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

QUARTERLY TECHNICAL PROGRESS REPORT 8

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ABSTRACT

The advanced fine-coal cleaning techniques such as column flotation, recovers a low-ash ultra-fine size clean-coal product. However, economical dewatering of the clean coal product to less than 20 percent moisture using conventional technology is difficult. This research program objective is to evaluate a novel coal surface modification technique developed at the University of Kentucky Center for Applied Energy Research in conjunction with conventional and advanced dewatering technique at a pilot scale. The study which is in progress is being conducted at the Powell Mountain Coal Company's Mayflower preparation plant located in St. Charles, VA.

During this quarter laboratory dewatering studies were conducted using a 4-in diameter laboratory chemical centrifuge. The baseline data provided a filter cake with about 32% moisture. Addition of 0.3 kg/t of a cationic surfactant lowered the moisture to 29%. Addition of anionic and non-ionic surfactant was not effective in reducing the filter cake moisture content.

In the pilot scale studies, a comparison was conducted between the high pressure and vacuum dewatering techniques. The base line data with high pressure and vacuum filtration provided filter cakes with 23.6% and 27.8% moisture, respectively. Addition of 20 g/t of cationic flocculant provided 21% filter cake moisture using the high pressure filter. A 15% moisture filter cake was obtained using 1.5 kg/t of non-ionic surfactant. Vacuum filter provided about 23% to 25% moisture product with additional reagents. The high pressure filter processed about 3 to 4 times more solids compared to vacuum filter.

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EXECUTIVE SUMMARY

Froth flotation technique is an effective and efficient process for recovering of ultra-fine (minus 74 μm) clean coal. Economical dewatering of an ultra-fine clean coal product to a 20% level moisture will be an important step in successful implementation of the advanced 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% 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 July 1 - September 30, 1996.

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. In addition, Decanter Machine Inc. and WesTech Engineering will provide their equipment for testing.

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

Laboratory centrifugal dewatering tests were conducted using a 4-in. diameter screen bowl chemical centrifuge manufactured by International Equipment Company. The study was conducted to evaluate effects of various surfactants on filtration of PMCC compliance and non-compliance ultrafine coal slurry. The results obtained from baseline tests with PMCC non-compliance coal have shown that cake moisture and solids recovery in centrifugal filtration are dependent on the rotation speed and filtration time. Higher rotation speed, i.e., higher centrifugal force, produced lower cake moisture and higher solids recovery. Increasing the rotation speed from 2500 to 5800 rpm (centrifugal force from 250 to 2400 g) lowered cake moisture from 43 to 23% and increased solids recovery from 78 to 97%. Most significant change in cake moisture with filtration time was observed from 10 to 30 seconds when cake moisture dropped from 40 to 27%.

Cationic surfactant reduced cake moisture from 33.8 to 29.5% at a dosage of 0.3 kg/t with the compliance coal. The reagent showed adverse effects on cake moisture at dosages higher than 0.9 kg/t. Solids recovery was reduced slightly when cationic surfactant was used. With the non-compliance coal the lowering of cake moisture was observed in the presence of 1.5 kg/t of cationic surfactant. Lower dosages of cationic surfactant slightly increased cake moisture. Solids recovery showed marginal changes over the dosage range examined.

Anionic surfactant had similar effects on the centrifugal dewatering of the compliance and non-compliance coals. It reduced cake moisture by a couple of absolute percentage at a dosage of 0.3 or 0.6 kg/t but increased cake moisture at higher dosages. Use of anionic surfactant essentially had no effect on solids recovery.

Non-ionic surfactant increased cake moisture and decreased solids recovery with the compliance coal. It increased solids recovery by up to 4% with the non-compliance coal.

In the pilot-scale study, a comparison of high pressure and vacuum filters performance on dewatering of the high sulfur (non-compliance) clean coal slurry was conducted. In general, high pressure dewatering produced a filter cake with 23.6% moisture, whereas as vacuum filter produced a filter cake with 27.8% moisture. Addition of 20 g/t of anionic flocculant provided 25.2% moisture product. However, cationic flocculant (20 g/t) provided 21% filter cake moisture using the high pressure filter. Addition of 0.8 kg/t of a cationic surfactant provided 19.1% moisture filter cake and addition of 1.5 kg/t of non-ionic surfactant provided 15.1% moisture filter cake using high pressure filters. Using the same amount of reagents, vacuum filter provided 23 to 25% moisture filter cake. Addition of 500 mg/kg of copper chloride lowered filter cake moisture to 20.8% using high pressure and 24.8% using vacuum filter. In general, high pressure filter was more effective in providing lower moisture product and also processed 3 to 4 times more solids than vacuum filter.

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% moisture. Recently developed column flotation technique, which provides higher recovery of low ash product, also suffers from the same problem of high moisture product. Dewatering of the fine coal to a low (~20%) 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 conventional and 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 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. In addition to the above project team members, the Decanter Machine Inc. and WesTech Engineering provided screen bowl centrifuge and vacuum filters for the project, respectively. The project schedule for the first two years of the program is shown in Figure 2.

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% or lower moisture in the fine clean coal product and to provide technical and economic evaluation of the integrated concept in sufficient detail for a coal company to decide to install the dewatering process in their plant.

The project has been divided into tasks and subtasks listed in Table 1. Each task and subtask has specific objective which can be inferred from its title. During this quarter (July 1 to September 30, 1996) work was done on Tasks 2 and 6.

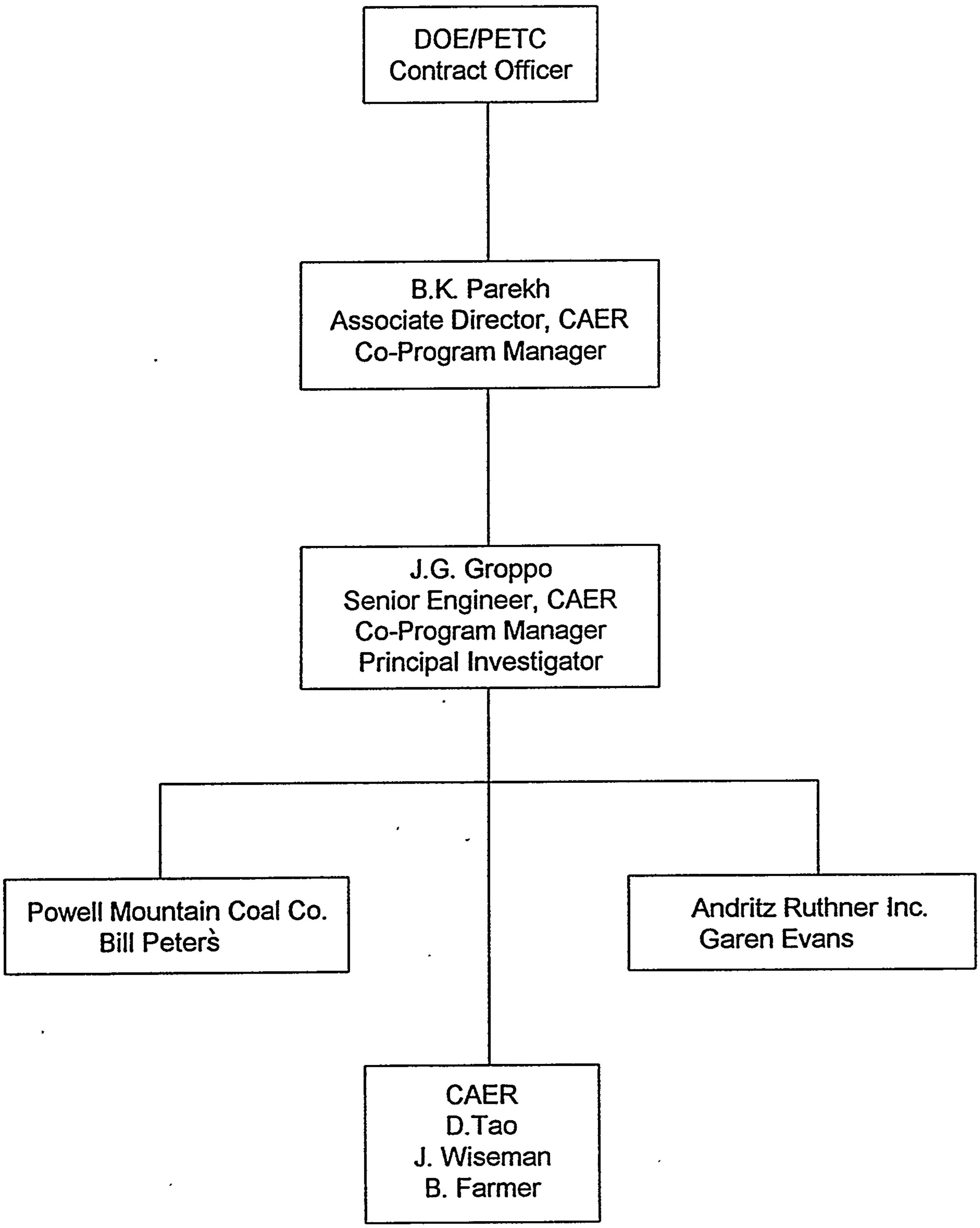

Figure 1. Project management organization chart

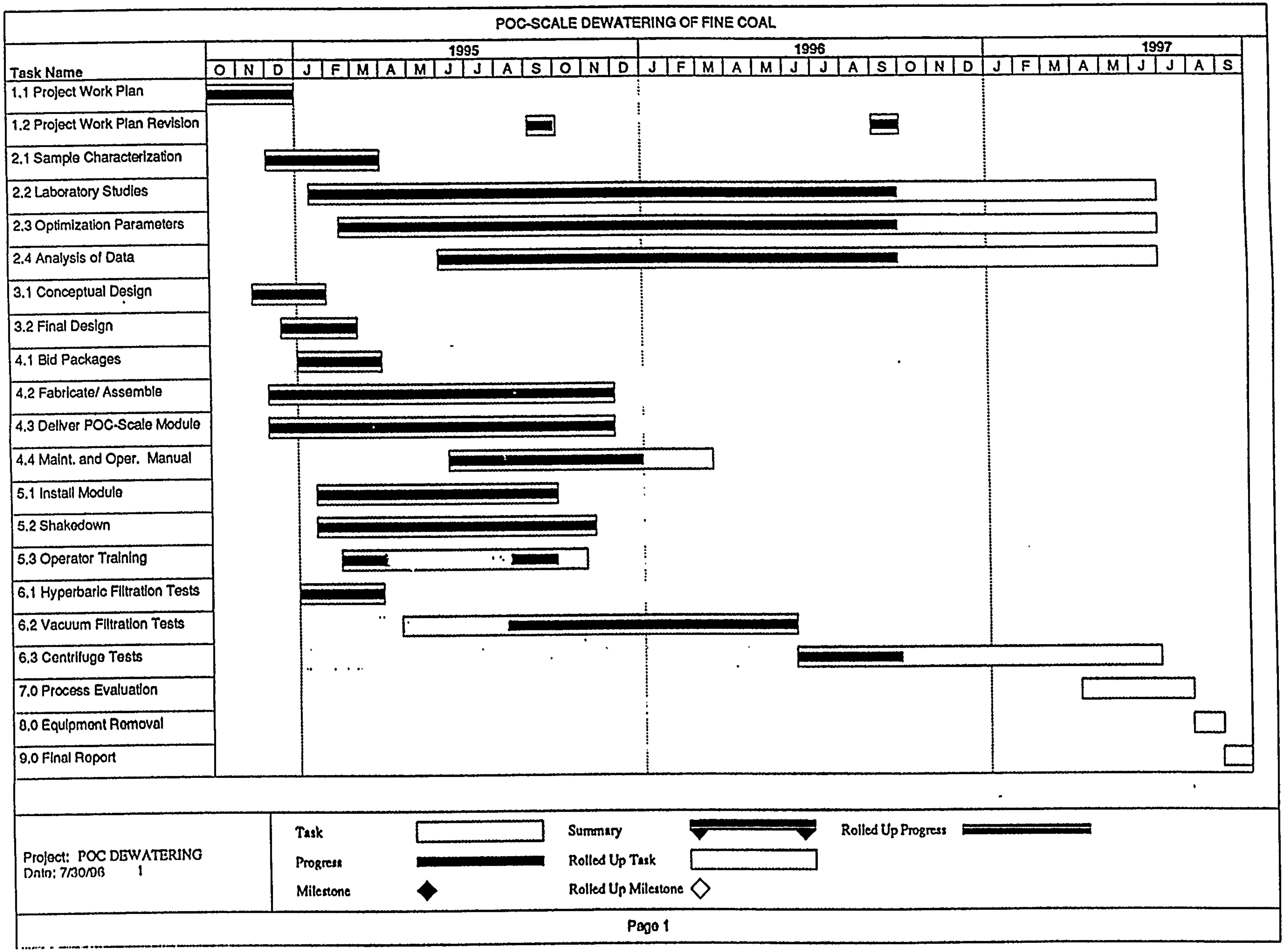

Figure 2. Up-to-date project schedule.

Table I. 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

RESULTS AND DISCUSSIONS

Task 2. Sample Analysis and Laboratory Testing:

The laboratory dewatering tests were conducted using both compliance (low sulfur) and non-compliance (high sulfur) clean coal slurries obtained from the Powell Mountain Coal Co. The particle size distribution and other properties of both coal slurries have been presented in the previous quarterly progress reports.

Centrifugal Dewatering

During the past quarter laboratory centrifugal dewatering tests were carried out with both PMCC compliance and non-compliance coals. The objective of this task was to identify optimum operating conditions of a screen bowl centrifuge for dewatering of ultra-fine clean coal slurries. The centrifugal dewatering tests were conducted on both coals under various operating conditions. The reagents used in this work are believed to enhance coal dewatering by modifying the coal surface to provide favorable dewatering characteristics such as:

high hydrophobicity

- low surface tension
- large aggregate size
- high permeability of filter cake, etc.

Reagents used in centrifugal dewatering tests include anionic (sodium 2-ethylhexyl sulfate), nonionic (octyl phenoxy polyethoxy ethanol), and cationic (1-hexadecyl pyridium chloride) surfactants; anionic Procol 156 and cationic Procol 371 flocculants; trivalent and divalent metal ions (Al^{3+} and Cu^{2+}). In the last quarter major efforts were devoted to investigation of effects of different surfactants on centrifugal dewatering of PMCC compliance and non-compliance coal samples.

Baseline Tests

Laboratory centrifugal dewatering tests were conducted using an IEC Chemical Centrifuge (International Equipment Co.) with a metal basket of 5-in. diameter. Baseline centrifugal dewatering tests were first conducted with the PMCC non-compliance coal to determine appropriate operating conditions. Each test was done using 1000 ml slurry and 60 second dewatering time. The dewatering time was defined as the duration of time that began after the slurry was added to the centrifuge and ended when the centrifuge was turned off. It was observed that the centrifuge took additional 1.5 minutes to reach a complete stop. Centrifugal dewatering performance was evaluated with two parameters: cake moisture and solids recovery. Figure 3 shows data on cake moisture and solids recovery as a function of centrifuge rotation speed. As the rotation speed increased from 2500 to 5800 rpm, (250 to 2400 g) cake moisture reduced from 43 to 23% and solids recovery increased from 78 to 97%. The higher solids recovery achieved at higher rotation speed was possibly due to the increased difference in centrifugal forces (ΔF) exerted on large and small particles ($\Delta F = a\Delta m$, a is acceleration and m is the mass of particles) that rendered large particles to settle much faster than small ones and created a compacted bed of large particles that prevented small particles from passing through.

Figure 4 shows the cake moisture as a function of centrifugal filtration time. The rotation speed was set at 5000 rpm in these tests. Each test was carried out using 450 ml slurry. As can be seen from the figure, the sharpest reduction in cake moisture was observed when the filtration time was increased from 10 to 30 seconds. There were moderate effects on cake moisture of filtration time from 30 to 90

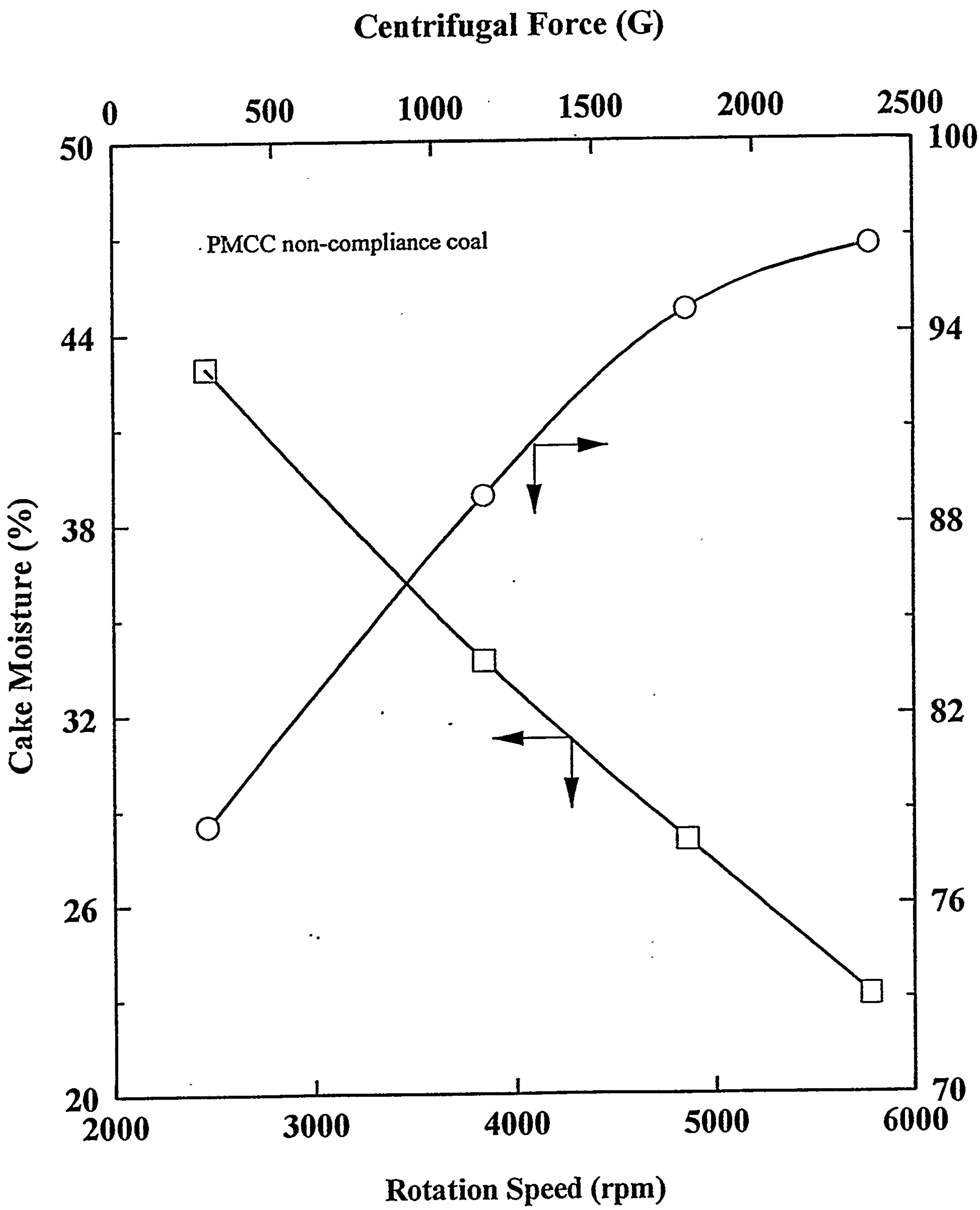

Figure 3. Effect of centrifuge rotation speed on cake moisture and solids recovery with non-compliance coal

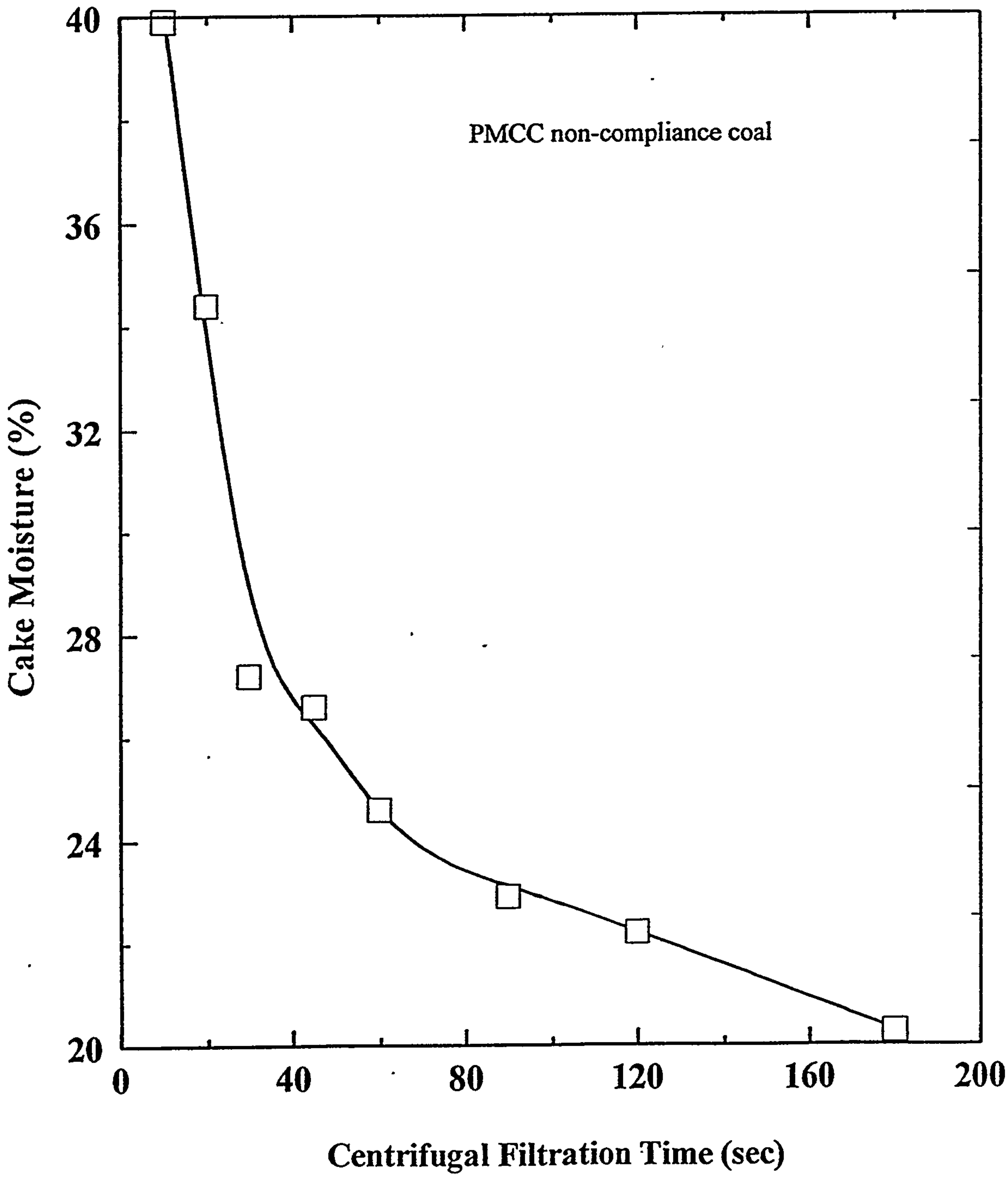

Figure 4. Effect of centrifuge filtration time on cake moisture and solids recovery with non-compliance coal

seconds. Further increase in filtration time from 90 to 180 seconds showed relatively small improvement on cake moisture.

Effects of Cationic Surfactant

Figures 5 and 6 show the effects of cationic surfactant on centrifugal dewatering of compliance (low sulfur) and non-compliance (high sulfur) clean coal slurries, respectively. The results were obtained under the following operating conditions: 1000 ml slurry, 5000 rpm rotation speed, and 30 second filtration time. Figure 5 indicates that with the compliance coal (low sulfur) slurry use of cationic surfactant at dosages of 0.3 or 0.6 kg/t decreased cake moisture from 33.8% to 29.5%. Higher dosage of cationic surfactant produced wetter cakes possibly due to increased viscosity of slurry. Increase in cationic surfactant dosage from 0 to 1.2 kg/t also resulted in decrease in solids recovery from 89 to 84%.

Effects of the cationic surfactant dosage on centrifugal dewatering of the non-compliance (high sulfur) coal slurry is shown in Figure 6. In general, use of cationic surfactant increased cake moisture by a couple of absolute percentage points except at a dosage of 1.5 kg/t at which the cationic surfactant lowered the cake moisture from 29.3 to 27.8%. Solids recovery showed no change with respect to dosage of cationic surfactant. Cationic surfactant showed less significant effects on centrifugal dewatering of the non-compliance coal than the compliance coal slurry.

Figures 7 and 8 show the effects of anionic surfactant on centrifugal dewatering of compliance and non-compliance coal slurries, respectively. Both coal slurries showed similar behavior of cake moisture on the dosage of anionic surfactant. At low dosages, e.g., 0.3 or 0.6 kg/t, cake moisture was lowered by about

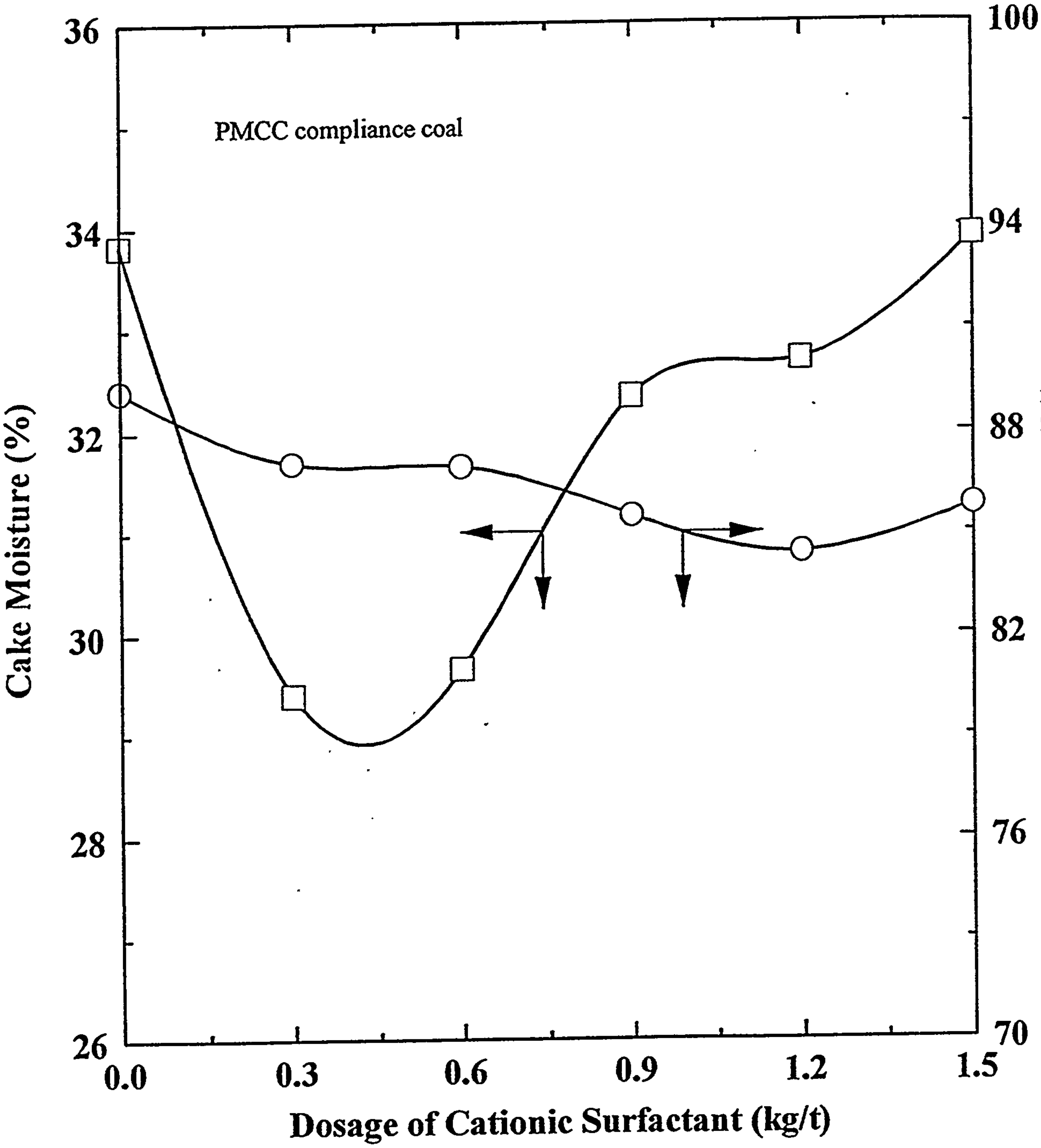

Figure 5. Effects of cationic surfactant on cake moisture and solids recovery with compliance coal

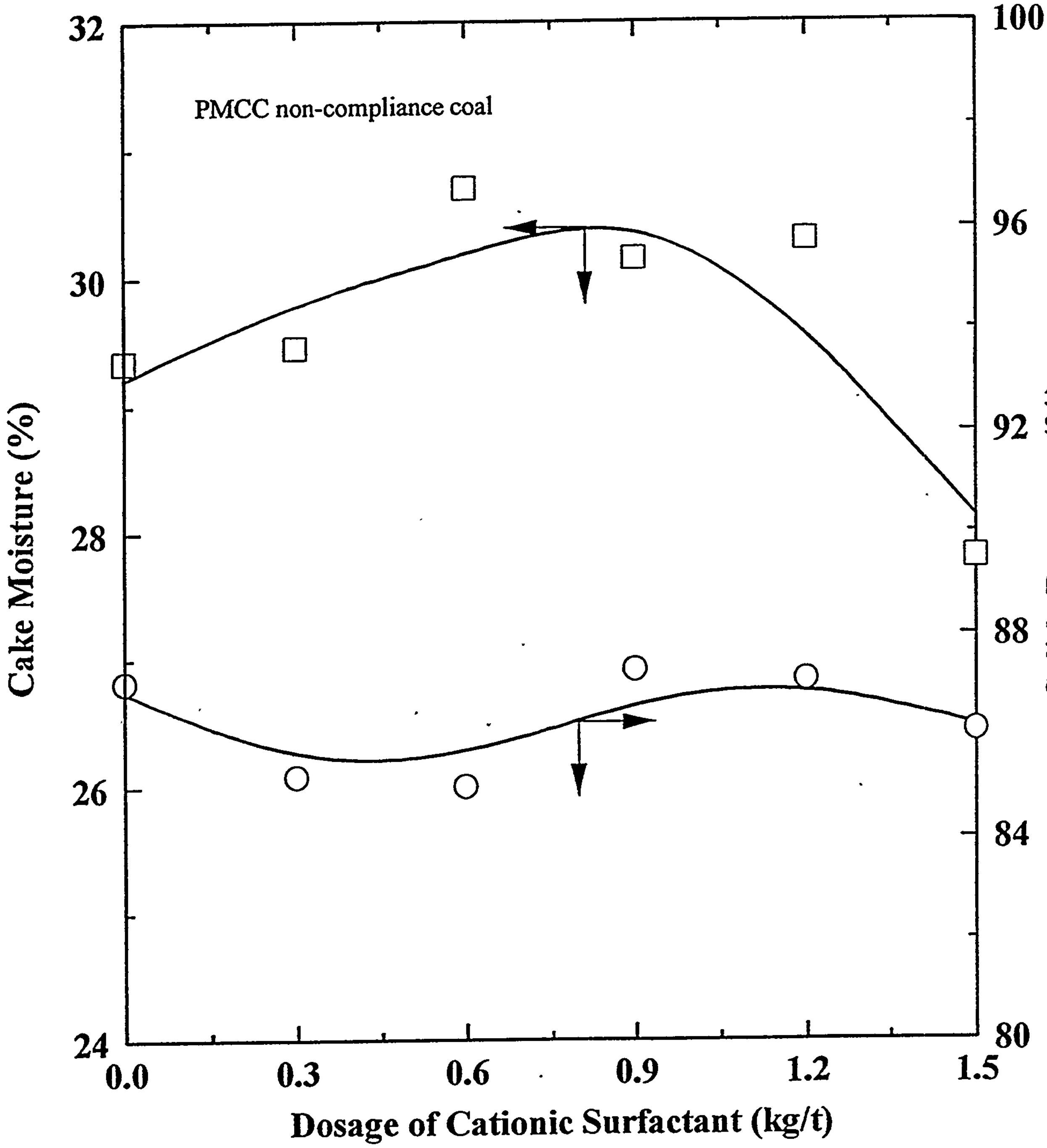

Figure 6. Effects of cationic surfactant on cake moisture and solids recovery with non-compliance coal

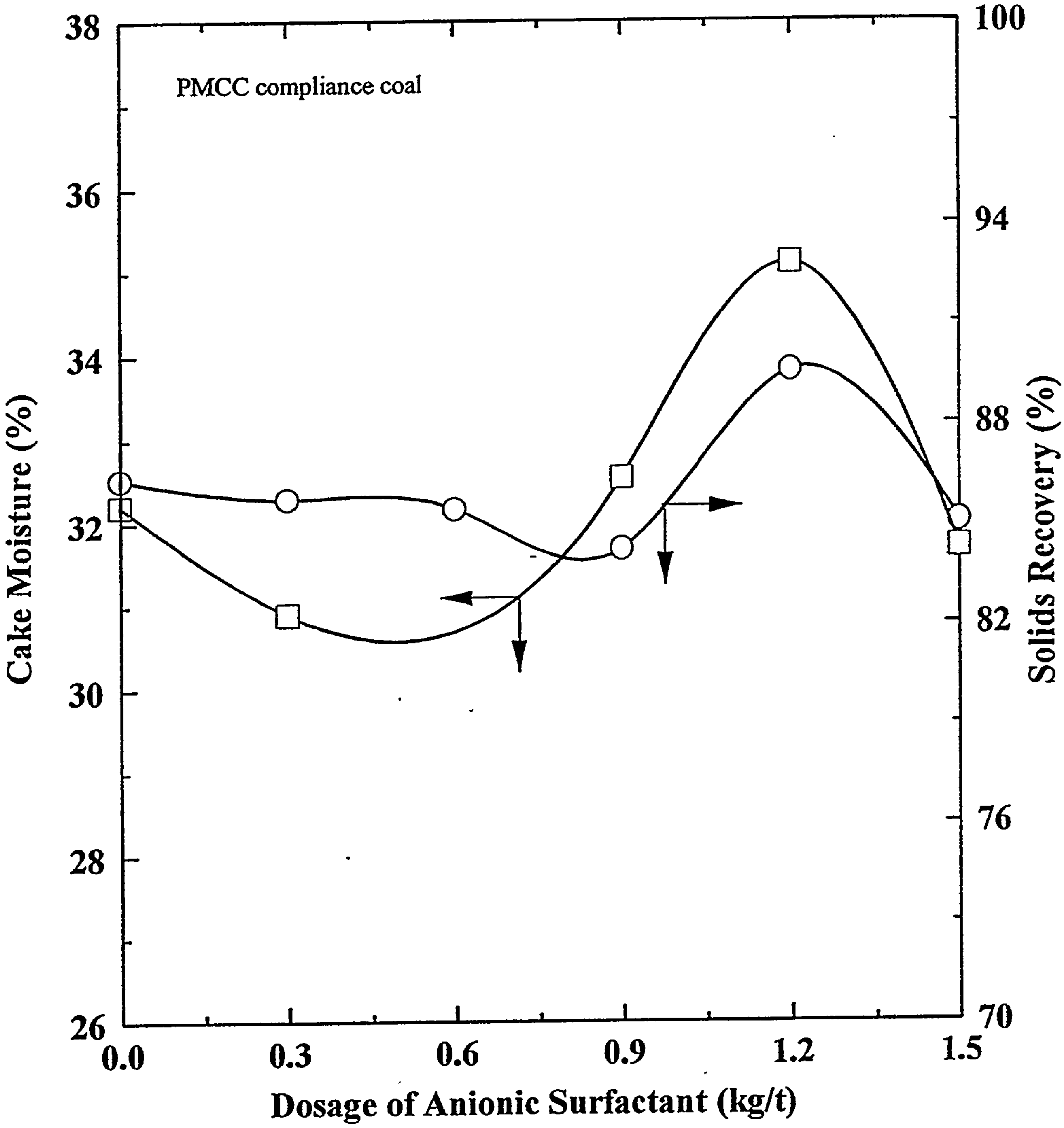

Figure 7. Effects of anionic surfactant on cake moisture and solids recovery with compliance coal

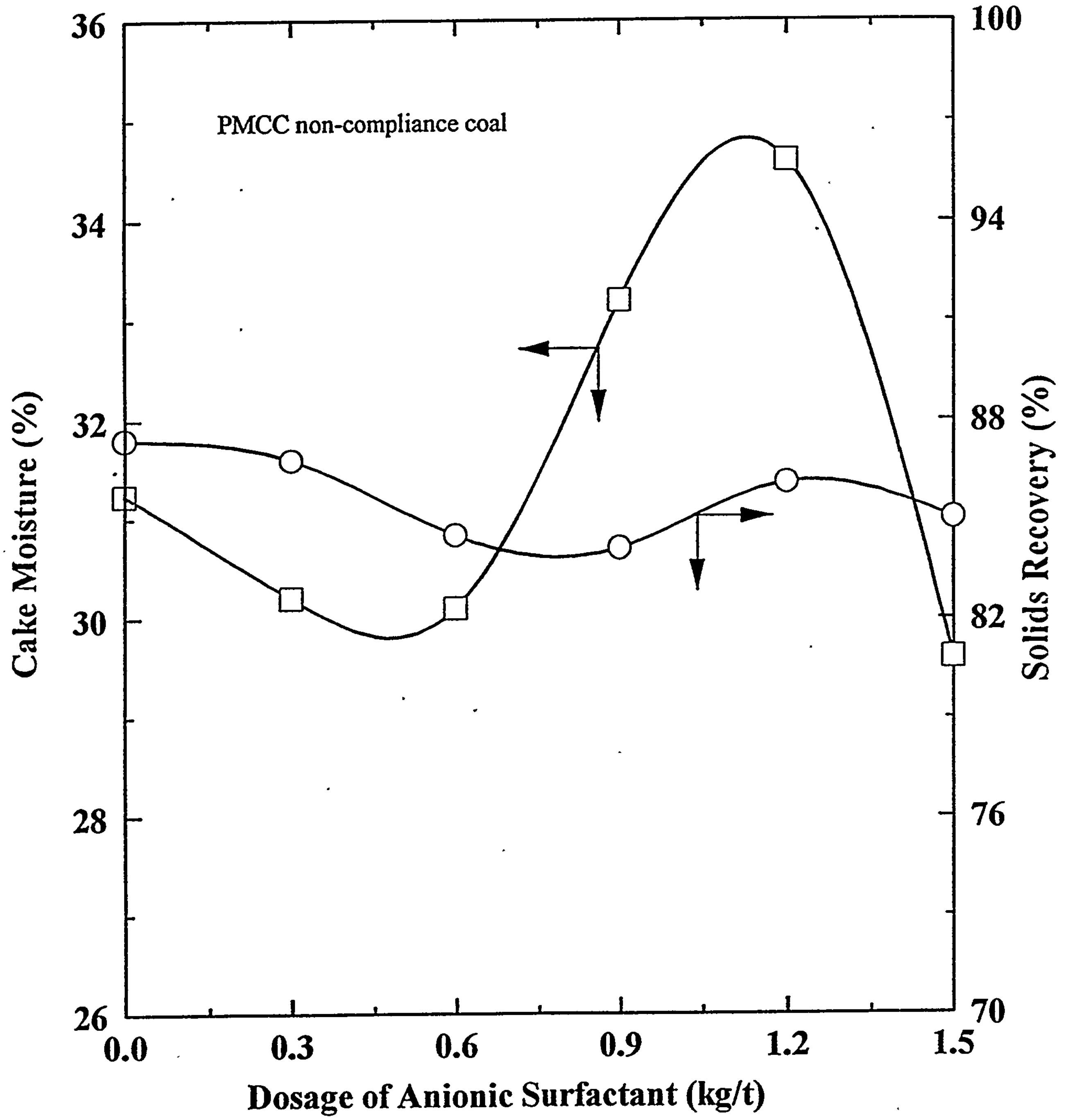

Figure 8. Effects of anionic surfactant on cake moisture and solids recovery with non-compliance coal

one absolute percentage. But at higher dosages of anionic surfactant cake moisture increased significantly. For instance, the cake moisture of non-compliance coal was 34.6% in the presence of 1.2 kg/t of anionic surfactant as compared with 31.3% in the absence of the surfactant. No significant change in solids recovery were observed with both coal samples when anionic surfactant was used.

Effects of non-ionic surfactant on centrifugal dewatering of PMCC compliance and non-compliance coal slurries are shown in Figure 9 and 10, respectively. Figure 9 indicates that centrifugal dewatering performance was adversely affected by the addition of non-ionic surfactant with the compliance coal slurry. For example, a dosage of 0.9 kg/t of non-ionic surfactant increased cake moisture from 30 to 31.8% and reduced solids recovery by about one absolute percentage point (i.e., from 28.7 to 27.9%). The dewatering data obtained for the compliance clean coal slurry with the non-ionic surfactant were very erratic. For example, the cake moisture reduced from 31 to 29.4% in the presence of 0.3 kg/t of non-ionic surfactant but then increased to 33.3% when the dosage was increased to 0.6 kg/t. Increasing the surfactant dosage from 0.9 and 1.2 kg/t reduced cake moisture back to 29.5%. However, cake moisture again increased to 32% when 1.5 kg/t of the non-ionic surfactant was used.

Task 6. System Operation:

In this task, we have completed evaluation of hyperbaric (high pressure) and vacuum filters on dewatering of low sulfur and high sulfur clean coal slurries. In this report, a comparison of both the technologies for dewatering of the high sulfur clean coal slurries is given.

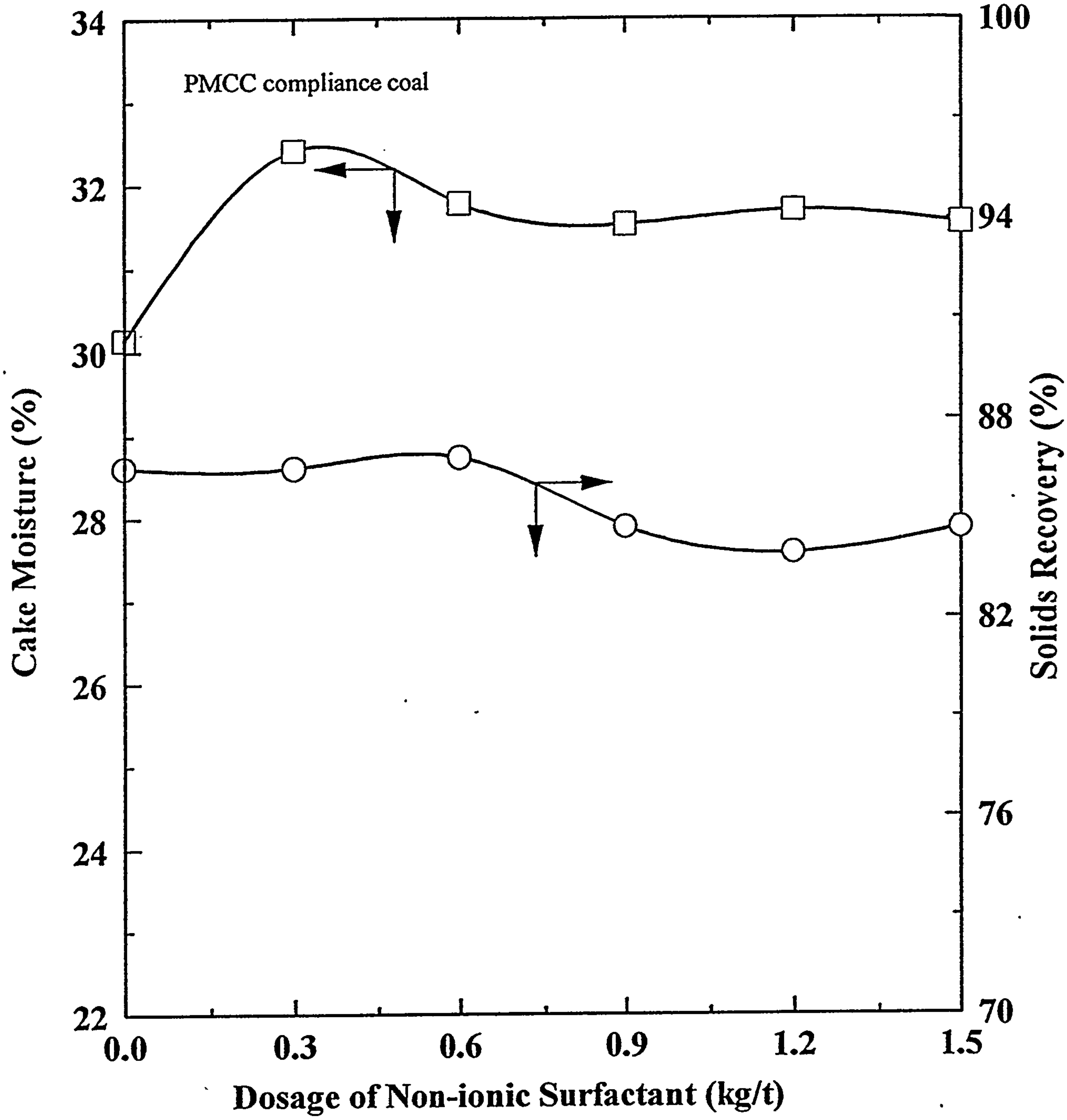

Figure 9. Effects of non-ionic surfactant on cake moisture and solids recovery with compliance coal

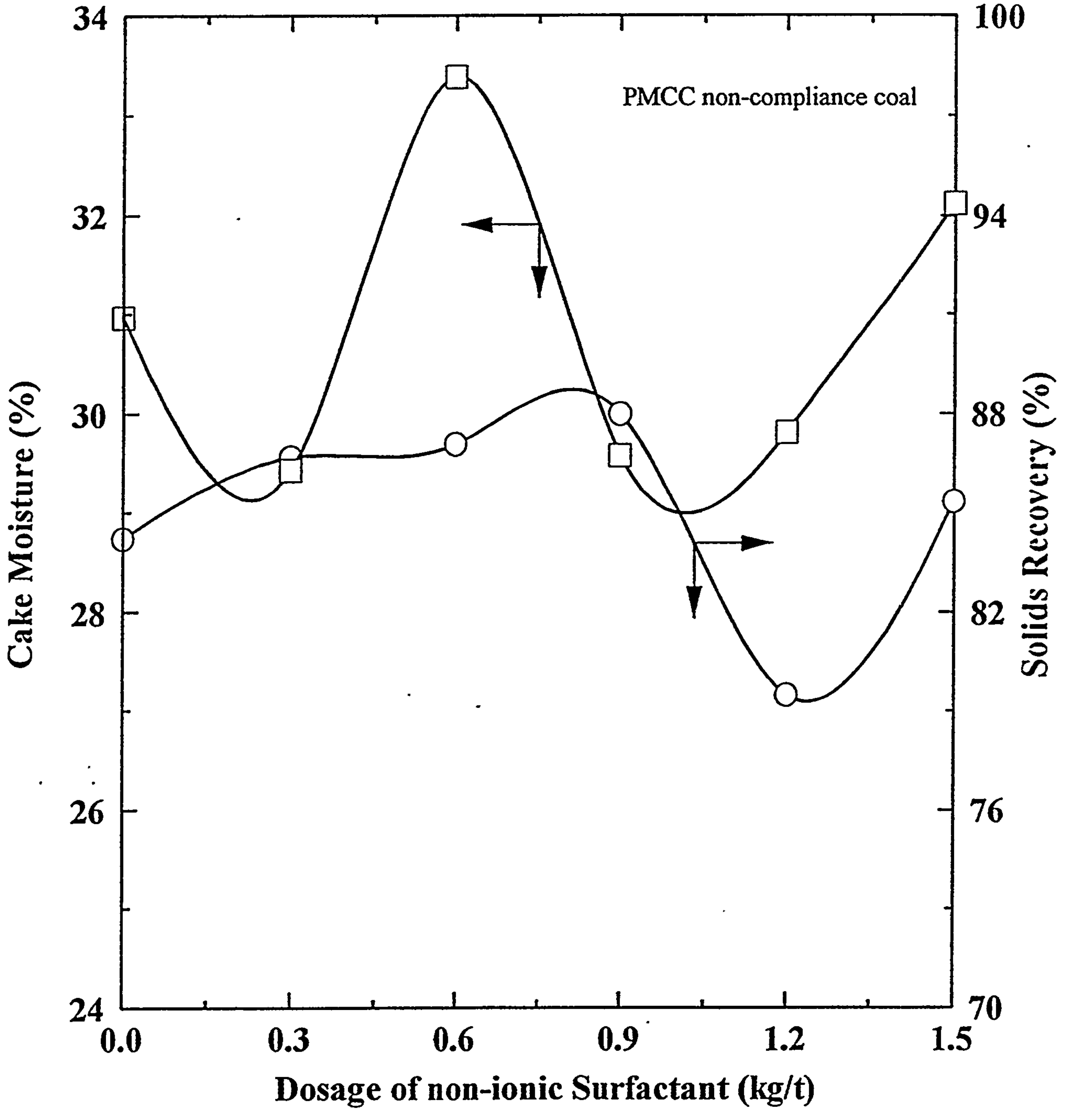

Figure 10. Effects of non-ionic surfactant on cake moisture and solids recovery with non-compliance coal

The pressure filter used in this study was an Andritz hyperbaric unit with a 1.4 meter (4.6 ft) diameter disc filter with 2 m^2 (22 ft^2) filter area. The filter was enclosed in a 2.5 m (8.2 ft) diameter pressure vessel. Baseline testing was conducted to determine the appropriate testing conditions to produce the lowest cake moisture with the highest throughput and minimum air consumption. The baseline conditions selected for the high sulfur coal were 3 bar (43.5 psi) pressure, 1.5 rpm filter speed and a cake formation angle of 165°. These conditions produced a filter cake with 23.6% moisture with a throughput of 165 lb/ft^2/hr with air consumption of 460 scfm/ton.

The vacuum filter used was a WesTech Engineering 0.9 m (3 ft) diameter, 0.6 m (2 ft) width drum with a filter area of 1.7 m^2 (18.8 ft^2). Baseline testing concluded that for the high sulfur coal, a drum speed of 1 rpm and a drum submergence of 30% produced a cake moisture of 27.8% with a throughput of 25 lb/ft^2/hr.

The results reported using various chemical additives were all obtained using the baseline operating conditions described above. When chemical additives were used, a test using baseline operating parameters was conducted before and after each test series.

A comparison of the cake moisture obtained with vacuum and pressure filtration with the anionic flocculant is shown in Figure 11. The anionic flocculant used was Allied Colloids Procol 156 with a molecular weight of 12 million. For pressure filtration, baseline conditions produced a cake moisture of 22.5%. Increasing the flocculant dosage to 15 g/t increased the cake moisture to 25.6%. For vacuum filtration, baseline conditions produced a cake with 27.8% moisture which was reduced to 25.7% moisture with 15 g/t anionic flocculant. Both filters produced

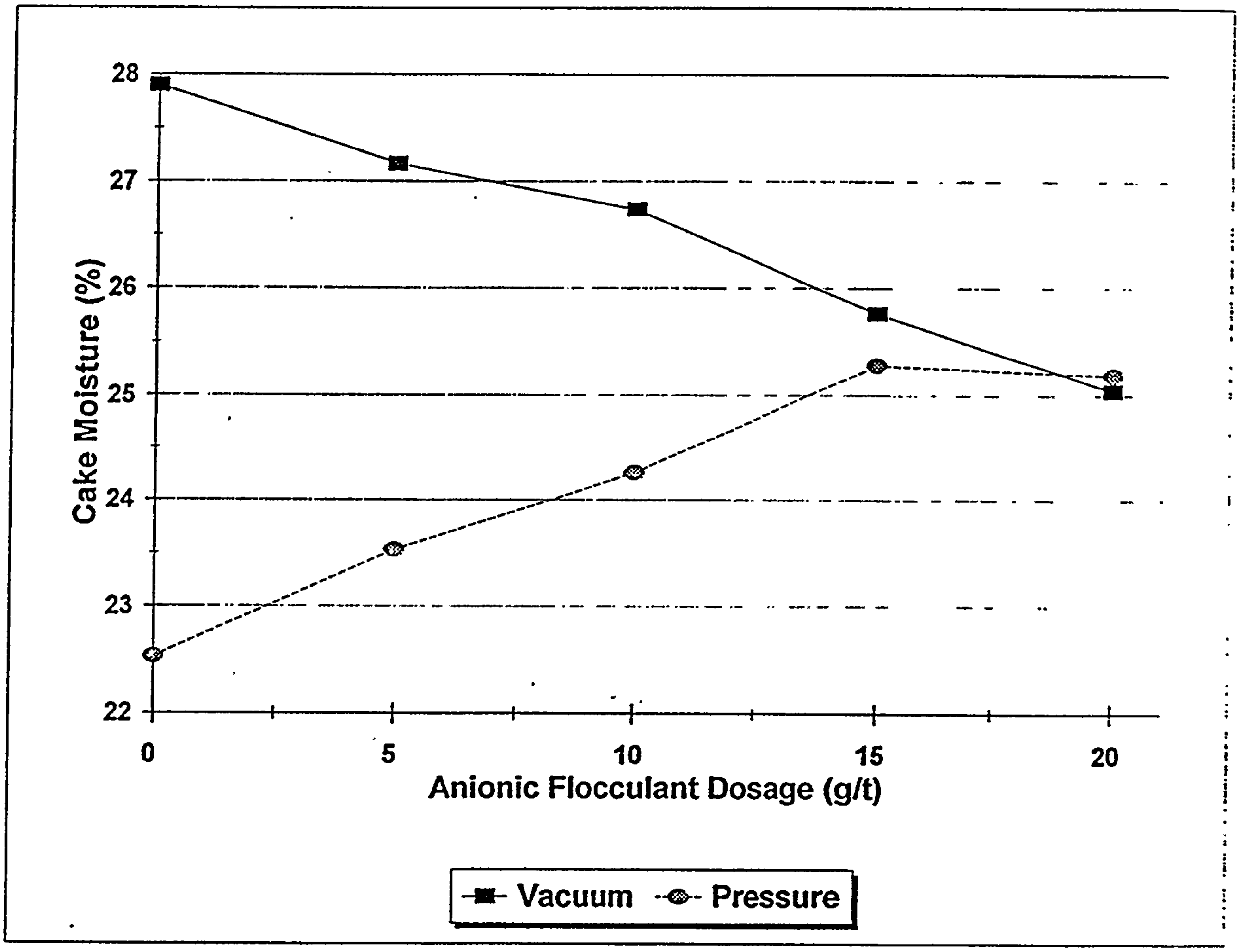

Figure 11. Effect of anionic flocculant dosage on dewatering of low sulfur coal using vacuum and pressure filtration.

cakes with 25.2% moisture with a dosage of 20 g/t. There was a significant difference in the throughput of the different filters as shown in Figure 12. The vacuum filter throughput was 25 to 50 $lb/ft^2/hr$ throughout the flocculant dosage range tested while the pressure filter throughput was 150 to 225 $lb/ft^2/hr$. In general, increasing flocculant dosage increased throughput for both devices. Throughout the testing, the pressure filter provided 3 to 4 times the throughput of the vacuum filter.

The effect of cationic flocculant (Allied Colloids Procol 371, MW 5 million) dosage on cake moisture is shown in Figure 13. No change in moisture occurred with the pressure filter at dosages as high as 15 g/t (23 to 24% moisture) however the cake moisture was reduced to 21% at a dosage of 20 g/t. As with the results obtained with anionic flocculant, the throughput was 3 to 4 times higher than the pressure filter.

Using cationic surfactant (cetyl pyridinium chloride), pressure filtration reduced cake moisture from 22.4% to 19.1% as the dosage was increased from 0 to 0.8 kg/t while little or no change was observed with the vacuum filter as shown in Figure 14. Figure 15 shows the results obtained using anionic surfactant (sodium 2 ethylhexyl sulfate). No significant changes in cake moisture occurred with pressure filtration (23.5% moisture) using dosages as high as 1.5 kg/t. However, with vacuum filtration, cake moisture was reduced from 29.5% to 23% over the same dosage range.

The nonionic surfactant used was octyl phenoxy polyethoxy ethanol. Increasing nonionic surfactant dosage decreased cake moisture with both pressure and vacuum filtration as shown in Figure 16. For pressure filtration, cake moisture was reduced from 21 to 15.9% as the dosage was increased from 0 to 1.5 kg/t while

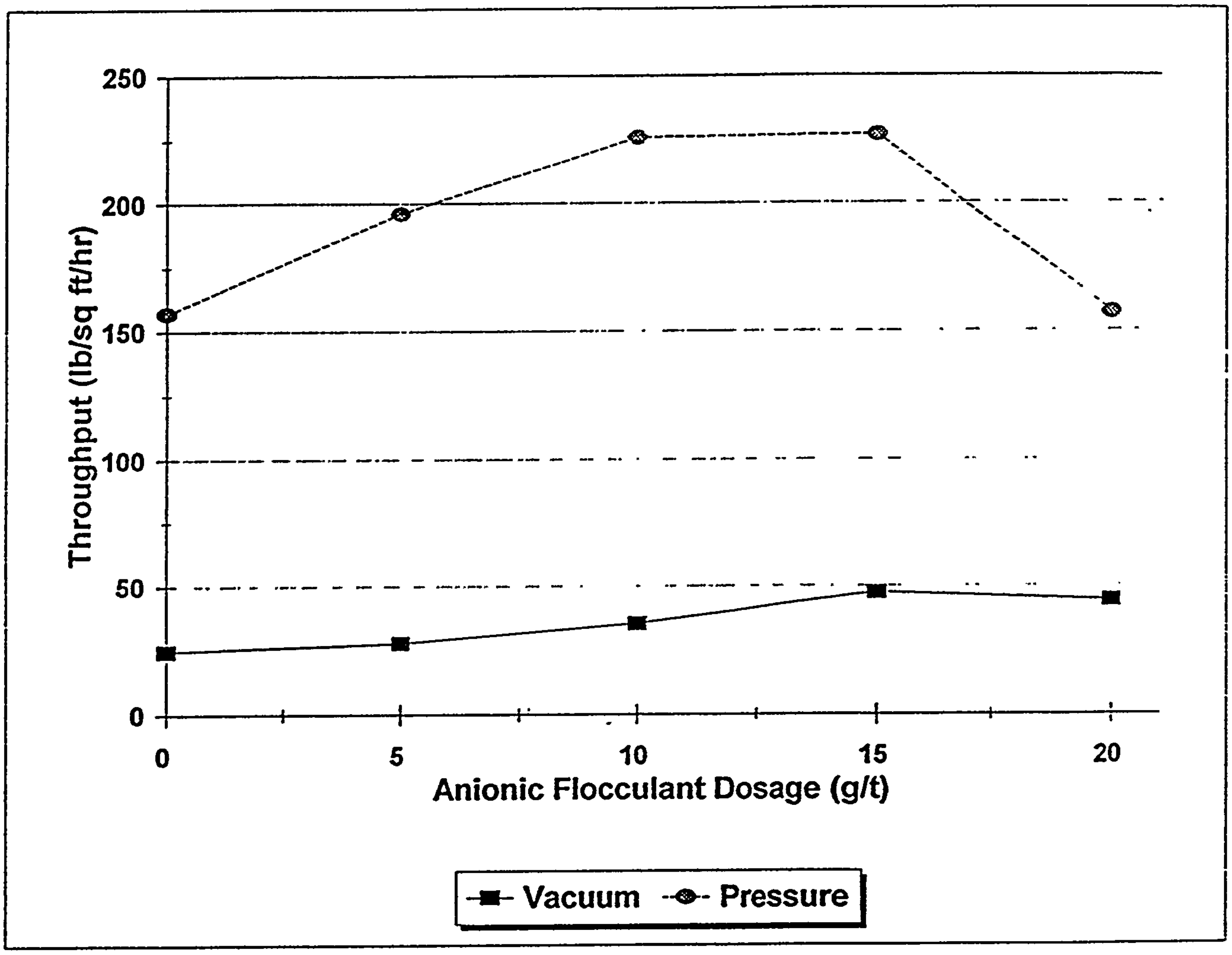

Figure 12. Effect of anionic flocculant dosage on solids throughput using vacuum and pressure filtration.

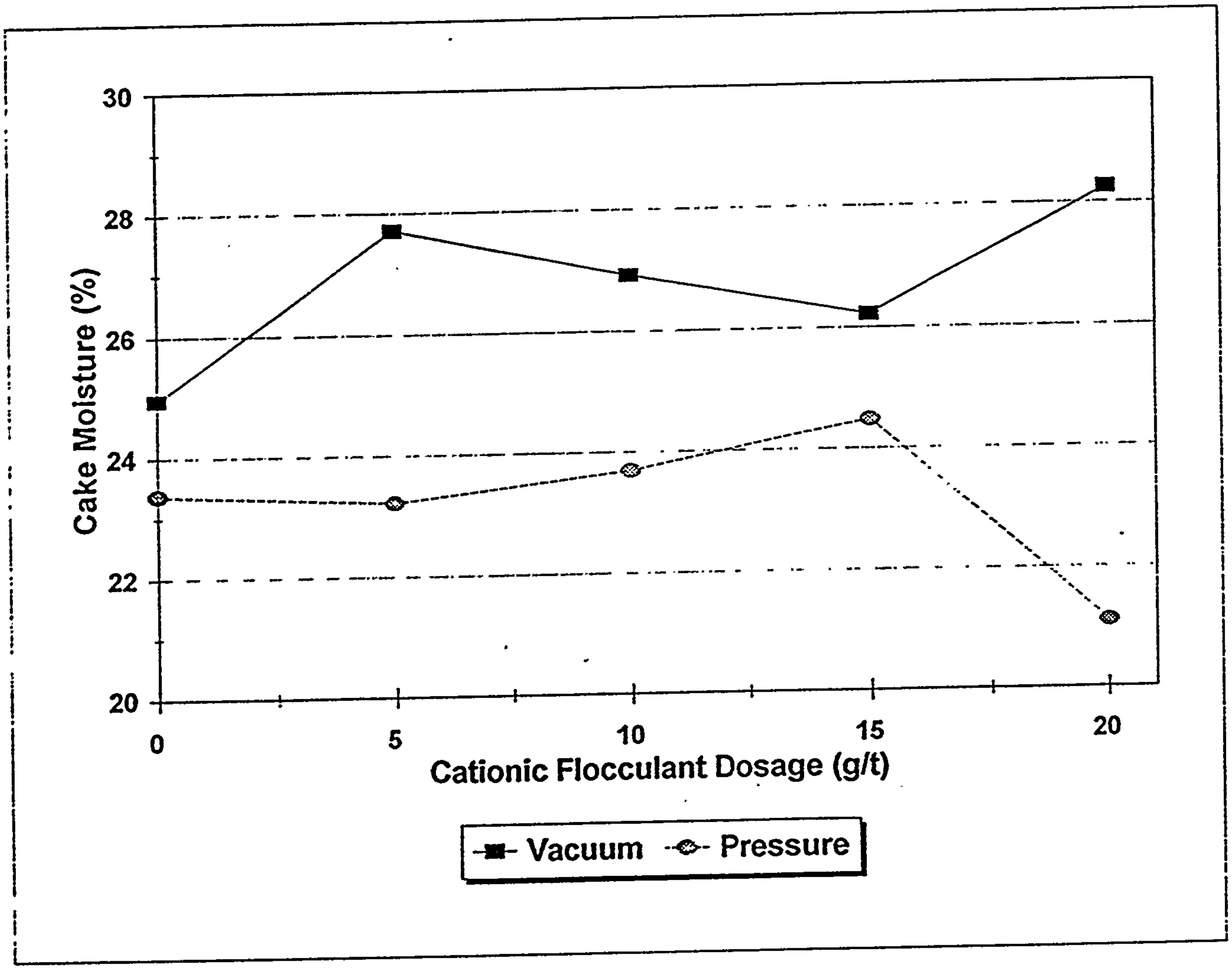

Figure 13. Effect of cationic flocculant dosage on filter cake moisture using vacuum and pressure filtration.

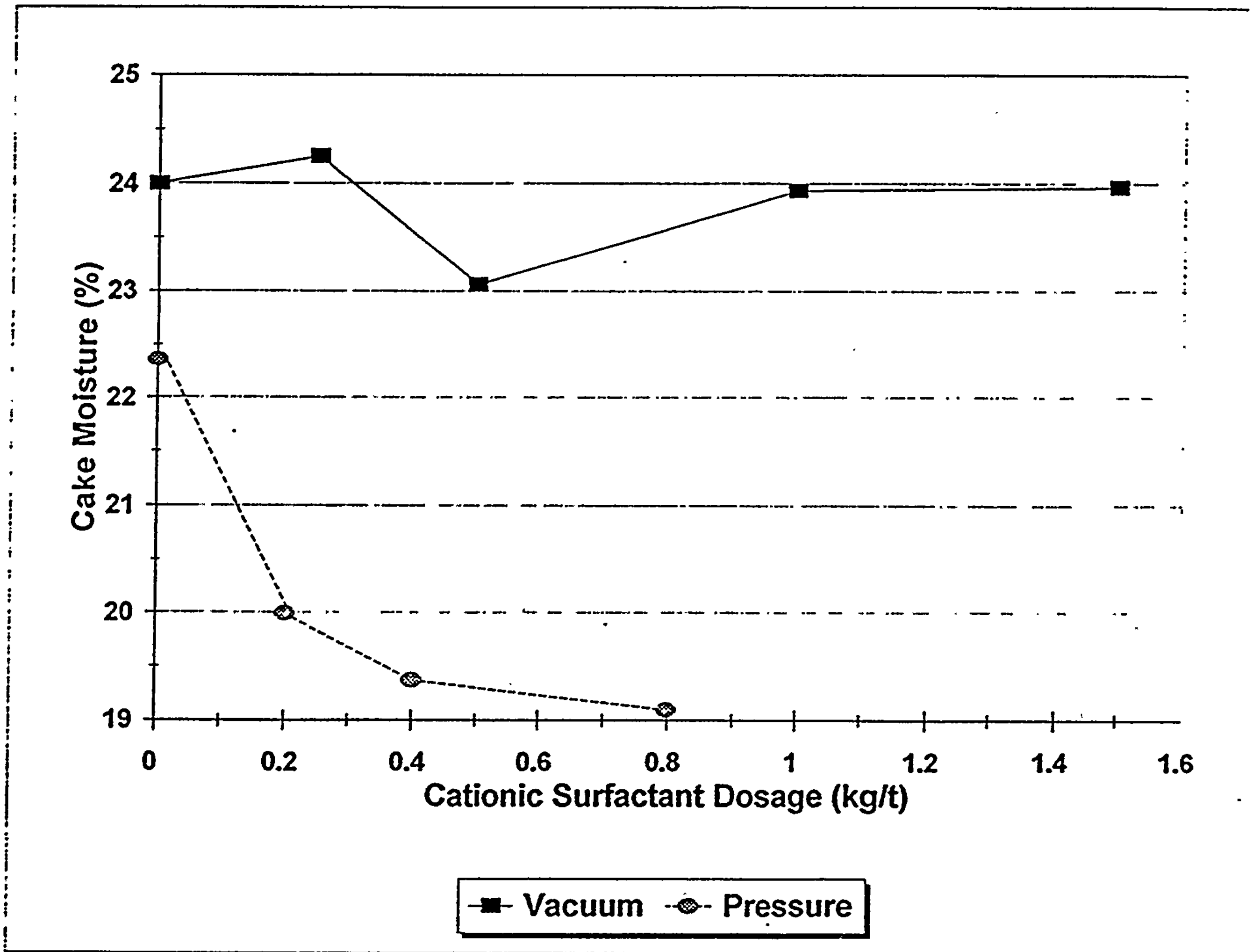

Figure 14. Effect of cationic surfactant dosage on filter cake moisture using vacuum and pressure filtration.

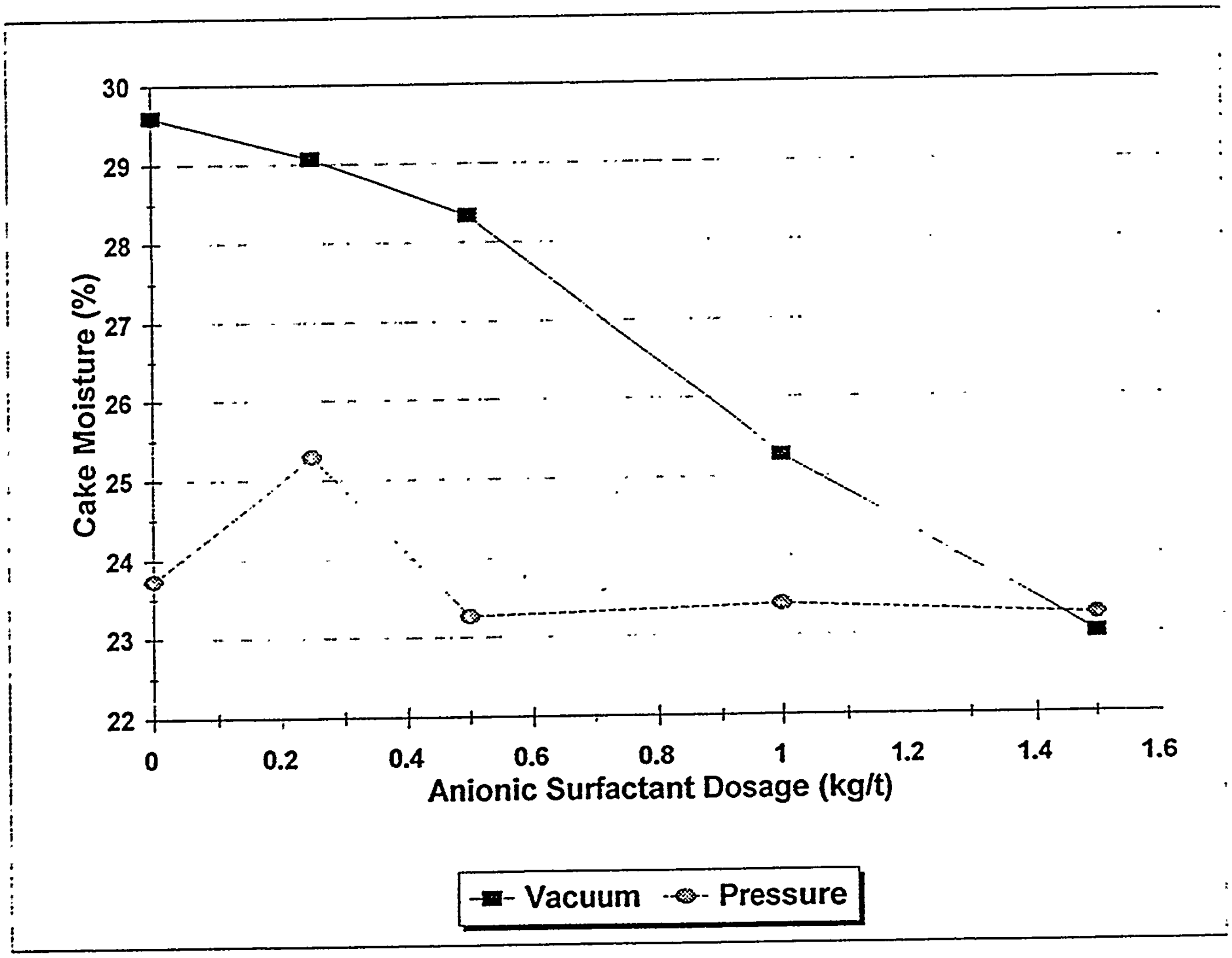

Figure 15. Effect of anionic surfactant dosage on filter cake moisture using vacuum and pressure filtration.

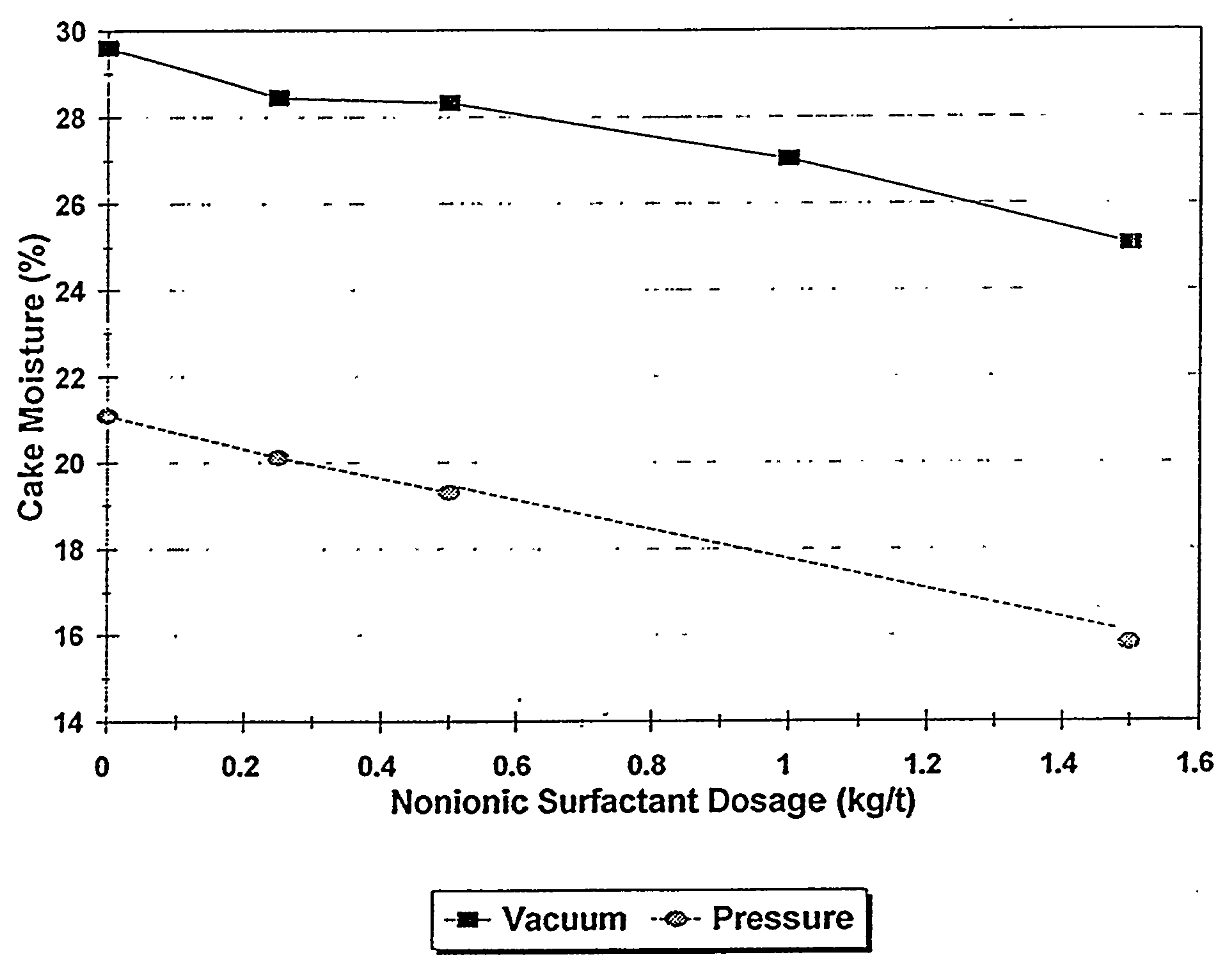

Figure 16. Effect of nonionic surfactant dosage on filter cake moisture using vacuum and pressure filtration.

for vacuum filtration, the cake moisture was reduced from 29.6 to 25.2% over the same dosage range.

The results obtained using copper chloride solution ($CuCl_2$) are shown in Figure 17. Using pressure filtration, cake moisture was reduced from 23.2% to 20.7% with the addition of 250 mg/kg $CuCl_2$. Higher dosages did not provide any additional moisture reduction. Using vacuum filtration, cake moisture was reduced from 27% to 24.8% with a dosage of 500 mg/kg $CuCl_2$. As with pressure filtration, higher $CuCl_2$ dosage did not provide any further moisture reduction.

CONCLUSIONS

- The laboratory centrifugal dewatering studies showed that using 30 sec. centrifugation time at about 1700 'g' force, both the low sulfur and high sulfur coal provided about 32% moisture filter cake. Addition of 0.3 kg/t of the cationic surfactant lowered filter cake moisture to 29% for the low sulfur coal slurry. For the high sulfur coal slurry a 28% moisture filter cake was obtained using 1.5 kg/t of the surfactant.
- Addition of an anionic and a non-ionic surfactant did not provide any significant reduction in filter cake moisture contents.
- Both the high pressure and vacuum filters were effective in providing a low moisture filter cakes. However, high pressure filter provided 23.6% filter cake moisture compared to 27.8% obtained with the vacuum filter.
- Addition of about 20 g/t of the anionic flocculant both filters provided a 25.2% moisture product. It appears that, in case of high pressure, the moisture entrapped in flocs could not be removed, which provided a little higher moisture product. However, the solids throughput was about 3 to 4 times higher in

pressure filtration compared to vacuum filtration.

- Cationic flocculant was effective in lowering filter cake moisture to 21% at a dosage of 20 g/t using high pressure filter.
- Addition of 0.8 kg/t of the cationic surfactant lowered the filter cake moisture to 19.1% whereas addition of 1.5 kg/t of nonionic surfactant lowered the filter cake moisture to 15.1%, using the high pressure filter. For both of the surfactant vacuum filter provided 23 to 25% moisture filter cakes.
- Addition of 500 mg/kg copper chloride ($CuCl_2$) lowered moisture to 20.7% using high pressure and 24.8% using vacuum filter techniques.

In general, high pressure filter was more effective in lowering the moisture content of filter cake using reagents and also provided 3 to 4 times solids throughput compared to vacuum. However, from the capital and operating costs point-of-view, vacuum filter will be much lower in comparison to high pressure.

ACTIVITIES FOR NEXT QUARTER

Laboratory centrifugal dewatering tests will be continued in the next quarter. Reagents to be investigated include two types of flocculants, two types of metal ions, and combinations of three surfactants and two metal ions.

Work will be initiated with a small-scale continuous vacuum filter to investigate significance of various operating factors in vacuum dewatering. Statistical design of experiments will be employed to accomplish this task. Once this work is finished, optimum operating conditions for vacuum dewatering will be identified.

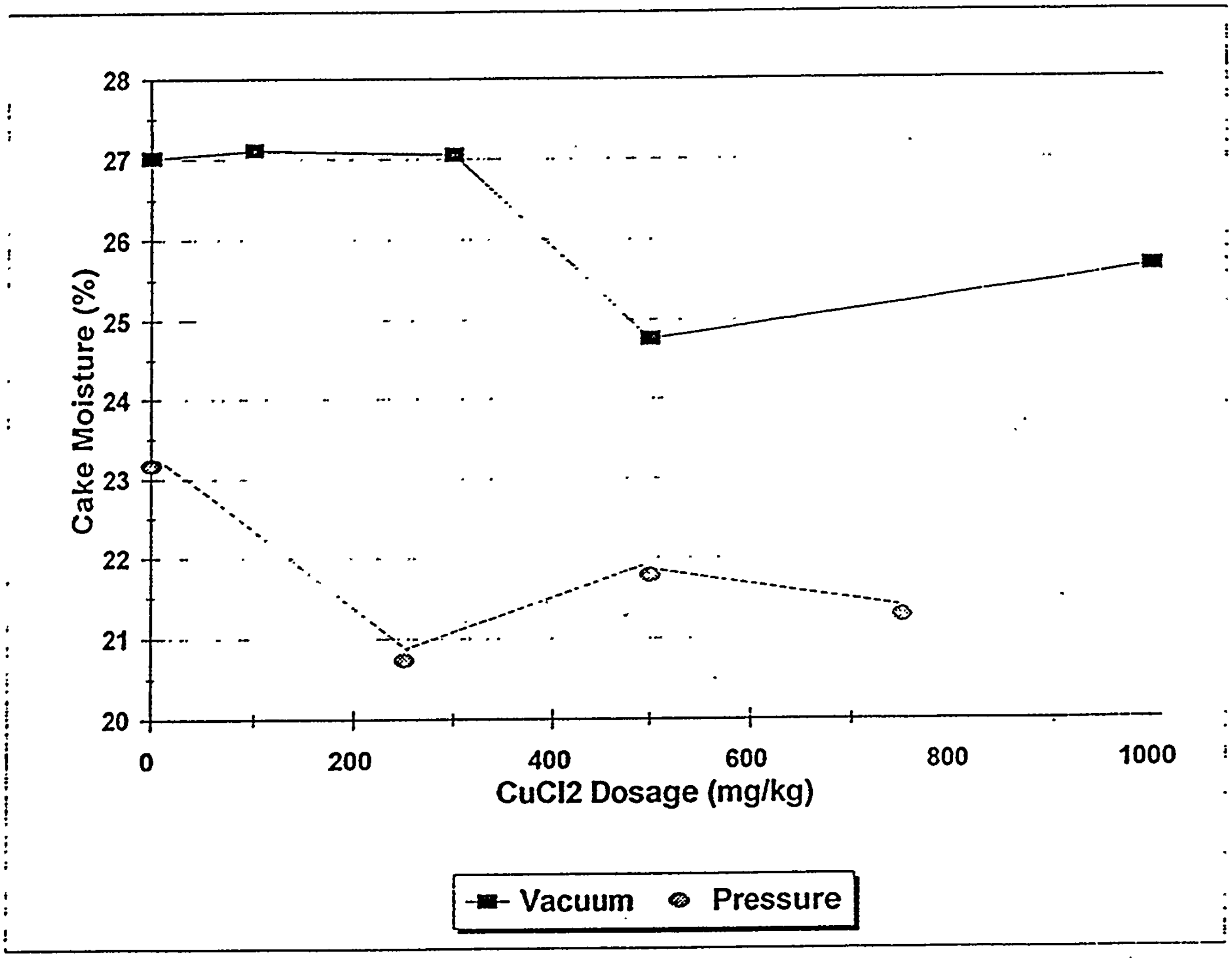

Figure 17. Effect of $CuCl_2$ dosage on filter cake moisture using vacuum and pressure filtration.

Pilot plant testing using the 18-inch diameter Decanter centrifuge will be continued using various reagents. We also plan to conduct a few tests with USDOE/PETC developed process using oriemulsion. These tests will be conducted in joint collaboration between the UKCAER and PETC scientists.