DOE/PC/90177--T11

EVALUATION, ENGINEERING AND DEVELOPMENT OF ADVANCED CYCLONE PROCESSES

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QUARTERLY TECHNICAL PROGRESS REPORT

Quarterly Report #16
For The Period July 1, 1994 to September 30, 1994

Work Performed Under DOE Contract # DE-AC22-90PC90177

For

U.S. Department of Energy
Office of Fossil Energy
Pittsburgh Energy Technology Center
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By

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EXECUTIVE SUMMARY

The project goal is to develop an advanced coal beneficiation technology that can achieve high recovery of the parent coal's calorific value, while maximizing pyritic sulfur removal. Coal cleaning is to be accomplished by physical means incorporating an advanced gravimetric process. Evaluation of different media types and their attendant systems for recovery, concentration, and regeneration is to be completed.

Phase I, Media Evaluation, now completed, involved a paper study and a number of laboratory tests to eliminate all but the best media options. Phase II, Media Testing, involved detailed testing of the more promising media and separators in a closed–loop pilot facility.

In the final phase, Phase III, it is proposed to test individual components of the process using the optimum medium, separator, and medium recovery system(s) selected in prior phases.

Major activities and developments that occurred during this reporting period are reviewed below.

CTC prepared for and participated in the Contractors Conference held July 18, 19 and 20, 1994, during which a draft of the pending revised Work Plan was provided and informally discussed. Recent revisions have focused on the scope of the component testing program for the disk filter and decanter centrifuge.

Management and Technical Services (MATS), an engineering consulting firm headed by Mr. Ed Zawadzki, was retained to prepare a preliminary economic study. As a result of the study a report entitled "Technical and Economic Factors Affecting Calcium Nitrate Process" was submitted focusing on means to reduce process costs. The report is included as Appendix A.

INTRODUCTION

"Evaluation, Engineering and Development of Advanced Cyclone Processes" is a research and development project aimed at reducing of pyritic sulfur in coal products. Minimum project goals are to produce a 6% product ash and 85% pyritic sulfur rejection while retaining 85% of the parent coal's heating value. A number of media and separator options are to be evaluated and tested and performance characteristics of critical process components investigated in a 1,000 lb/hr closed–loop test stand constructed on a site provided by Coal Technology Corporation (CTC) in Bristol, Virginia.

The project involves the physical beneficiation of coal based on the density differential that exists between clean coal and its impurities, i.e., pyrite and ash bearing minerals. Coal may be beneficiated by employing a parting liquid or pseudo–liquid with a specific gravity between that of coal and its impurities. A number of parting liquids (separating media) were considered for evaluation and testing in this program. They represented three families of liquids: aqueous solutions, organic liquids, and aqueous suspensions. The aqueous suspensions of starch and solutions of sugar, though environmentally benign, were dropped from consideration early in the program because of their high viscosity and handling difficulties. Micronized magnetite, an aqueous suspension, was also dropped because another firm plans to develop it to commercialization.

Except for the aqueous suspensions, the candidate media may be classified as true heavy liquids. True heavy liquids are not affected by the multiple gravities (g) required in fine coal gravimetric separation processes, whereas suspensions may deteriorate if subjected to excessive g force. Multiple gravities in combination with true heavy liquids can be used to increase the speed and efficiency of separation of particles of small size having slight differences in density. Generally, the higher the gravity, the more precise the separation. This implies the use of small diameter, high–pressure cyclones or high gravity centrifuges. Therefore for this project, the term cycloning encompasses centrifuges and other enhanced–gravity devices where fluid motion or mechanical motion is converted to centrifugal force.

Task 1 - Project Planning and Management

Task Description or Objective(s): The objective of this task is good technical and fiscal control and management of this project, both internally and externally, by Coal Technology Corporation (CTC), the prime contractor. CTC is responsible for interfacing with the DOE and ensuring that all subcontractors fulfill their responsibilities and meet the milestones and goals of the Project Work Plan. The subcontractors are:

- Process Technology, Inc. (PTI) – providing analytical services and conducting Phases I and II laboratory and closed–loop media testing.

- ICF Kaiser Engineers, Inc. (ICF–KE) – performing detailed design of a 1000 lb/hr Bench Scale Circuit.

- Intermagnetics General Corporation (IGC) – providing media, separator, and technical service for magnetically enhanced media.

Project management is an ongoing effort designed to monitor the subcontractors, keep the project running smoothly, resolve problems, and in general ensure that the project is performed on a timely and cost–effective basis.

Activity: Due to the limited funds remaining in the project budget it was decided to undertake component testing rather than the construction and testing of a complete integrated circuit as originally planned. Critical components include size reduction, separation, and filtering systems. It is also proposed that evaporative studies investigating pH variation, corrosion potential, and medium condition be performed by a qualified vendor. Several revisions of the Work Plan were developed during this reporting period, with work concentrating on defining the test matrices utilized in component testing and defining the costs to perform them. Finalization and approval of the revised Work Plan is pending.

Task 2 - Coal Procurement and Characterization (Three Phases)

Task Description or Objective(s): The objective of this task is to provide characterized feedstock for all three phases of the program. The three phases are associated with: (I) Separating Media Evaluation, (II) Separating Media Testing, and (III) Process Optimization Testing. A total of four coals have been selected for the program. The four coals constitute a substantial reserve, are technically difficult to clean, and contain significant amounts of pyritic sulfur. The characterization determined the degree of liberation needed to reach the project goals. This information will be used as a database for the entire program and to measure the performance of individual tests.

The project's requirements for the four coals include:

- Raw coals must have moderate to high pyritic sulfur contents that are not sufficiently liberated in conventional cleaning.

- Precleaning operations must recover 90 to 95% of the parent raw coal's heating value while principally removing coarse rock and fine clays.

- Raw and clean coal handling systems must facilitate readily obtaining one–to–two ton samples of the raw and precleaned coals for Phase I and III characterization

Activity: No activity during this period.

Task 3 - Evaluation Plan and Test Plan Formulation

Task Description or Objective(s): Task 3 represents the planning stage of the work that will be conducted during Phases I through III of Task 6. It is the technical basis of the program and provides for evaluating the media by paper study supplemented by laboratory study, selection of medium and separator combination, and implementation of one medium/separator option for long–term, open–loop testing. The three phases of this task are:

- Phase I — Media Evaluation
- Phase II — Separating Media Testing
- Phase III — Process Optimization Testing

These plans detail Task 6, Scope of Work.

Activity: The Separating Media Evaluation Plan was approved by DOE in February, 1991. The Preliminary Separating Media Evaluation Report contains the Separating Media Test Plan, which was carried out during Phase II. A draft Process Optimization Test Plan for Phase III was submitted on December 18, 1992, intended as a plan for an integrated circuit. The pending Work Plan would require a Component Test Plan instead.

Task 4 - Bench Scale Test Circuit Design

Task Description or Objective(s): This completed task has provided the design of a fully–integrated bench–scale advanced cycloning test circuit (BSC). The design of the advanced cycloning test circuit was based on the Separating Media Evaluation and Testing results (Phases I and II) and the detailed characterization of the four proposed test coals. ICF–KE was the lead team member for Task 4.

The BSC design fully integrates all pretreatment, cleaning, and post–cleaning operations necessary to allow continuous steady–state operation including at least one (1) uninterrupted run of 100 hours duration for each of the four test coals.

Activity: No activity during this period. The revised Work Plan suggests that the bottom portion of the BSC design be used in erecting a smaller facility designated as Component Test Stand (CTS). The CTS will allow closed–loop testing of the capillary action filter and the Sharples P–3000 decanter centrifuge in lieu of the fully integrated circuit (BSC) previously planned.

Task 5 - Bench Scale Test Circuit Set-Up and Commissioning

Task Description or Objective(s): This task covers the functions necessary to construct and commission the Bench Scale Circuit module at CTC in Bristol, Virginia. The construction will be performed by an experienced contractor with construction management provided by CTC. The start–up will be supervised by CTC and performed by craft labor supplied by the construction contractor.

Activity: This activity is on hold pending approval of the revised Work Plan. The pending Plan proposes construction of a Component Test Stand (CTS) utilizing the bottom portion of the BSC structure, as designed.

Task 6 - Evaluation and Test Plan Implementation

Task Description or Objective(s): This task consists of the technical implementation of plans produced and approved under Task 3. Please refer to the project Separating Media Evaluation Plan and Separating Media Test Plan.

Phase I - Media Evaluation

Activity: The media evaluation has been completed and reported in the revised Preliminary Separating Media Evaluation Report (PSMER) during a prior reporting period. In the PSMER, methylene chloride/perchloroethylene, calcium nitrate/water, MEM (Magnetically Enhanced Media) and water were selected as media for inclusion in the test matrix for performance testing during Phase II.

Phase II - Separating Media Testing

Activity: At the conclusion of Phase II calcium nitrate was selected as the preferred medium as reported in the Final Separating Media Evaluation and Test Report (FSMER).

Phase III - Process Optimization Testing

Activity: It is proposed in the pending Work Plan revision that Component Testing replace Process Optimization Testing.

Task 7 - Data Analysis and Reporting

Task Description or Objective(s): This task takes place throughout the project to keep up with day–to–day data logging and reporting requirements. Dissemination of data to the Project Team members is vital to the project. Analysis and interpretation of the data are critical to this task. Numerous reports are required during the life of the project. Technical reports required under the contract include the following: Biweekly and Quarterly Progress/Status Reports, Washability Analyses Report, Preliminary Separating Media Evaluation Report, Final Separating Media Evaluation and Test Report, and the Final Report.

Activity: The Biweekly and Quarterly reports have kept DOE informed concerning the progress of the project. Other reports and plans are covered under their applicable Tasks.

Management and Technical Services (MATS), an engineering consulting firm, was retained to prepare a preliminary economic study. The resulting report, entitled "Technical and Economic Factors Affecting Calcium Nitrate Process," focused on means to reduce process costs. The Report is included in Appendix A.
The suggested methods to reduce process costs are: 1) utilize a coal fired boiler for evaporator steam production, 2) produce calcium nitrate on site, 3) develop a means to enhance medium recovery (medium disengagement) and, 4) utilize counter current washing on coal and refuse cakes.

As a result of the MATS report, a program to study the mechanism of medium attachment to coal solids was added to the pending Work Plan. The goal of the program is to reduce process operating costs by improving medium recovery rates through enhanced medium disengagement from refuse and clean coal solids.

MATS will also be retained to perform a final economic study for the Final Report.

Task 8 - Conceptual Design

Task Description or Objective(s): This task is performed with the objective of providing DOE with a conceptual description and detailed estimate of the cost to construct and operate a 20 tph advanced cycloning test module. This is a modification to the contract, which originally called for detailed design of a 3 tph circuit. CTC will be the lead team member for Task 8. This Task involves the conceptual design of a fully integrated, continuous operation, advanced cycloning test module. The conceptual design will be sized for 20 tph feed rate and will include all necessary pre–treatment, cleaning and post–treatment unit operations. The conceptual design will be based on the results of the Process Optimization Tests (Component Tests) performed under Phase III of Task 6.

Activity: No activity during this period.

Task 9 - Final Reporting

Task Description or Objective(s): The Project Team members will submit a Draft Final Technical Report in the 41st month of the project. This report will be preceded by a detailed outline to be reviewed by the DOE. The final report will meet contract requirements as stated in the Project Work Plan and will comply with DOE Order 1332.1A (Uniform Reporting System).

Activity: No activity during this period.

Task 10 - Decommissioning

Task Description or Objective(s): CTC shall be responsible for decommissioning, protecting, removing, and disposing of all contractor–installed property encompassed by the contract. Contractor–procured Government property shall be protected and dispositioned as directed by the DOE Contract Officer. This is strictly limited to the cost of decommissioning, removal, protection, and shipment from CTC to PETC.

Activity: No activity during this period.

APPENDIX A

Review of Technical and Economic Factors Affecting the Development of the Calcium Nitrate Process for Fine Coal Cleaning

Introduction

Coal Technology Corporation is developing a new fine coal cleaning process which utilizes aqueous Calcium Nitrate solutions as the separating medium. Laboratory scale tests have shown that sharp separations are possible with this new technology. The technology is further enhanced by the utilization of an improved separating device. This device uses a commercial centrifugal separation device which provides high throughput while maintaining good separations of fine coal.

The purpose of this study is to examine the obstacles to finalizing the design of a demonstration test unit and to provide alternative solutions to problems encountered in the evaluation of the existing process. No significant technical constraints are apparent from a review of the available data on this concept. The principle concerns are the operating cost, specifically the cost of recovering spent calcium nitrate solutions from the clean coal and reject streams.

The current process flow diagram recovers calcium nitrate using a disk filter with one stage of rinsing. The concentrated medium is recovered as "dense medium" and reused. The quantity of rinse water used is such that significant thermal energy must be used to concentrate the dilute medium to a concentration usable in the process. Further the concentration step uses a conventional multi stage evaporator. While this device is highly efficient, it requires the use of natural gas as a fuel. The process operating expenses, including capital recovery, labor, power, and maintenance, appear to be comparable with other processes of this type and even with commercial conventional coal preparation processes. It is the energy cost and the replacement cost of calcium nitrate which currently drive up the economics of the technology .

There exists a significant need for technology of this type to succeed and to be commercialized. More rigorous environmental regulations will shortly require the coal burning utilities to meet SOx, NOx, CO2 and Air Toxic regulations which if forced to meet these regs by the addition of post combustion technology, will drive the cost of power generation to significant levels. DOE goals of capping the increase in utility rates due to post combustion control of air contaminants to 40% may be difficult. Pre combustion technology is required to, at the very least, reduce the overall economic impact of post combustion control of air contaminants.

With this in mind, MATS has proposed a number of alternatives to the basic CTC flowsheet for the $Ca(NO_3)_2$ process. If adopted and proven technically feasible, these alternatives will enhance the technology, and in fact provide a pattern for use in other similar technologies.

Description of the CTC Process

Details of the process have been presented by CTC in various publications and technical reports. In essence the technology consists of precleaning coal using conventional technology to remove coarse contaminants, milling the clean product to fine sizes to liberate additional minerals, gravimetric separation of the residual minerals using aqueous calcium nitrate solutions using a *****developed for use with this technology, recovery of "dense medium" using standard dewatering equipment, then rinsing the residual calcium nitrate off of the coal and refuse using high volumes of rinse water. The rinse water is concentrated by evaporation using multi effect gas fired evaporators.

The single most important economic impediment to the process is the recovery of calcium nitrate. From the standpoint of process development however, it should be solvable by using technology currently or previously used in other industries. This technology transfer needs to be reviewed and evaluated by CTC and DOE however it is functional and can easily be implemented in subsequent extensions of this project.

Recovery of Calcium Nitrate

a. Observations on analytical methodology currently in use to measure Calcium Nitrate losses. - An indirect method is currently in use to provide data on the residual calcium nitrate in the clean and refuse products. The method involves analysis for calcium, correction of calcium value in untreated coal, and then calculation of the quantity of calcium nitrate from the calcium analysis. The method used involves standard chemical procedures, however, at least one anomaly exists which should encourage the project team to evaluate alternative methods of analysis. There is a significant difference between the quantity of calcium nitrate lost in the refuse compared to the clean coal. The question arises , are there interferences due to other chemical species present which cause these differences. One explanation is that the physical character of the refuse is sufficiently different to "hold" more calcium nitrate. If this is so, then we should be able to remove the highly soluble calcium nitrate by more extensive washing. Apparently this has been tried but without changing the residual content of calcium nitrate in the refuse. I believe that alternative methods of analysis should be explored, especially one which uses a direct method for nitrate. A specialist in the field of analytical chemistry should be consulted.

The significance of the analytical method accuracy is great and affects decisions related to the recovery process. This matter should, at the very least, be reviewed by a competent third party.

b. Rinsing procedure.

Tests conducted by others have shown that, with the current equipment, a ratio of rinse water to solids of 1.3 is required to reduce calcium nitrate levels in the clean coal and reject to ******* and ****** per ton of solid material. There are alternatives to this approach of high volume of rinse water for removal of dissolved species. The best of these is the procedure called by some reverse cascade rinsing wherein the volume of fresh rinse water is controlled to minimize the subsequent processing of waste water or in this case to minimize the quantity of thermal energy required to recover the calcium nitrate medium.

This technology basically uses multiple stages of rinsing with the last rinse being a controlled amount of fresh water. The intermediate rinses are concentrates received from prior washes.

Another alternative is to use a larger number of rinses with less volume of total rinse water than is currently used. Consider the following:

Currently the rinse rate is set at 1.33 tons of water per ton of dry solids. This is equivalent to a rinse rate of 319 gallons per ton of coal. The current cost of concentrating this quantity of solids to "dense medium" is approximately $9.19/tons of feed coal. The residual calcium nitrate in the "rinsed product" is estimated to be 54 pounds of calcium nitrate per ton of feed coal. The nitrate loss adds $16.60/ton of feed coal. As a comparison, magnetite losses for minus 100 mesh fine coal cleaning in dense medium cyclones are of the order of 2 to 3 pounds of magnetite per ton of product. Magnetite sells for 3 to 4 cents per pound.

Using multiple rinsing with smaller volumes of water per rinse could reduce the evaporation costs to about $5.55/ton of coal and more importantly could reduce calcium nitrate costs to $1.12/ton of coal. The residual nitrate would be reduced to about 0.14 tons/ton of coal due to the increased number of rinses.

Table 1 summarizes a case where the number of washes is increased to 9, but the total rinse water used is 1.13 tons per ton of coal. The summary economics are shown in Figure 1 and Table 2.

As in the reverse cascade rinse, the equipment of choice for this unit operation would be a vacuum belt filter with alternating drain and rinse sections.

Use of coal firing for evaporation.

The firing of coal rather than natural gas would impact the operating costs even further. Natural gas, for this and previous economic studies reported by CTC, is proceed at $3/MM Btu. Coal firing should reduce the cost of evaporation by at least 50 % or more. Coal ash from the coal firing would not be an unacceptable contaminant in the densified medium. However, if it is found to be undesirable, then an indirect coal fired evaporator could be used. For installations located near a utility plant waste heat in the form of flue gas or low pressure steam could also be provided. The also exists new evaporation technology which uses pulsed combustion for direct fired evaporation. Commercial applications of the pulsed combustion evaporator/dryer exists. As far as is known, this technology has not been applied to coal drying but has been applied to concentrating solutions.

Table 3 summarizes the cost of medium recovery using $1,50/MM Btu as the cost of energy to the dryer. Table 3 also reflects the cost of using lower proceed calcium nitrate. produced at or near the advanced coal prep facility.

Production of calcium nitrate

Calcium nitrate is currently produced as a by-product of commercial fertilizer production. In , it has little commercial use. Production of calcium nitrate could be conducted at or near the coal processing site. In its simplest form, the production could result from the reaction of nitric acid and limestone or lime. Reduction of calcium nitrate costs from 40 cents per pound(100% basis) to 20 cents per pound are reflected in Table 3.

The combined effect of lower calcium nitrate cost and use of lower cost energy source for evaporation could reduce medium recovery operating costs to $3.33/ton of coal. These results are summarized in Table 4 and Figure 2.

Conclusions and recommendations

1. The technical feasibility of the calcium nitrate should be demonstrated in the proposed pilot unit. This would provide confidence in the technology and also provide a basis for evaluating aspects of the process which would not be apparent from bench scale tests.

2. The technology if successfully demonstrated should have broad use in the industry if the operating costs can be lowered. The calcium nitrate solutions are odor free, non volatile, non toxic, and are handleable without special hazard control equipment.

3. Multiple washings can easily reduce calcium nitrate losses using commercially available equipment.

4. Reverse cascade rinsing should be further evaluated to obtain design data for scale up.

5. Use of coal fired evaporators or waste heat evaporators will significantly improve operating costs and thereby improve the overall economics of the process.

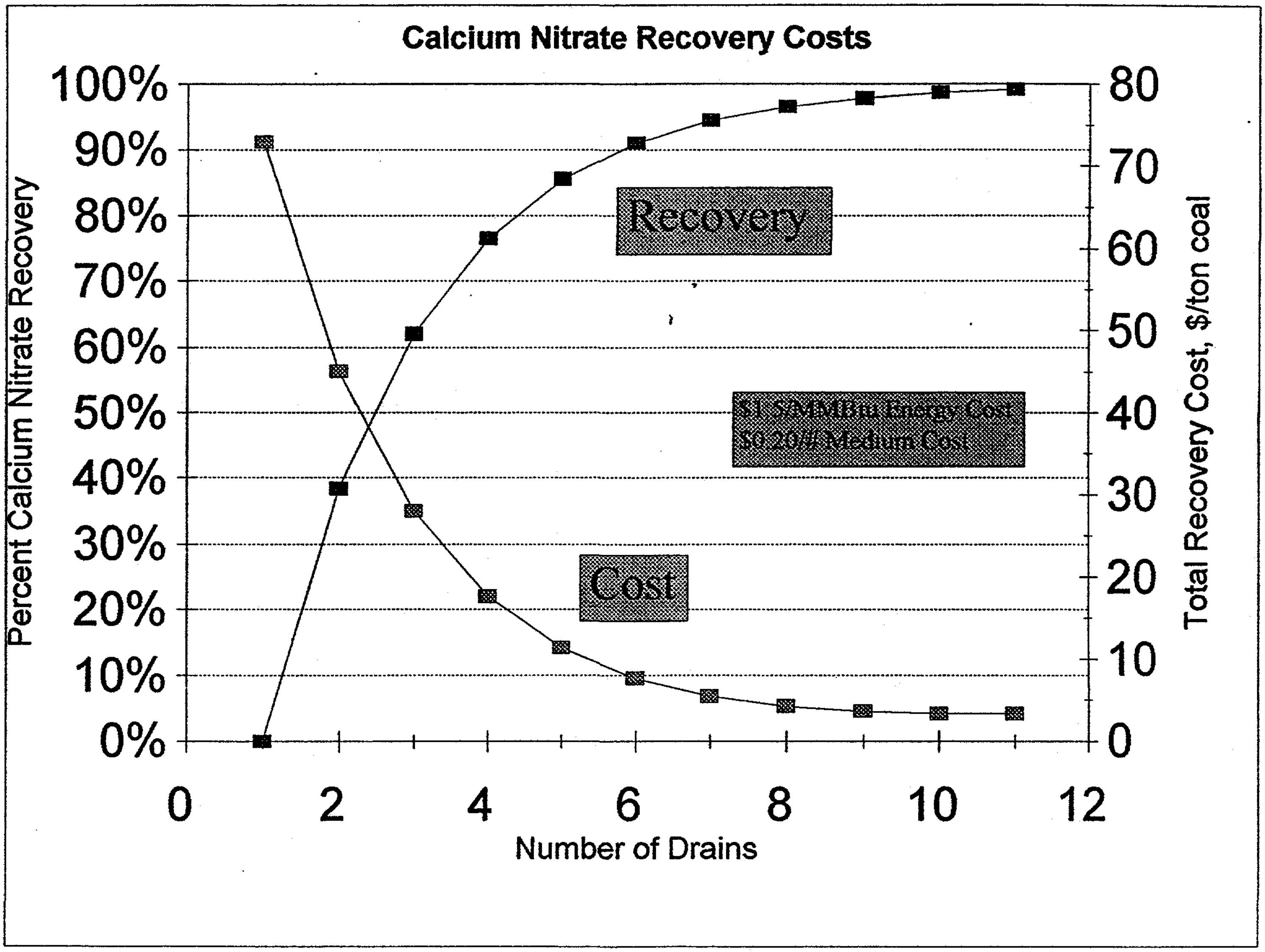
6. Investigate the use of pulsed combustor drying technology for concentrating the medium.

7. Conduct a technical and economic study to determine if low cost calcium nitrate production is feasible.

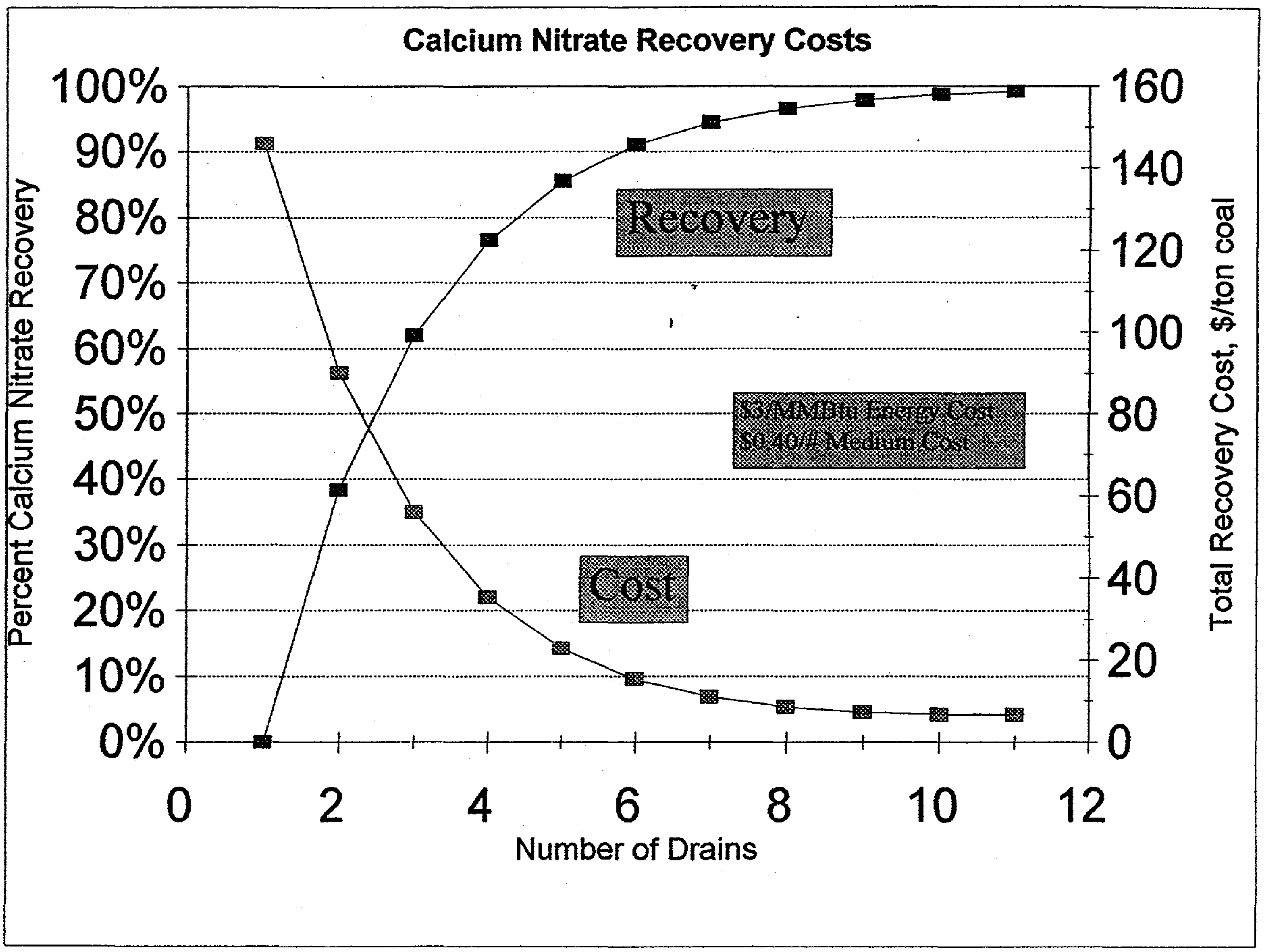
Number of drains	residual ca, tons	cumul. ca remov. t	% ca rem	Ca loss $/ton coal	vol rw tons	cum tons rw	evap load mmbtus	evap cost $/t coal	ca rec cost,$t cc
1	18.25	0	0	$73.00	0	0	0.00	$0.00	$73.00
2	11.24	7.01	38.41%	$44.96	12.45	12.45	8.44	$0.13	$45.09
3	6.93	11.32	62.03%	$27.72	11.87	24.32	22.06	$0.33	$28.05
4	4.27	13.98	76.60%	$17.08	11.55	35.87	38.92	$0.58	$17.66
5	2.63	15.62	85.59%	$10.52	11.35	47.22	57.77	$0.87	$11.39
6	1.62	16.63	91.12%	$6.48	11.21	58.43	77.82	$1.17	$7.65
7	1	17.25	94.52%	$4.00	11.13	69.56	98.62	$1.48	$5.48
8	0.62	17.63	96.60%	$2.48	11.05	80.61	119.83	$1.80	$4.28
9	0.38	17.87	97.92%	$1.52	11.05	91.66	141.36	$2.12	$3.64
10	0.23	18.02	98.74%	$0.92	11	102.66	163.01	$2.45	$3.37
11	0.14	18.11	99.23%	$0.56	11.05	113.71	184.90	$2.77	$3.33

Assume: No Calcium Nitrate & Coal Interaction

	Tons/100Tons of Coal												Cumulative Tons	
	Coal H_2O	Ca	Rinse H_2O	Coal	Total	Coal H_2O	Ca	Rinse H_2O	Coal	Total	Ca/H_2O		Rinse H_2O	Ca
feed	21.43	18.25		100.00	142.86	15.00%	12.78%		70.00%		1.17			
r1	21.43	18.25	11.00	100.00	150.68	14.22%	12.11%	7.30%	66.36%		0.56			
uf1	1.45	7.01	11.00		19.46	7.46%	36.02%	56.53%	0.00%				12.45	7.01
f2	19.98	11.25	0.00	100.00	131.22	15.22%	8.57%	0.00%	76.21%					
r2	19.98	11.25	11.00	100.00	142.22	14.05%	7.91%	.7.73%	70.31%	100.00%	0.36			
uf2	0.87	4.31	11.00		16.18	5.40%	26.63%	67.97%	0.00%	100.00%			11.87	4.31
f3	19.10	6.93	0.00	100.00	126.04	15.16%	5.50%	0.00%	79.34%	100.00%				
r3	19.10	6.93	11.00	100.00	137.04	13.94%	5.06%	8.03%	72.97%	100.00%	0.23			
uf3	0.55	2.66	11.00		14.22	3.90%	18.72%	77.38%	0.00%	100.00%			11.55	2.66
f4	18.55	4.27	0.00	100.00	122.82	15.10%	3.48%	0.00%	81.42%	100.00%				
r4	18.55	4.27	11.00	100.00	133.82	13.86%	3.19%	8.22%	74.73%	100.00%	0.14			
uf4	0.35	1.64	11.00		12.99	2.71%	12.63%	84.66%	0.00%	100.00%			11.35	1.64
f5	18.20	2.63	0.00	100.00	120.83	15.06%	2.18%	0.00%	82.76%	100.00%				
r5	18.20	2.63	11.00	100.00	131.83	13.80%	2.00%	8.34%	75.86%	100.00%	0.09			
uf5	0.21	1.01	11.00		12.22	1.70%	8.27%	90.03%	0.00%	100.00%			11.21	1.01
f6	17.99	1.62	0.00	100.00	119.61	15.04%	1.36%	0.00%	83.61%	100.00%				
r6	17.99	1.62	11.00	100.00	130.61	13.77%	1.24%	8.42%	76.56%	100.00%	0.06			
uf6	0.13	0.62	11.00		11.76	1.14%	5.30%	93.57%	0.00%	100.00%			11.13	0.62
f7	17.85	1.00	0.00	100.00	118.85	15.02%	0.84%	0.00%	84.14%	100.00%				
r7	17.85	1.00	11.00	100.00	129.85	13.75%	0.77%	8.47%	77.01%	100.00%	0.03			
uf7	0.05	0.38	11.00		11.43	0.46%	3.34%	96.20%	0.00%	100.00%			11.05	0.38
f8	17.80	0.62	0.00	100.00	118.42	15.03%	0.52%	0.00%	84.45%	100.00%				
r8	17.80	0.62	11.00	100.00	129.42	13.76%	0.48%	8.50%	77.27%	100.00%	0.02			
uf8	0.05	0.24	11.00		11.29	0.46%	2.09%	97.44%	0.00%	100.00%			11.05	0.24
f8	17.75	0.38	0.00	100.00	118.13	15.03%	0.32%	0.00%	84.65%	100.00%				
r8	17.75	0.38	11.00	100.00	129.13	13.75%	0.29%	8.52%	77.44%	100.00%	0.01			
uf8	0.00	0.15	11.00		11.15	0.00%	1.30%	98.70%	0.00%	100.00%			11.00	0.15
f9	17.75	0.23	0.00	100.00	117.98	15.04%	0.20%	0.00%	84.76%	100.00%				
r9	17.75	0.23	11.00	100.00	128.98	13.76%	0.18%	8.53%	77.53%	100.00%	0.01			
uf9	0.05	0.09	11.00		11.14	0.47%	0.81%	98.72%	0.00%	100.00%	0.01		11.05	0.09
p9	17.70	0.14	0.00	100.00	117.84	15.02%	0.12%	0.00%	84.86%	100.00%	0.01		113.73	18.11



Calcium Nitrate Recovery Costs
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent Calcium Nitrate Recovery
80
70
60
50
40
30
20
10
0
Total Recovery Cost, $/ton coal
0
2
4
6
8
10
12
Number of Drains
Recovery
$1.5/MMBtu Energy Cost
$0.20/# Medium Cost
Cost



Calcium Nitrate Recovery Costs
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent Calcium Nitrate Recovery
160
140
120
100
80
60
40
20
0
Total Recovery Cost, $/ton coal
0
2
4
6
8
10
12
Number of Drains
Recovery
Cost
$3/MMBtu Energy Cost
$0.40/# Medium Cost

Number of drains	residual ca, tons	cumul. ca remov. t	% ca rem	Ca loss $/ton coal	vol rw tons	cum tons rw	evap load mmbtus	evap cost $/t coal	ca rec cost,$t cc
1	18.25	0	0	$146.00	0	0	0.00	$0.00	$146.00
2	11.24	7.01	38.41%	$89.92	12.45	12.45	8.44	$0.25	$90.17
3	6.93	11.32	62.03%	$55.44	11.87	24.32	22.06	$0.66	$56.10
4	4.27	13.98	76.60%	$34.16	11.55	35.87	38.92	$1.17	$35.33
5	2.63	15.62	85.59%	$21.04	11.35	47.22	57.77	$1.73	$22.77
6	1.62	16.63	91.12%	$12.96	11.21	58.43	77.82	$2.33	$15.29
7	1	17.25	94.52%	$8.00	11.13	69.56	98.62	$2.96	$10.96
8	0.62	17.63	96.60%	$4.96	11.05	80.61	119.83	$3.59	$8.55
9	0.38	17.87	97.92%	$3.04	11.05	91.66	141.36	$4.24	$7.28
10	0.23	18.02	98.74%	$1.84	11	102.66	163.01	$4.89	$6.73
11	0.14	18.11	99.23%	$1.12	11.05	113.71	184.90	$5.55	$6.67