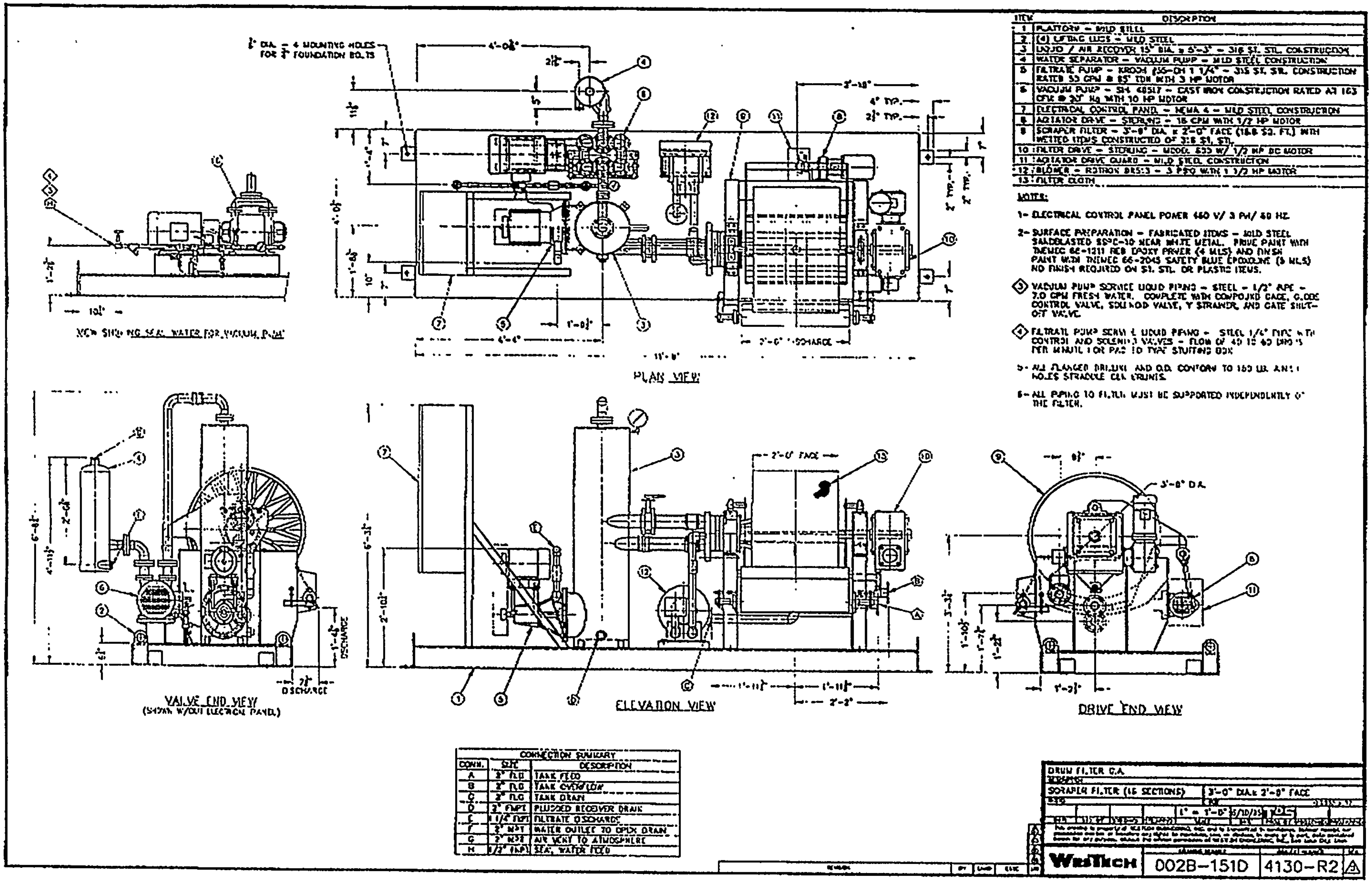

Figure 8. Line diagram of the POC-Scale vacuum drum filter.

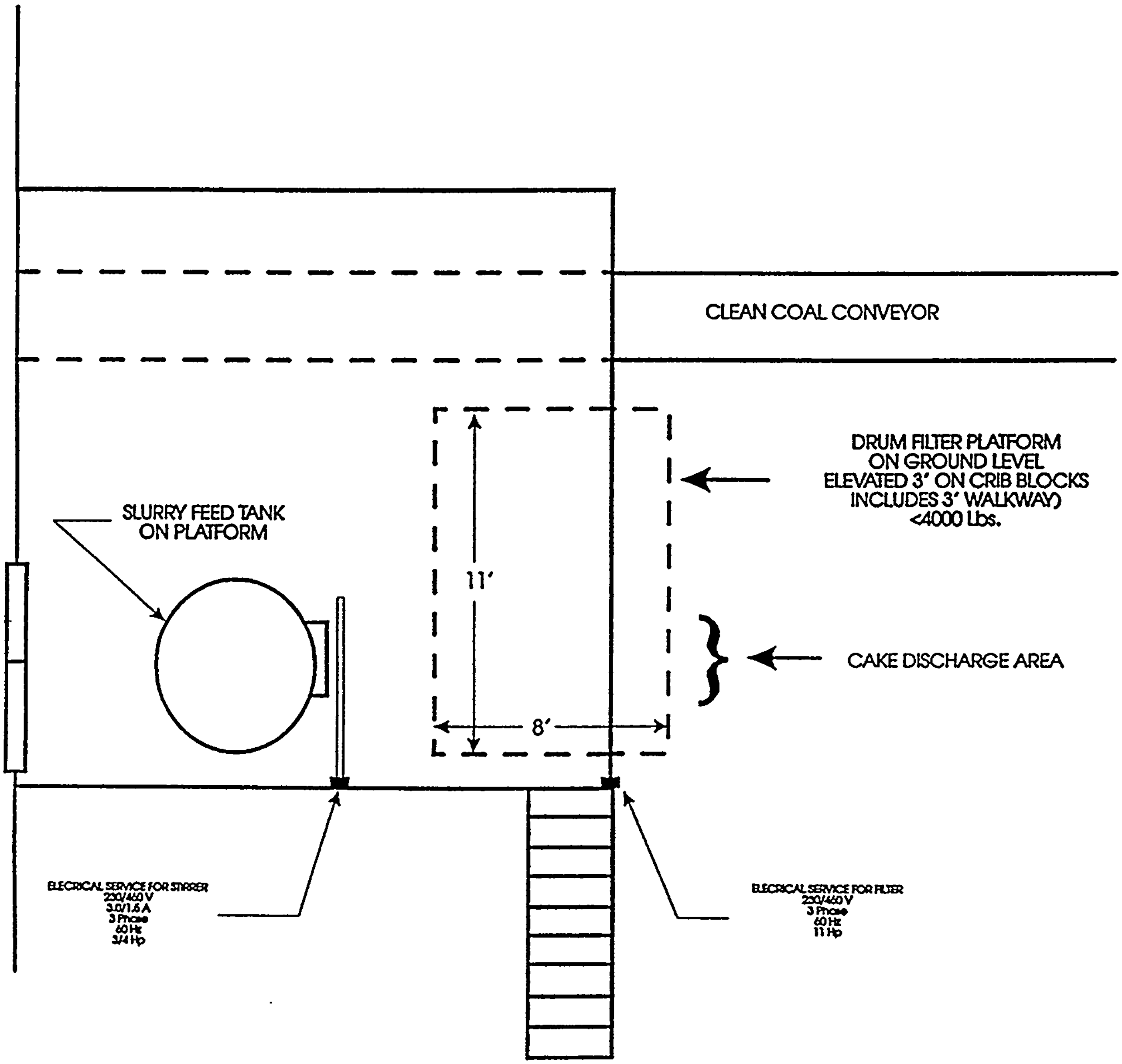

Figure 9. Proposed layout of the vacuum filter installation at the Powell Mountain Coal Company.

with 23.6% conditions produced a 18 mm thick filter cake with 23.6 moisture using the optimum operating conditions the solids throughput of 165 lb/ft^2/hr was achieved with an air consumption of 460 scfm/ton.

Reagent Addition:

The hyperbaric filter tests were conducted with addition of various dewatering reagents, such as surfactants, flocculants, and metal ions.

Figure 10 shows effect of anionic and cationic flocculant dosages on filter cake moisture of the non-compliance (high sulfur) coal. Note, that the moisture content of filter cake increased with the increase of flocculant dosage. These results are very similar to the one obtained in another U.S. DOE sponsored project conducted at one of the Consol Inc. preparation plants. Figures 11 (a) and (b) shows the solids throughput and air consumption for the various dosages of the surfactant. Note, that solids throughput using the anionic flocculant shows a sharp decline in solids throughput above 15 ppm dosage. The air consumption remains at 500 scfm/ton up to 15 ppm flocculant dosage then it also increases significantly. The typical dewatering behavior above 15 ppm could be due to formation of large loose flocs. Figure 12 shows effect of anionic flocculant dosage on filter cake moisture for the compliance (low sulfur) and non-compliance clean coal slurries. Note, that the compliance coal shows a lowering of moisture, whereas non-compliance shows increase of filter cake moisture as the flocculant dosage increases. It is speculated that the low filter cake moisture for compliance coal could be due to low solids

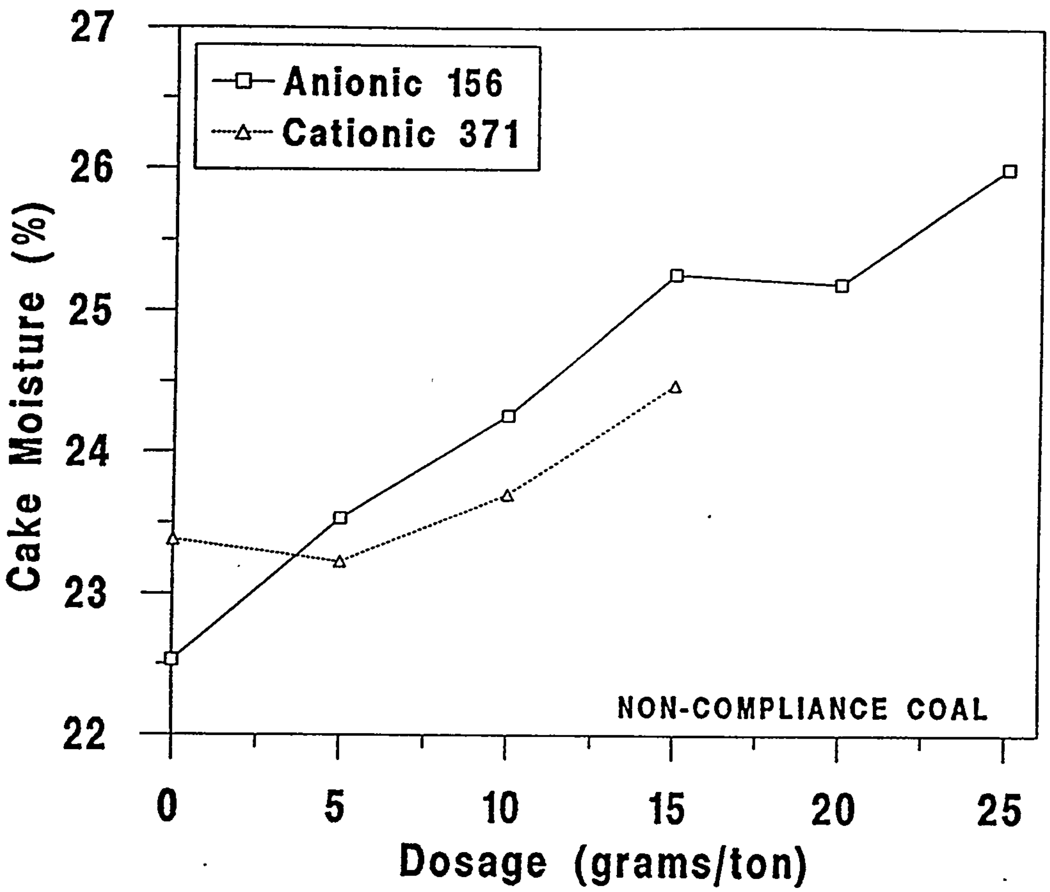

Figure 10. Effect of flocculant addition on filter cake moisture of non-compliance coal.

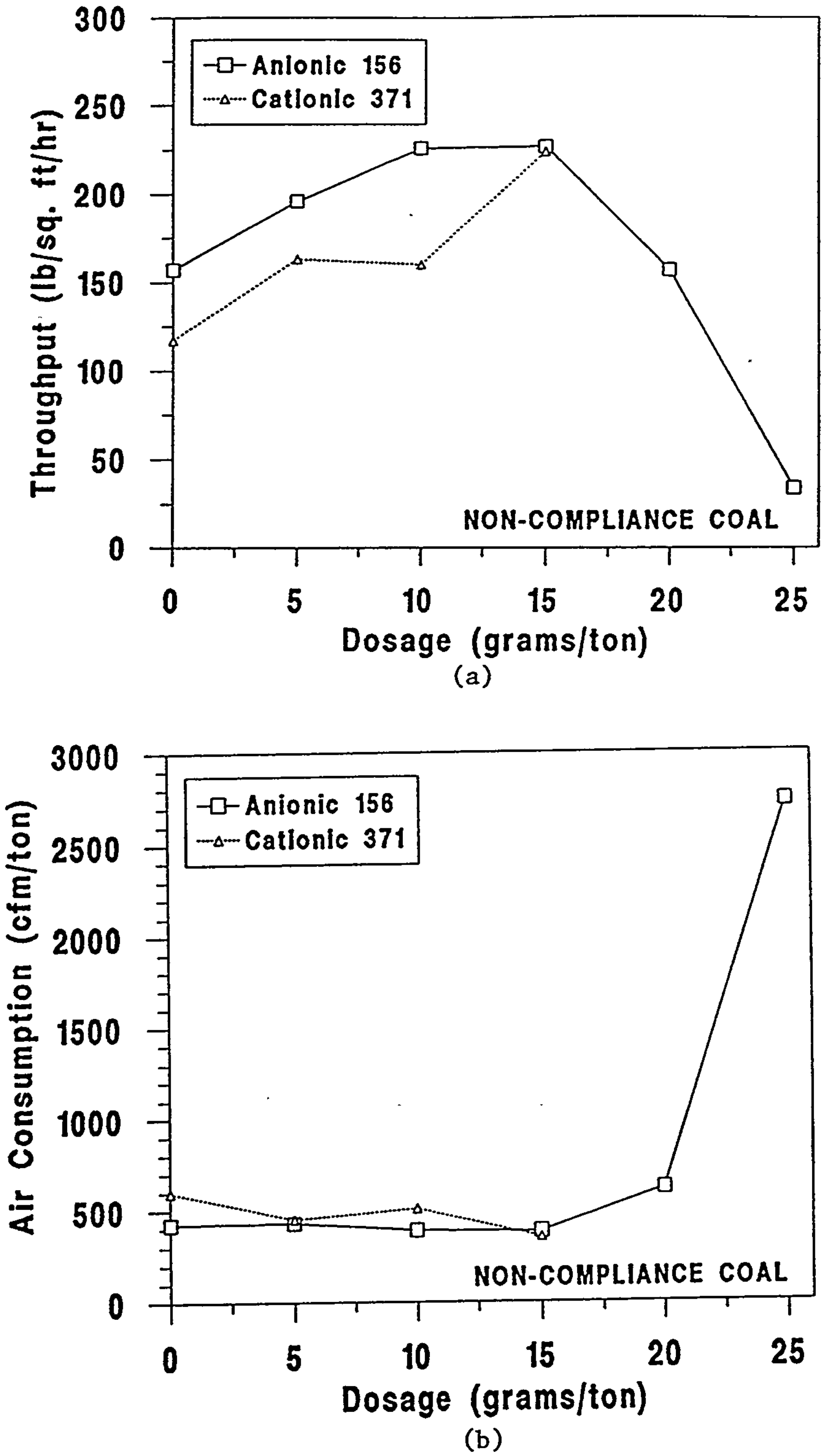

Figure 11. Air consumption and solids throughput for various dosages of anionic and cationic flocculants.

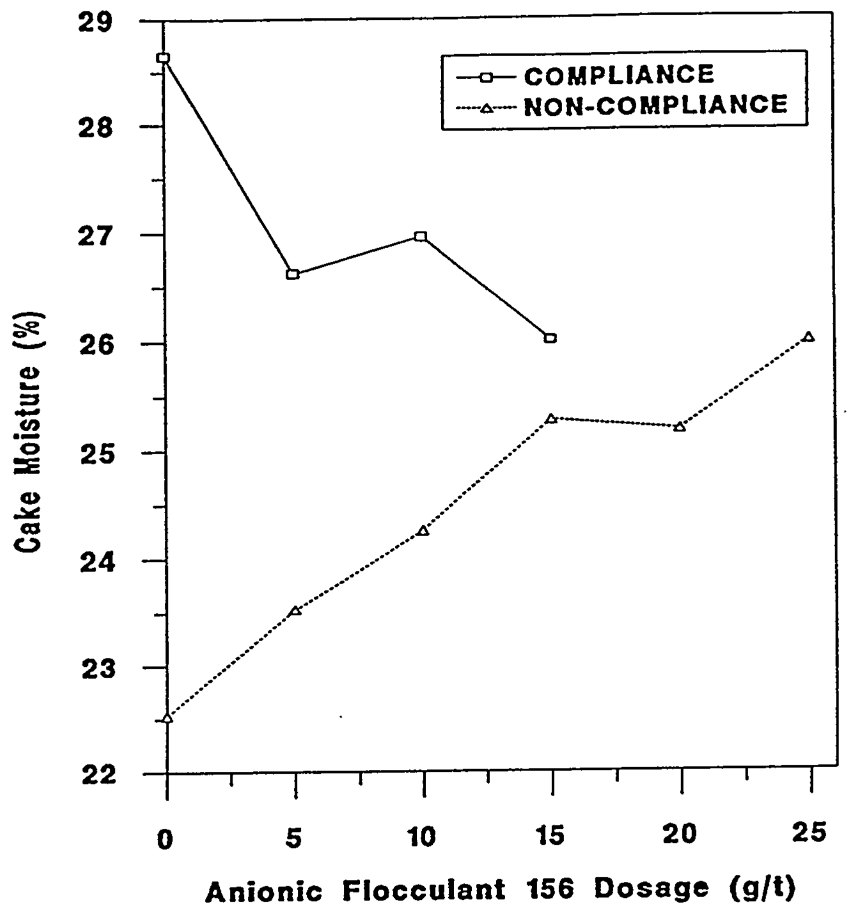

Figure 12. Effect of anionic flocculant dosage on dewatering of compliance and non-compliance clean coal slurry.

content in the slurry which provided a thinner cake, and provided a lower moisture filter cake. Due to limited availability of the compliance coal slurry, repeat tests could not be performed at the plant, however, laboratory studies are being conducted to ascertain the validity of the results. Figures 13 (a) and (b) show the solids throughput and air consumption comparison for the compliance and non-compliance clean coal slurries, respectively. The results show that solids throughput for the compliance coal slurry was lower than for the non-compliance coal slurry due to lower solids content of the feed. The air consumption was similar for both coals. As mentioned earlier, due to limited availability of compliance coal slurry tests were no conducted above 15 ppm dosage.

Effect of surfactant dosages on filter cake moisture of the compliance and non-compliance clean coal slurries is shown in Figures 14 (a) and (b), respectively. For the compliance coal slurry addition of anionic and non-ionic surfactants did not lower the filter cake moisture, whereas, for the non-compliance coal slurry both non-ionic and cationic surfactants were effective in lowering of moisture. For the non-compliance coal slurry a higher (1.5 Kg/t) dosage of non-ionic surfactant was effective in lowering of filter cake moisture by five percentage points. No dewatering tests with cationic surfactant were performed with the compliance coal slurry due to limited availability of the product at the preparation plant. We are conducting laboratory dewatering studies using the cationic surfactant. Figures 15 (a) and (b) show the solids throughput and air consumption for the compliance coal slurry using various

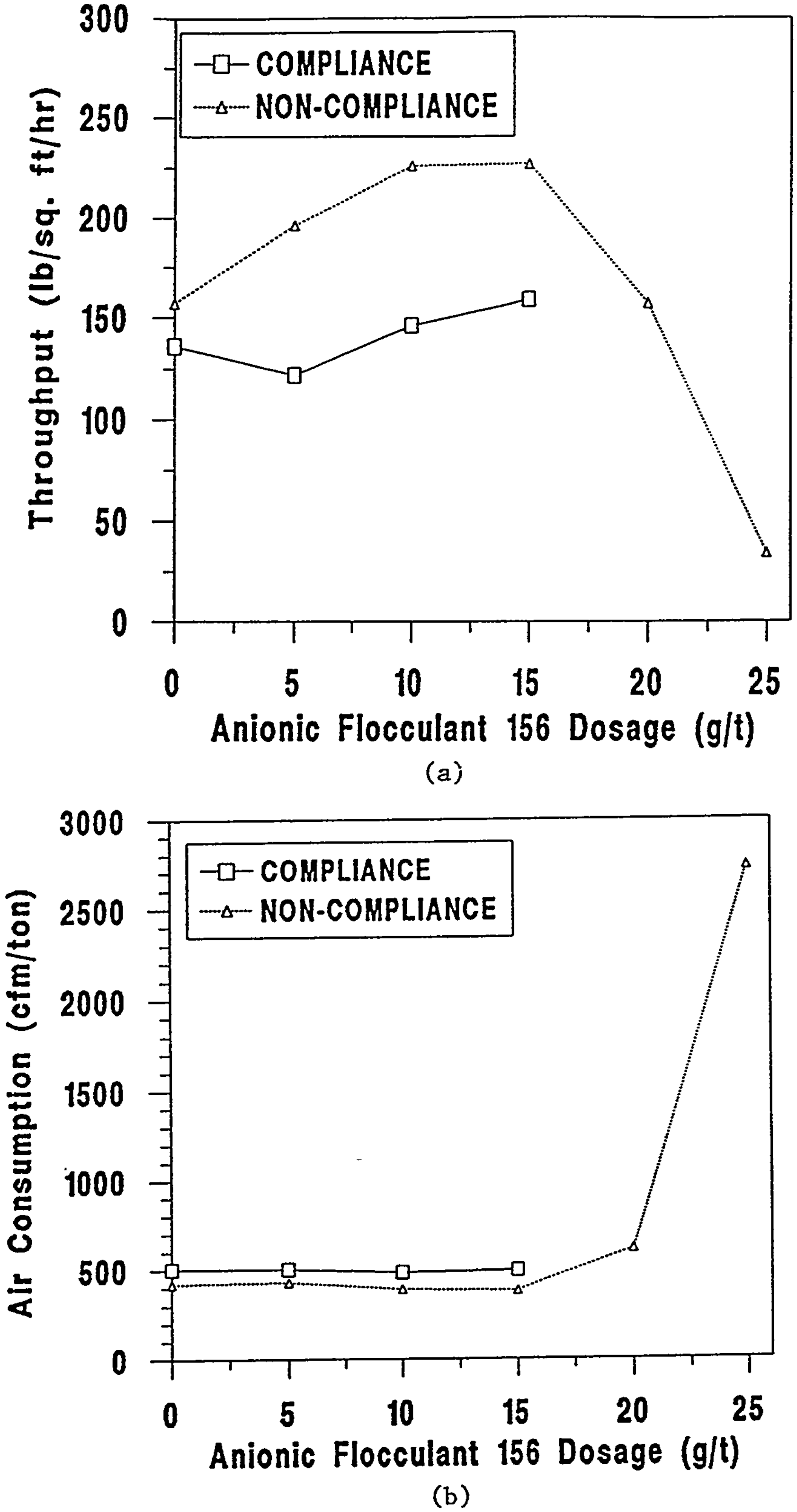

Figure 13. Solids throughput and air consumption for various dosages of anionic flocculant for the compliance and non-compliance clean coal slurries.

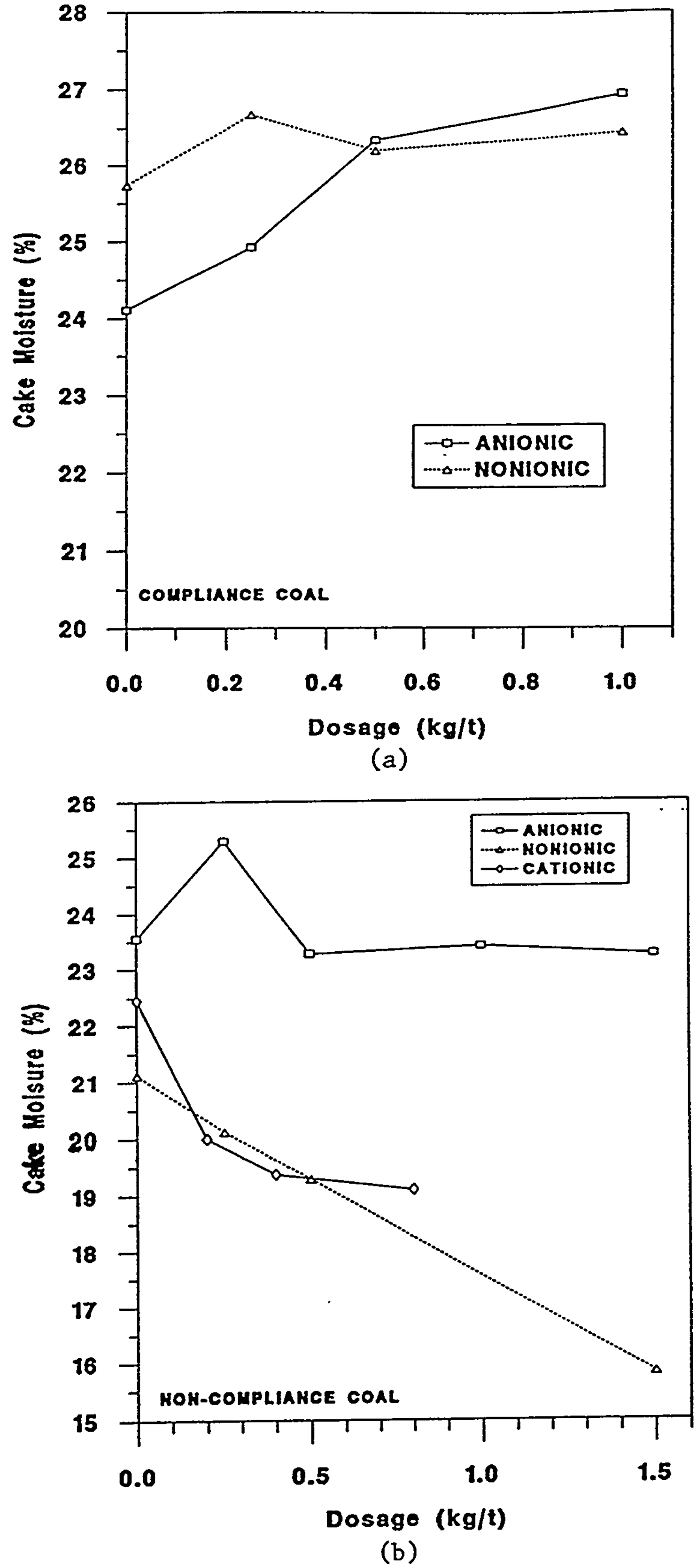

Figure 14. Effect of surfactant dosage on filter cake moisture of the compliance and non-compliance clean coal slurries.

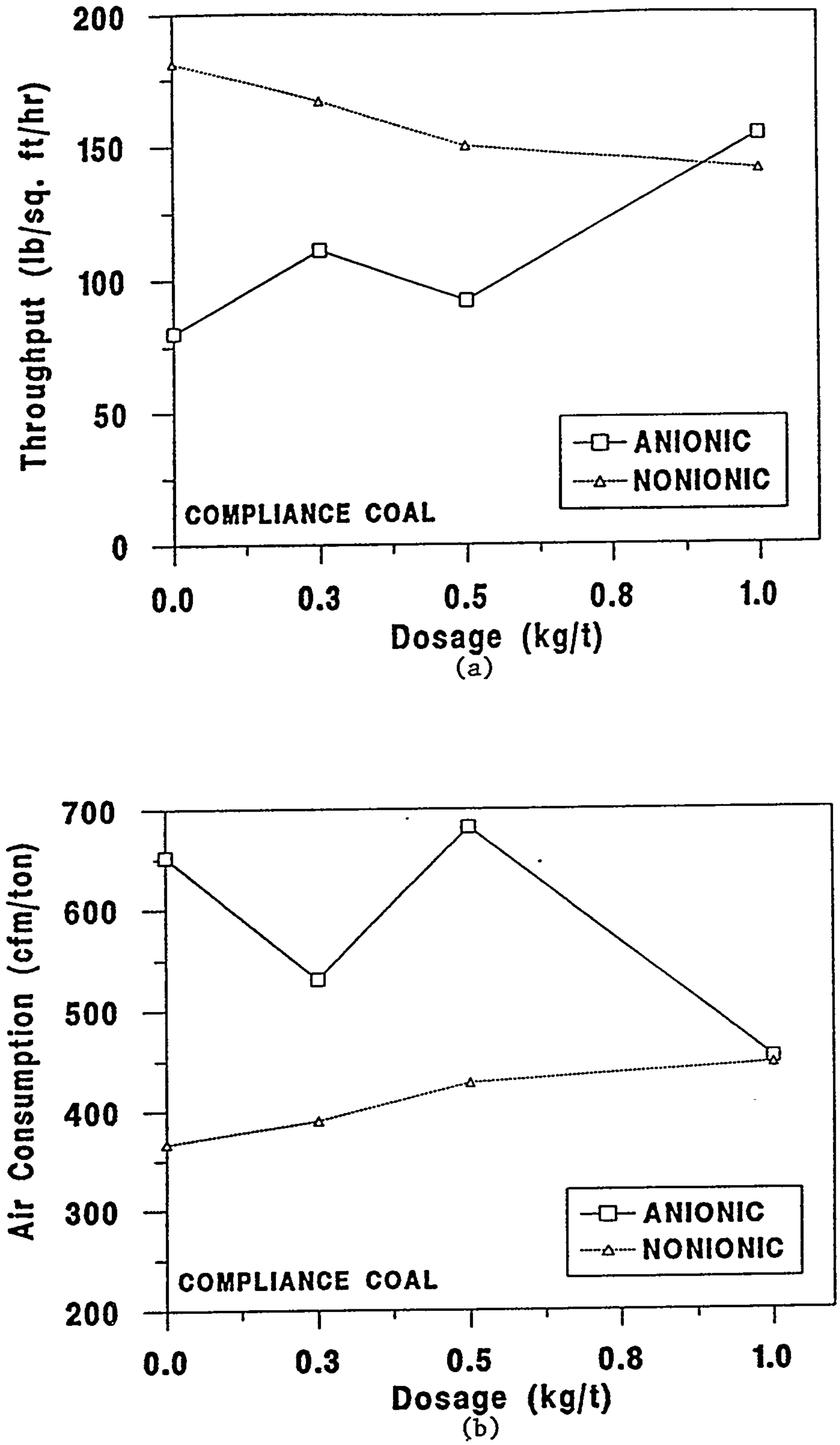

Figure 15. Solids throughput (a) and air consumption (b) as a function of surfactant dosage for the compliance coal slurry.

dosages of surfactant. The solids throughput shows an increase with increase in surfactant dosages, whereas with non-ionic surfactant a slight decline in solids throughput was noted. Air consumption with anionic surfactant was erratic, whereas with non-ionic an increasing trend was observed. The air consumption and solids throughput for the non-compliance clean coal slurry is shown in Figures 16 (a) and (b), respectively. Note, that only anionic surfactant showed a significant lowering of air consumption and solids throughput with increasing surfactant dosage.

Effect of copper and aluminum ions addition on filter cake moisture of the compliance coal slurry is shown in Figure 17. The data clearly shows that addition of about 25 ppm of copper ions lowers the filter cake moisture by about two percentage points; with aluminum ions the filter cake moisture was reduced by only about one percentage point. Figure 18 shows the solids throughput (a) and air consumption (b) recorded during dewatering studies conducted using the copper and aluminum ions. It is interesting to note that solids throughput lowers and air consumption increases at about 20 ppm copper ion dosage. The filter cake moisture also was lowest at 20 ppm dosage. The data confirms that addition of metal ions forms agglomerates of fine coal. The data obtained with aluminum ions were insufficient to reach a definite conclusion. Figure 19 shows effect of addition of metal ions with surfactant on dewatering of the compliance coal slurry. Note, that addition of cationic surfactant along with 25 ppm copper ions did not improve filter cake moisture over that obtained with metal ions alone. However, combination of the cationic surfactant

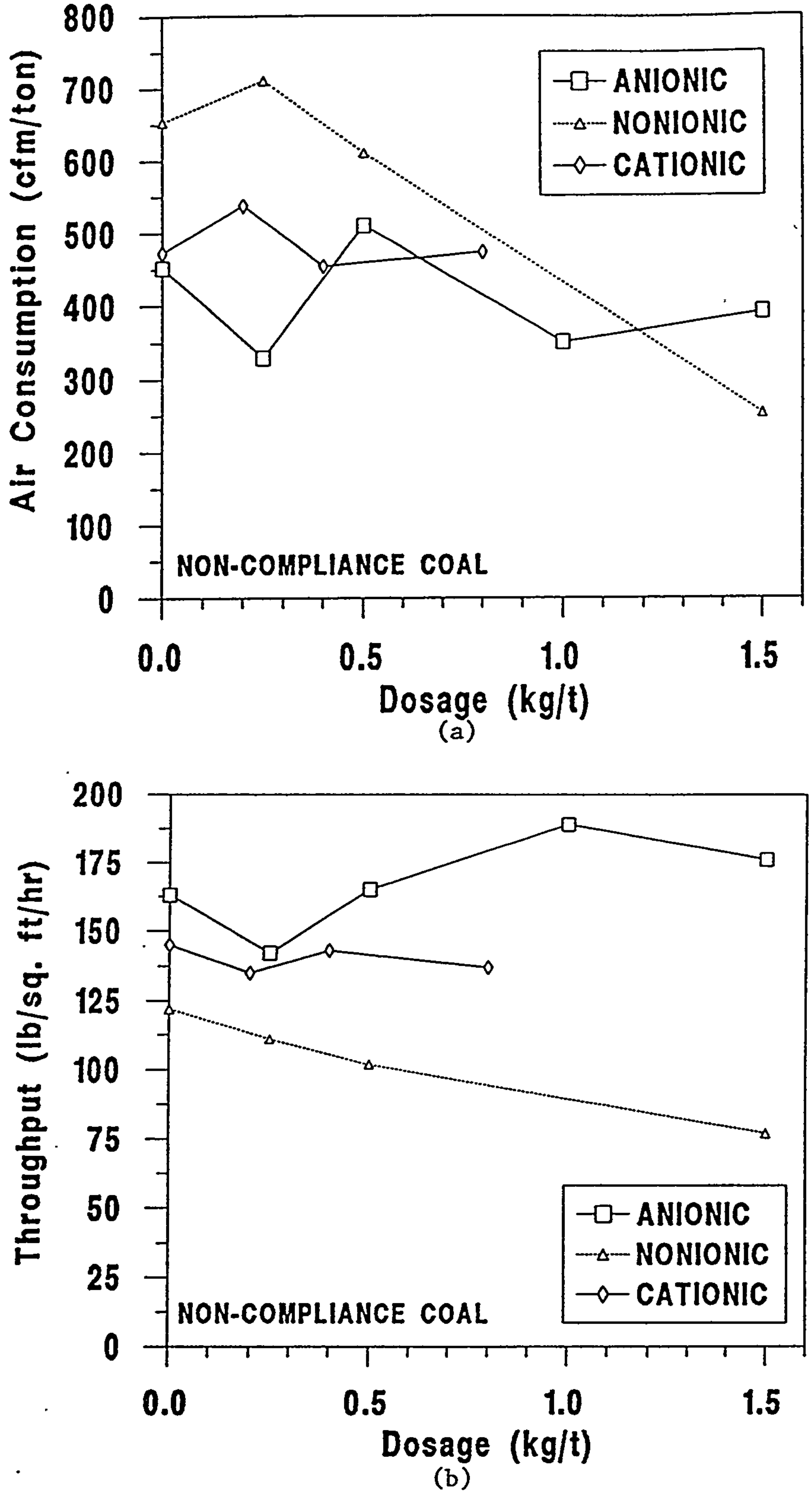

Figure 16. Air consumption (a) and solids throughput (b) as a function of surfactant dosage for the non-compliance clean coal slurry.

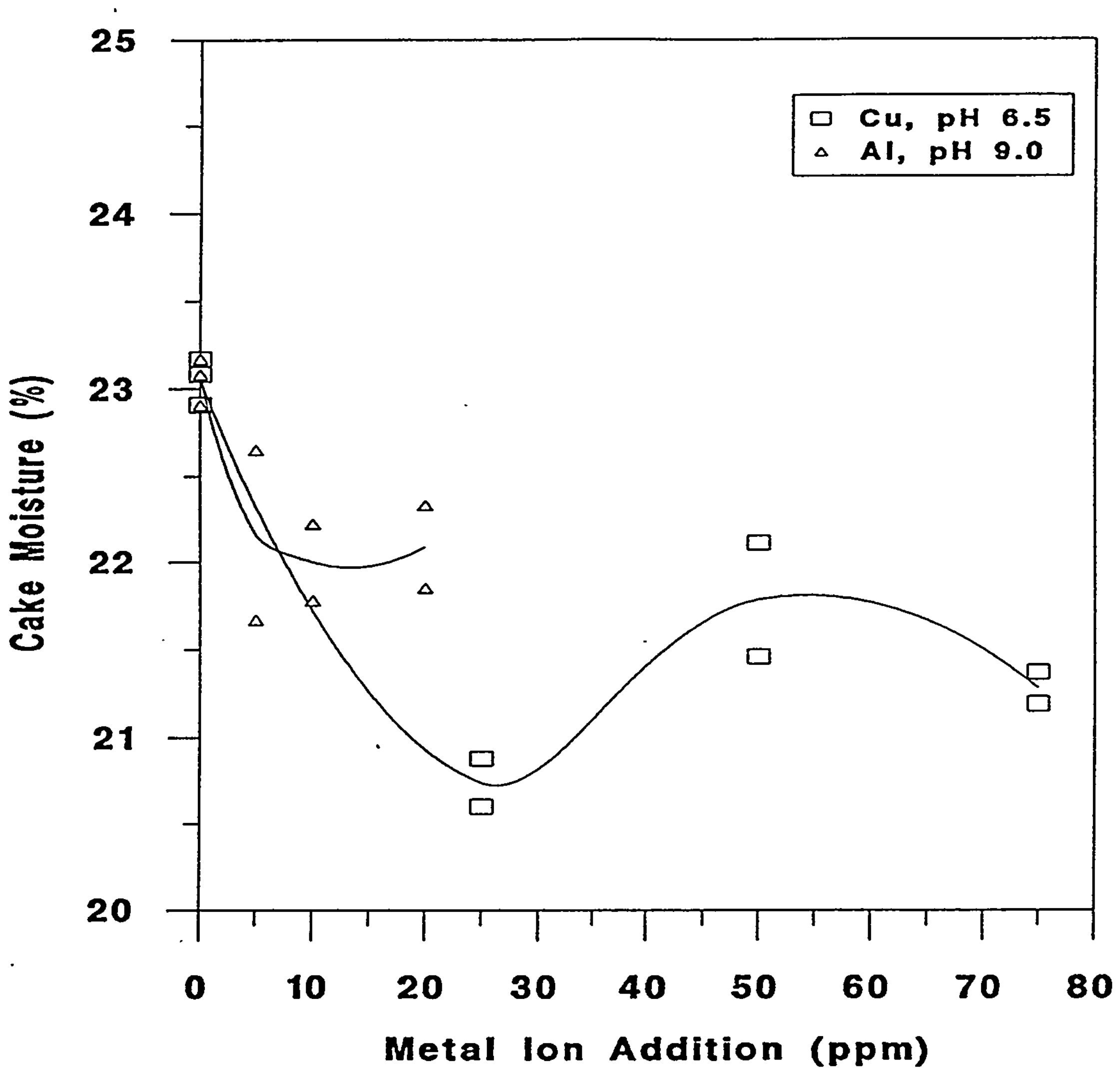

Figure 17. Effect of copper and aluminum ion addition on filter cake moisture of compliance coal.

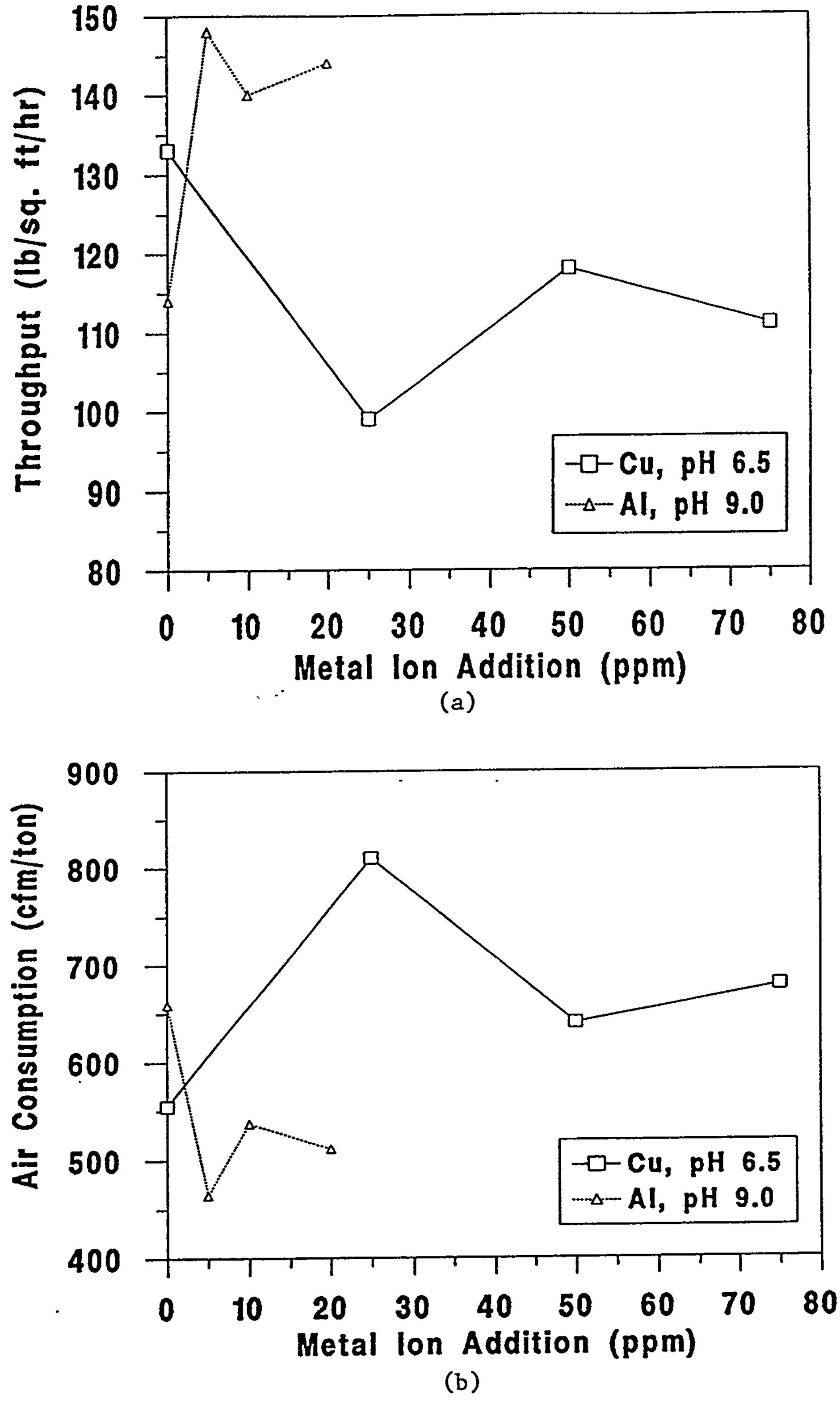

Figure 18. Solids throughput (a) and air consumption (b) using various amounts of metal ions for the compliance coal slurry.

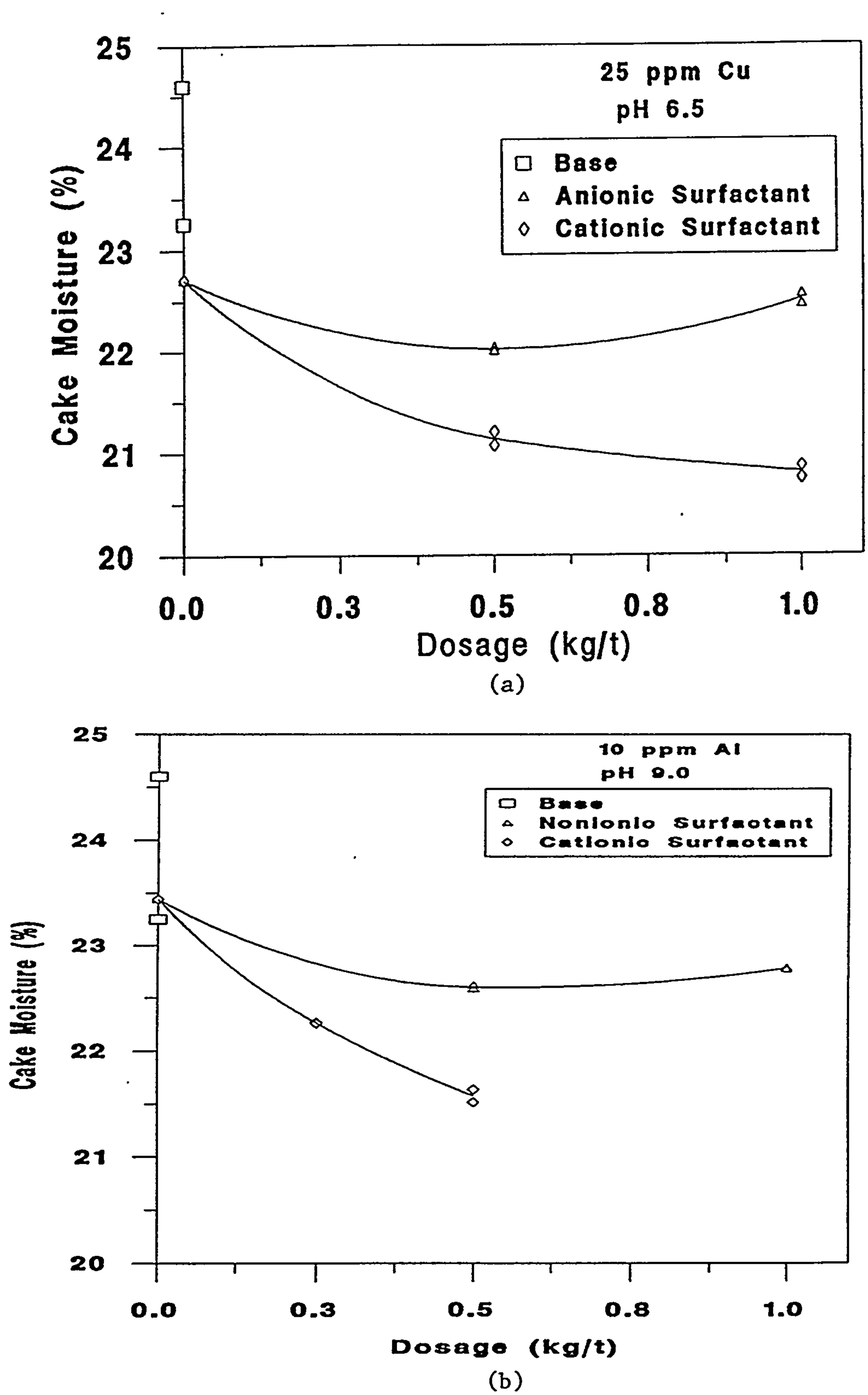

Figure 19. Effect of surfactant dosages in presence of 25 ppm Cu^{+2} (a) and 10 ppm Al^{+3} (b) ions on dewatering of non-compliance coal slurry.

with aluminum ions provided about two percentage point moisture reduction, which is about one percentage point more than that obtained with aluminum ion alone. Figure 20 shows dewatering data of non-compliance coal slurry as function of the cationic surfactant dosage. Note, that addition of 0.2 to 0.4 Kg/ton of surfactant alone lowered the filter cake moisture from 22.5% to 19.5%. Mixing with 25 ppm copper ions did not provide any significant lowering of moisture. Figure 21 shows the solids throughput and air consumption data for the dewatering test with the cationic surfactant. Note, that with the combination of copper ion and surfactant a high solids throughput and lower air consumption was observed.

ACTIVITIES FOR NEXT QUARTER

The WesTech vacuum drum filter will be installed at the Mayflower preparation plant. A series of dewatering tests will be conducted using the compliance and non-compliance clean coal slurries using the vacuum drum filter.

Laboratory dewatering studies using the Andritz filter will be completed.

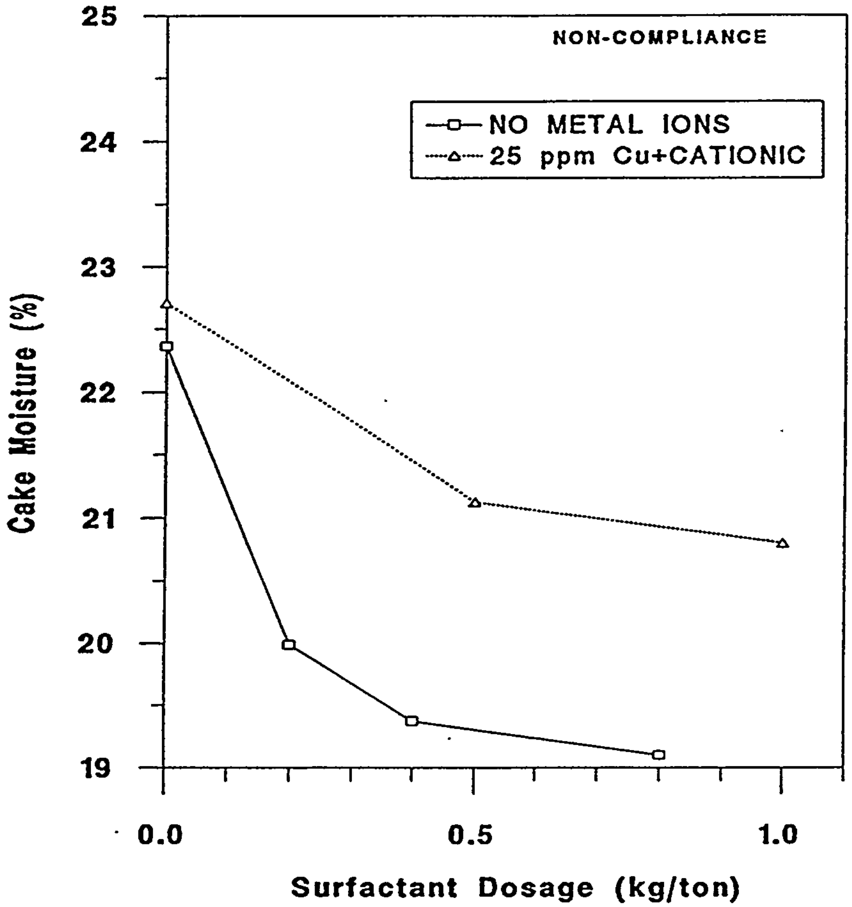

Figure 20. Dewatering data of non-compliance coal slurry as a function of a cationic surfactant dosage with and without presence of 25 ppm Cu^{+2} ions.

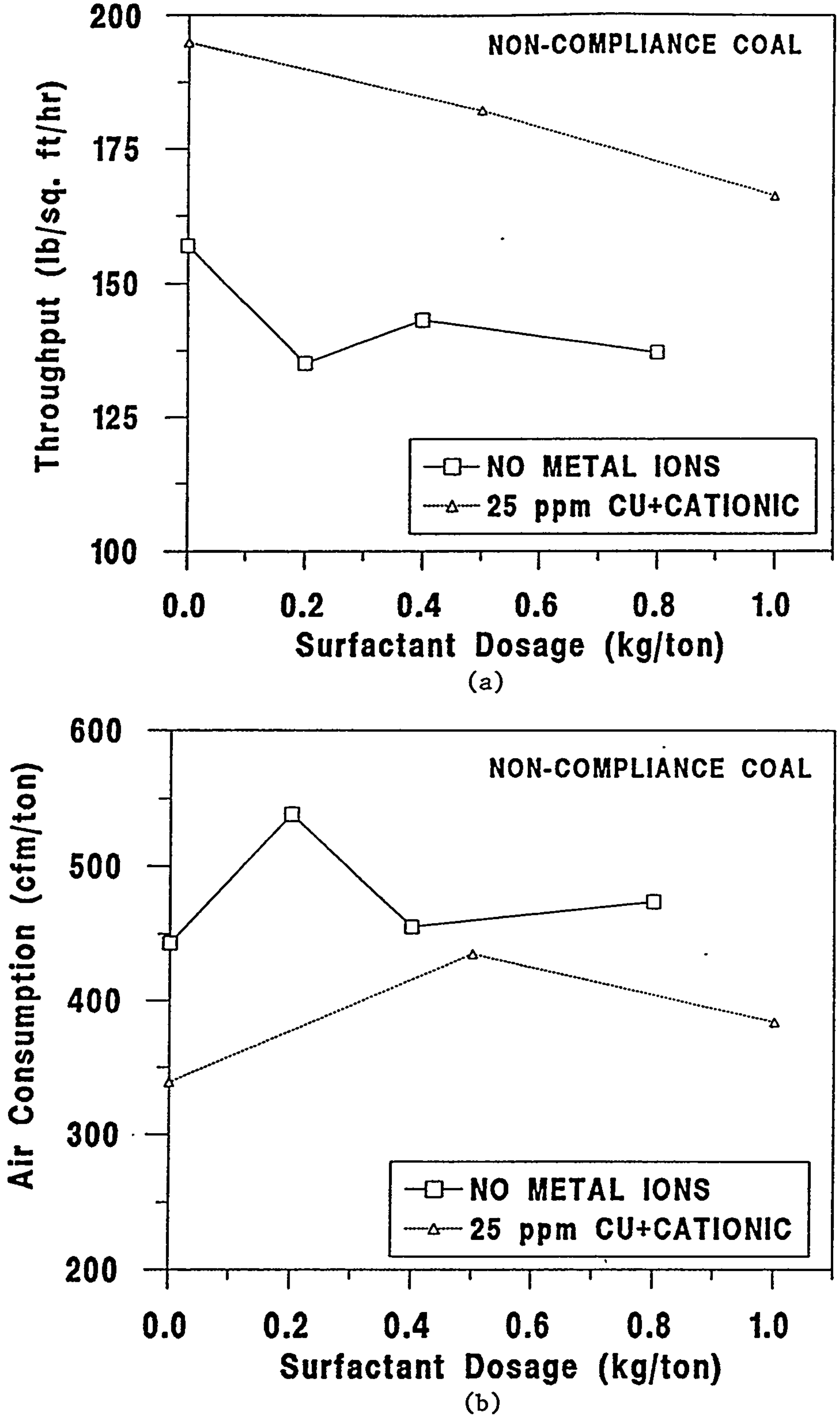

Figure 21. Solids throughput (a) and air consumption (b) for dewatering of non-compliance coal slurry with respect to the cationic surfactant dosage with and without addition of 25 ppm Cu^{+3} ions.