FINAL TECHNICAL REPORT
September 1, 1995, through August 31, 1996

Project Title: **INNOVATIVE PROCESS FOR CONCENTRATION OF FINE PARTICLE COAL SLURRIES**

DOE Cooperative Agreement Number: DE-FC22-92PC92521 (Year 4)
ICCI Project Number: 95-1/5.2A-3P
Principal Investigator: Marcus Rajchel, Williams Technologies, Inc./Clarke Rajchel Engineering Joint Venture (WTI/CRE-JV)
Other Investigators: Henry P. Ehrlinger, Consultant; Dan Harnett (WTI); Dr. Anthony Fonseca, Consol; R. Maurer, Destec Energy.
Project Manager: Dr. K. Ho, ICCI

ABSTRACT

Williams Technologies, Inc. And Clarke Rajchel Engineering are developing a technology (patent pending) to produce high quality coal water slurries from preparation plant fine coal streams. The WTI/CRE technology uses the novel implementation of high-shear cross-flow separation which replaces and enhances conventional thickening processes by surpassing normally achievable solids loadings. Dilute ultra-fine (minus 100 mesh) solids slurries can be concentrated to greater than 60 weight percent and re-mixed, as required, with de-watered coarser fractions to produce pumpable, heavily loaded coal slurries. The permeate (filtrate) resulting from this process has been demonstrated to be crystal clear and totally free of suspended solids.

The primary objective of this project was to demonstrate the WTI/CRE coal slurry production process technology at the pilot scale. The technology can enable Illinois coal producers and users to realize significant cost and environmental benefits both by eliminating fine coal waste disposal problems and producing an IGCC fuel to produce power which meets all foreseeable clean air standards. Testing was also directed at concentrating mine tailings material to produce a tailings paste which can be mine-back-filled, eliminating the need for tailings ponds.

During the grant period, a laboratory-scale test apparatus (up to 3 GPM feed rate) was assembled and operated to demonstrate process performance over a range of feed temperatures and pressures. A dilute coal/water slurry from Consol, Inc.'s Rend Lake Preparation Plant was concentrated with the process to a maximum recorded solids loading of 61.9% solids by weight. Analytical results from the concentrate were evaluated by Destec Energy for suitability as an IGCC fuel.

"U.S. DOE Patent Clearance is **NOT** required prior to the publication of this document."

EXECUTIVE SUMMARY

It has been estimated that the Illinois coal industry discards over 4,000,000 tons of coal fines into tailings impoundments each year. Much of this coal is of fairly high quality due to a high degree of inherent natural mineral liberation. As such, this coal might be considered "pre-prepared" for a number of various fine coal beneficiation processes. Also, it does not require milling for feed to such processes as IGCC or co-firing with pulverized coal in utility boilers. Coal fines most often go under-utilized because of inadequate means of de-watering and because of associated filter-cake handling problems. Williams Technologies, Inc. and Clarke Rajchel Engineering are developing a technology (patent pending) to produce high quality coal water slurries from preparation plant fine coal streams.

In this engineering study, recovered fine coal from Consol Inc.'s Rend Lake Preparation Plant was concentrated with the WTI/CRE process. The highest recorded slurry concentration was 61.9 weight percent solids slurry. Flotation concentrate feed slurry from the Rend Lake fine coal cleaning circuit which had been cleaned (via flotation) to less than 6.5% ash and 1.3% sulfur and with a nominal concentration of 15 weight percent, and of a size suitable for feed to Destec's slurry fed coal gasification plant was utilized in this demonstration.

The primary objective of this project was to demonstrate the WTI/CRE coal slurry production process technology at a pilot plant scale. It is hoped that the technology will enable Illinois coal producers and users to realize significant cost and environmental benefits both by eliminating fine coal waste disposal problems while producing an IGCC fuel which will meet all foreseeable clean air standards. In addition, testing was also directed at concentrating mine tailings material to produce a tailings paste which can be mine-back-filled and thus eliminate the need for tailings ponds.

Central to the WTI/CRE process technology is the novel implementation of high-shear cross-flow separation which replaces and enhances the thickening process by surpassing normally achievable solids loadings. Dilute ultra-fine (minus 100 mesh) solids slurries can be concentrated and re-mixed, as required, with de-watered coarser fractions to produce pumpable, heavily loaded coal slurries. The permeate (filtrate) resulting from this process has been demonstrated to be crystal clear and totally free of suspended solids.

The project team was assembled to present a "total technology approach" to provide a package which addresses the interests of the Illinois power generation industry. The project team includes the proposers, Williams Technologies, Inc./Clarke Rajchel Engineering Joint Venture; Consol, Inc. coal company of Illinois; Destec Energy, Inc., and Southern Illinois University. An example of the target interest is represented by the planned Franklin County Industrial Park which has shown interest in providing an environmentally friendly supply of power to their users while maintaining the support of the Illinois Coal industry.

The specific goals of the effort are:

- To improve the overall plant efficiency of Illinois coal preparation facilities and thus reduce overall costs by reducing wastes and lowering plant capital and operating costs.
- To provide the slurry production technology to produce a fuel suitable for the Destec slurry fed gasification process using recovered preparation plant fines.
- To demonstrate a process which will reduce or eliminate the need for large tailings impoundments.
- To gather data which will provide the engineering information required to design a demonstration-scale process facility for the production of coal-water slurry fuels from preparation plant fines which is suitable for the Destec slurry fed IGCC process.
- To produce a cleaner fuel by taking advantage of the natural mineral liberation associated with preparation plant coal fines.
- To demonstrate the utility of the technology in producing a tailings paste which is suitable for mine back-filling.

The specific tasks involved in achieving these goals included:

A. <u>Process Set-up</u>
A model process plant was assembled and operated at the SIUC Coal Research Center, Carterville, Illinois. The test setup included a membrane separator, feed tanks and piping, and a steam generator.

B. <u>Ambient Temperature Tests</u>
This testing had, as goals, both equipment shake-down and base-line testing. Early in the testing it was found that pilot-scale filtration efficiency was substantially lower than previous lab-scale observations. This scale-up problem was traced to design differences in the vendor-provided separation unit. Re-design of the pilot-scale separator was beyond the scope and resources of this project. The test plan was modified to include a combination of lab scale ("L-Mode") and pilot scale ("P-Mode") testing:

L-Mode	To determine maximum achievable unit water removal rates.
P-Mode	To investigate maximum achievable slurry loading and other operations and process control issues presented by a multi-membrane separator.

C. Elevated Temperature Tests

Elevation of feed slurry temperature has an effect linked to reduced slurry carrier fluid viscosity. Unit water removal rate was observed to increase in a linear relationship with temperature between 65 and 200ºF.

D. Optimum Vibrational Frequency Tests and Feed Pulse

It was found that vibrational frequency (and thus vibration amplitude) had little effect on dewatering performance above a minimum value.

Feed pulsing is a strategy to increase flux (water removal) rate by disturbing the fines bed on the membrane surface. The effect of feed pulsing could not be established in the pilot configuration during the test program, primarily because the P-scale separator package would not allow rapid pressure/flow pulsations because of flow restriction.

E. Process Control Strategy Tests

Optimal operations in a commercial plant will most likely include some level of instrumentation which will aid in start-up, shut-down, normal run-mode operation, and product quality control. Process control strategies were developed to provide smooth start-up and reliable operation, including procedures to detect and prevent plugging and membrane damage.

F. Equilibrium Flux Rate at Elevated Slurry Concentration
(Formerly "Long Duration Testing")

This task was modified from the original proposed scope during the project. The original objective was to perform a set of long-duration tests to demonstrate equilibrium performance and investigate membrane degradation over a period of 100 hours or more. However, long duration tests proved to be impractical owing to equipment limitations of the test apparatus.

Rend Lake Flotation Concentrate feed slurry was concentrated at both ambient and elevated temperatures in the pilot-scale apparatus. Measurements at system equilibrium were taken at various values of feed slurry solids concentration to observe the variation of flux rate versus solids loading.

After system startup, flux rates were observed to decline from a high initial value to a stable equilibrium rate after about 15 minutes. Flux rate was fairly constant as concentration increased from 25 to over 40% solids.

G. Tailings Paste Production

Tailings material was concentrated to determine whether a paste suitable for mine back-fill can be produced or if the material can be concentrated such that a better feed for belt filtration and subsequent tailings pile stacking can be achieved.

A dilute tailings slurry from the Rend Lake Preparation Plant was concentrated from 1% to 3.5% solids. Further concentration was not attempted due to insufficient quantities of feed slurry. In addition, the tailings slurry tested was apparently not a representative sample of the Rend Lake waste product.

Limited L-Mode testing with the material showed that dewatering performance of the equipment did not appear economically interesting. However, this assertion is somewhat dubious in the absence of testing with a more representative sample.

H. Destec Slurry Fuel Evaluation

Samples of coal/water slurry fuel made from the Rend Lake Flotation Concentrate were prepared and analyzed. The fuel was a mixture of concentrated fine-coal slurry and screen-dewatered coarse (-28 x 100 mesh) coal. Analytical results were evaluated by Destec Energy, Inc. to determine gasifier acceptability and estimated IGCC heat rate for the fuels. Destec's analysis indicated that the best fuel sample, which was 61.9 wt% solids, would make an acceptable gasifier fuel with an estimated IGCC heat rate of approximately 8,000 Btu/KWH.

OBJECTIVES

The overall objective of this program was to demonstrate the fine particle slurry de-watering process being developed by the Williams Technologies, Inc.-Clarke Rajchel Engineering Joint Venture (WTI/CRE) through construction and operation of a nominal 5 gallon per minute pilot plant. The specific objectives of this research included:

1. Demonstration of an inexpensive high shear cross-flow membrane separation process for cost effective production of multiple use coal-water slurry (CWS) fuels/IGCC feeds.

2. Generate engineering data required to design a fully automated Coal-Water Slurry Fuel production plant for a commercial-scale demonstration facility. Testing was focused on a cleaned-coal slurry produced at Consol's Rend Lake Preparation Plant.

3. Prepare fuels for analysis by an IGCC manufacturer (Destec Energy) and determine both the suitability of the fuel for gasification feed and computation of unit power production costs.

4. Investigate process performance and determine economics for dewatering a dilute mine tailings slurry.

5. Generate preliminary process economic data for comparison with other fuel production and dewatering technologies.

INTRODUCTION AND BACKGROUND

The technological approach used to remove water from fine coal slurries in this program utilizes cross-flow membrane separation, heat, and feed pulsation to effect a separation of water from the fine particle slurries. The separation of water from CWS is effected by pumping the slurry across a fine pore membrane surface. The membrane is vibrated radially at high frequency (50-60 Hz) which prevents the pores from being blinded by the finest slurry particles. The product is a thickened slurry. In previous laboratory work, fine particle slurries approaching 60 weight percent coal have been produced. Major advantages of the technology include:

a) Eliminates flocculants required by both filtration and thickening processes.

b) Achieves higher solids concentrations than achievable in conventional thickeners.

c) Slurry concentration equipment is compact in comparison to other fine particle de-watering/thickening equipment. The footprint of the commercial machinery is approximately eight feet by eight feet, including pumps.

d) Equipment is simple requiring maintenance similar to that of a pump.

e) Provides a pumpable fuel for coal gasification and combustion technologies.

f) High potential for use as a NOx reducing re-burn fuel

The approach might also find utility in the de-watering of tailings muds from coal wash plants. Thickening tailings to a paste consistency will allow the waste material to be disposed of in a much smaller area.

EXPERIMENTAL PROCEDURES

Previous work (DoE Contract No. DE-FG03-93ER-81503) with the WTI/CRE technology established that it was both technically and economically interesting. The previous work included separation of water from CWS with a laboratory-scale separator which uses a single membrane surface with approximately one-half square foot of membrane separation area. In this work various recovered fine-coal feedstocks were concentrated to solids loadings up to 58.9 weight percent solids.

This program attempted to increase the process throughput to pilot scale with a feed flow rate up to five gallons-per-minute, or about 1.35 tph (slurry basis). The cross-flow separator in the pilot plant utilizes multiple membrane plates stacked vertically to increase the filtration area. The configuration was similar to (but not identical) that of the commercial-scale equipment. The total pilot cross-flow separator membrane area could be configured with up to 15 square feet of separation area.

In previous work, water removal performance has been shown to be enhanced by the addition of heat to the feed. The configuration of the pilot plant is depicted in Figure 1. A package boiler provided heat to the feed by direct steam injection. To reduce the process requirements, heat was recovered by exchange from both product slurry and separated water (permeate) with the feed in double-pipe heat exchangers.

The pilot plant program was divided into separate tasks described below:

Task A <u>Procurement and Set-Up</u>

The pilot plant apparatus was constructed at the SIU Coal Research Center in Carterville, Illinois. All equipment, supplies, and slurry feedstocks were delivered to this site and connected by SIUC and WTI/CRE personnel. Major equipment included one New Logic International, Inc. V-SEP "Series P" high-shear membrane separator and a 6.93-horsepower Chromalox process steam generator. Samples of both froth flotation concentrate and fine coal wastes were obtained from Consol's Rend Lake Preparation Plant. The plant was commissioned and tested first with water and then with slurry.

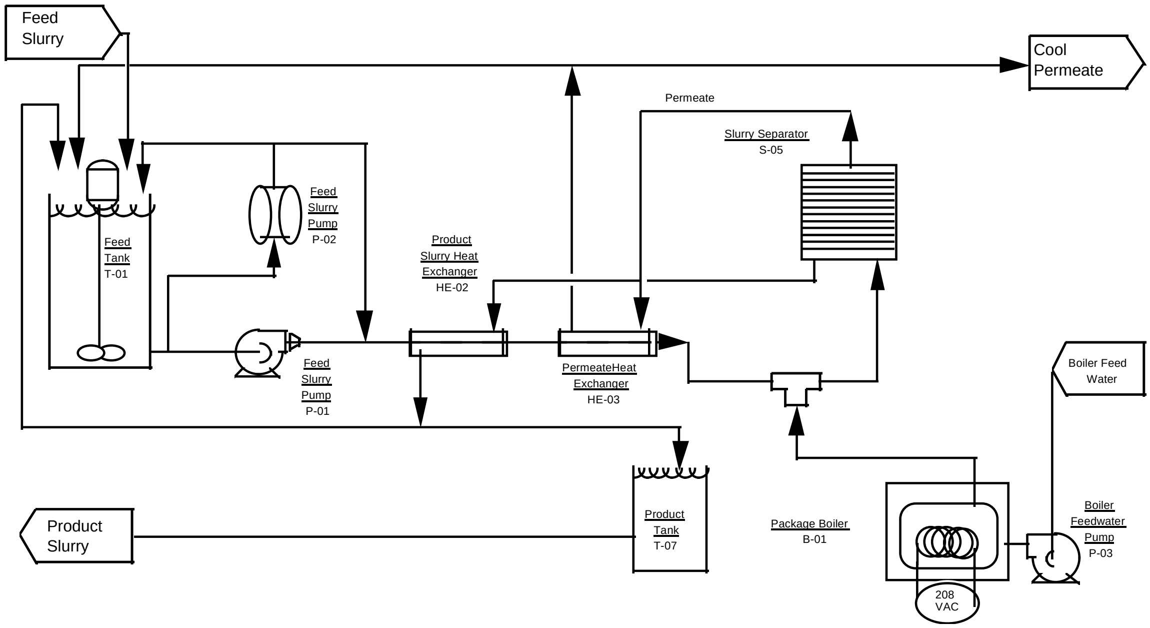

Figure 1 -- Pilot Plant Process Flowsheet

Task B Ambient Temperature Tests

This testing was performed to accomplish both equipment shake-down and base-line testing. The first work included various concentration tests at ambient temperatures, and was to duplicate earlier, laboratory scale work at the pilot scale.

Task C Elevated Temperature Tests

Rend Lake Flotation Concentrate (RLFC) was concentrated to maximum solids loading at a temperature of 120 ^{o}F. The manufacturer has indicated that the standard V-SEP machine can be reliably operated at temperatures up to 300 ^{o}F and 200 psig. Because of some of the materials of construction in the pilot scale unit, temperatures were kept below 200 ^{o}F. Flux rate (water removal rate) was measured versus slurry feed temperature at temperatures ranging from ambient to 200 ^{o}F.

Task D Optimum Vibrational Frequency Tests and Feed Pulse

Previous test work by the principal investigator suggested that improvement in water removal rates of between 10% and 25% can be achieved if the feed pressure is periodically pulsed between the normal operating pressure and some lower pressure. It has been postulated that the disturbance in the traveling fines bed which forms along the surface of the membrane decreases the cake resistance of the fines bed until the bed re-establishes itself. Also during Tasks B, C, and F, vibrational frequency was varied to produce a range of radial deflection from 0.75 inch to 1.25 inch.

Task E   <u>Process Control Strategy Tests</u>

The effect of start-up and shut-down procedures as well as the anticipated instrumentation required to produce a product of consistent quality were observed. Run-time procedures to detect and prevent plugging and membrane damage were developed.

Task F   <u>Equilibrium Flux Rate vs. Concentration Tests</u>
(formerly "Long Duration Testing")

The scope of Task F changed during performance of the test program. The original scope included two one-week continuous runs to demonstrate the durability of membrane separator under the seemingly harsh conditions of vibration found in the V-SEP. The focus of the new Task F work plan included runs to measure equilibrium flux rate at varying solids concentration followed by operation of the pilot equipment at elevated concentrations. This change was made in light of:

a. Industrial scale V-SEP units are currently operating at commercial facilities, indicating that the equipment will indeed withstand intense vibrational forces.

b. The initial work plan did not include work which quantified the effect of increasing solids concentration upon unit flux rates.

The new Task F consisted of concentrating one barrel of Consol Rend Lake Flotation Concentrate in steps until a maximum solids loading is achieved. At selected intervals, the apparatus was placed in the full-recycle mode (i.e., concentration of the feed was stopped) and equilibrium measurements of flux rate were taken. Tests were performed at both ambient and elevated temperature. In these tests, operation and relative performance at equilibrium of the multiple-tray system at elevated concentrations was observed. These tests were to demonstrate or give insight on the following:

a. Whether a V-SEP "membrane stack" can function reliably with fine coal flotation concentrate under conditions of high solids loading. Previous experience with a single membrane laboratory-scale separator has shown that a thick paste can be produced, but scale-up to a stack of membranes increases the complexity of operation by increasing the slurry water removal per pass through the machine.

b. Whether the relative water removal performance of a membrane stack tracks that of a single membrane apparatus.

c. Determine through inspection the problems or limitations which are inherent to the New Logic Series-P separator. In particular, does the membrane stack become partially plugged with de-watered paste in areas of low-cross flow?

Task G Tailings Paste Production

A Rend Lake tailings slurry was concentrated to determine whether a paste suitable for mine back-fill can be produced. It was also sought to determine if the tailings material could be concentrated to provide an improved feed for belt filtration and subsequent stacking could be achieved.

Task H Destec Slurry Fuel Evaluation

Fuel samples were prepared in consultation with Destec Energy, Inc. Destec performed a heat rate and gasifier acceptability analysis of two samples taken from test runs in Tasks C and F. Physical data from each sample was used as input for Destec's software gasification model.

RESULTS AND DISCUSSION

Task A Procurement and Pilot Plant Construction

Procurement of all equipment and supplies occupied much of September and October, 1995.

a. A 200 gallon tank and agitator for feed slurry was supplied on loan by Tecogen of Waltham, MA and is gratefully acknowledged.
b. A used electric steam generator was purchased.
c. Double-pipe heat exchangers were designed and built by the principal investigator.
d. A V-SEP Series L-P membrane separator with feed pump was supplied by New Logic, International of Emeryville, CA.
e. Samples of Rend Lake coal flotation concentrate and tailings material were procured by Mr. Henry Ehrlinger.
f. Process piping and instrumentation were procured and installed.

Task B Ambient Temperature Tests

The content of this report must digress at this point.

The V-SEP high shear membrane separator received by WTI/CRE for this project was New Logic’s “Series L/P”. This designation indicates that the unit may be configured to operate at either the laboratory scale or at the pilot scale.

a. The “L-Mode”
The unit may be configured to use a single-sided 1/2 square-foot membrane to perform quick experiments to observe the water removal performance of the method on particular slurries. The machine can be rapidly assembled and disassembled in this configuration, but the volume of water removal is small.

New Logic claims that this is the apparatus which best correlates to the performance of the commercial machinery.

b. The “P-Mode”
In this configuration, multiple membrane trays (up to 20) are stacked to give a total separation area of up to 15 square feet. Slurry flows from tray to tray from the entrance to the exit of the stack. In this configuration, larger volumes of slurry may be processed, but New Logic informed us during the pilot plant shake-down that they have never been able to correlate water removal rates with their commercial equipment.

New Logic states that this equipment finds greatest utility as a demonstration of the concept and as a means of producing larger volumes of slurry concentrate with the concentrate having the same general properties at that which would be produced in the industrial scale machines.

One of the limitations of this “Swiss Army Knife” approach (i.e., multiple uses) to equipment design is felt in the L/P unit’s piping. That is, the slurry piping was made small enough to handle the lower flow rates used for laboratory testing (about 1 gpm) while being just large enough to handle many of their typical P-mode applications. Sections of the slurry tubing had an inside diameter of 0.25 inches. For our application, this size was inadequate. For example, at a flow rate of 4.0 gallons per minute, the slurry velocity would be more than 26 ft/sec. Piping in the rest of the pilot plant had a minimum diameter of 0.5 inches.

Sustained flux rates (i.e., water removal rate per-unit-area) of up to 500 GFD (gallons of water removed-per-square-foot-per-day) were observed in L-series testing. For a machine configured with 15 square-feet of membrane area, this translates to 5.2 gallons of permeate per minute. A true pilot machine should be capable of accepting 7.5 gpm of feed slurry; clearly, this machine could not.

A second problem which exacerbated the piping situation was that the positive displacement pump supplied with the unit could not deliver more than 1.5 gallons per minute at discharge pressures above atmospheric. A double-diaphragm pneumatic pump was used in its place for some of the test work, and this solution presented its own operational problems.

L-Mode Tests

The original plan was that the pilot plant would be operated in the “P-Mode” with Rend Lake Flotation Concentrate (RLFC). When operating in the P-mode with 7.5 square feet of membrane area, lower than expected flux rates were found. Previous work with coal slurries indicated that flux rates on the order of 150 to 200 GFD should be expected at ambient temperatures; instead, flux rates of 70 GFD or less were observed at 69 °F. For our investigation, we decided to try to duplicate earlier work at the lab-scale by converting the pilot plant to the L-mode.

Two L-mode runs were made. In each run, data was taken at ambient and elevated temperatures. The results are summarized in Figures 2 through 6. Figures 2 and 3 show the observed flux rate versus temperature using RLFC which had been screened at 100 mesh.

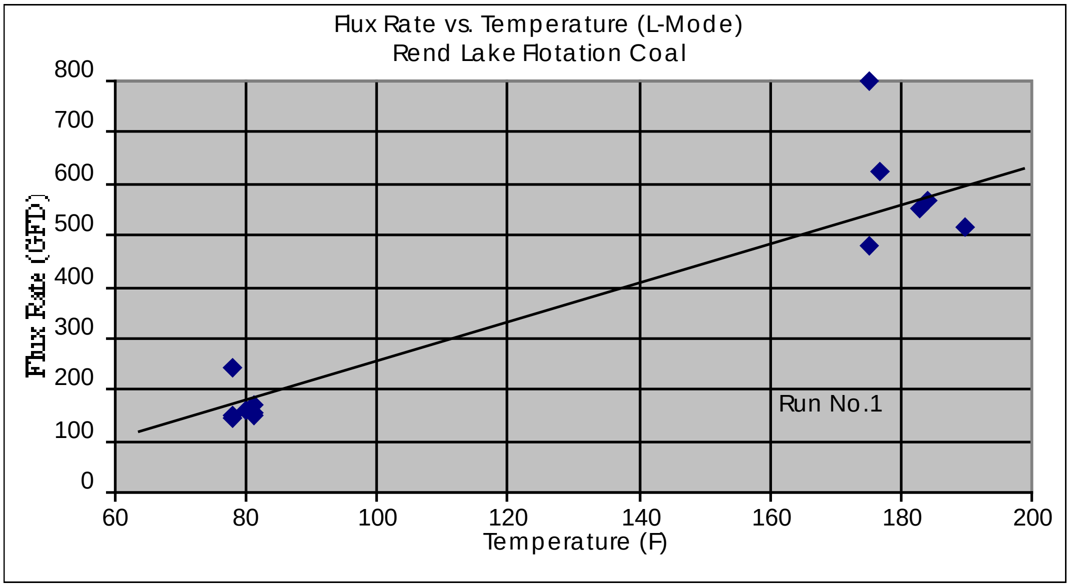

Figure 2

The maximum observed flux rate was 800 GFD at 180 °F. The equilibrium flux rate, however, was 500 GFD; in general, the highest flux rates are observed at the onset of the run and then decline to some equilibrium value. During this transient period, a sludge bed of fine slurry forms along the surface of the membrane. When the rate of sludge formation along the surface equals the rate of sludge withdrawal, the permeate rate stabilizes. (Work in this program attempted to take advantage of this knowledge in Task D -- Feed Pulse Tests). The equilibrium flux rate in this experiment at 80 °F was about 150 GFD.

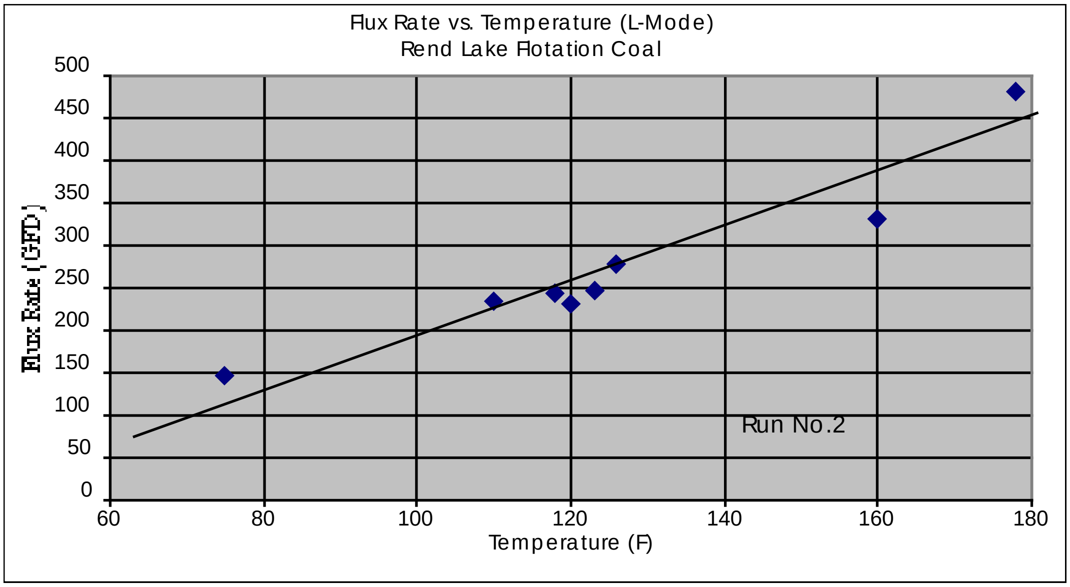

Figure 3

Equilibrium flux rate in Run No. 2 was similar to that found in Run No. 1. The differences in flux rate at 180 degrees can only be speculated on; one possible reason is that the membrane cloths were known to be from different production periods from the same manufacturer with the Teflon fabric used in Run No. 1 being superior.

Figures 4 and 5 show the aforementioned fall to an equilibrium flux rate with run time at a constant temperature.

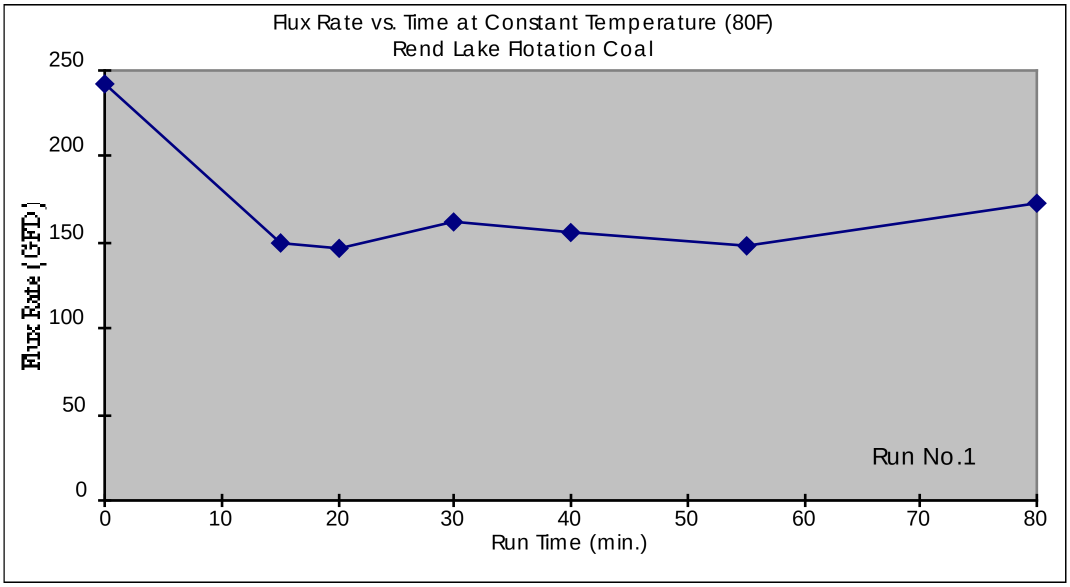

Figure 4

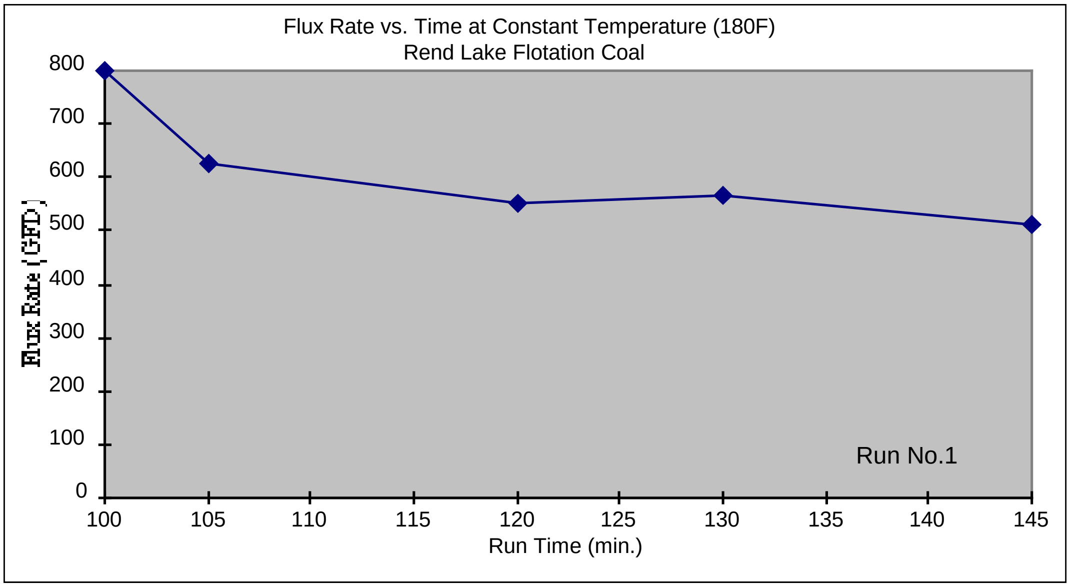

Figure 5

For most coal slurries, the effect of pressure on filtration (flux) rate is generally minimal. In Run No. 2, the slurry-side pressure was increased to 60 psig from 30 psig after 30 minutes of operation. The effect on flux rate is displayed in Figure 6.

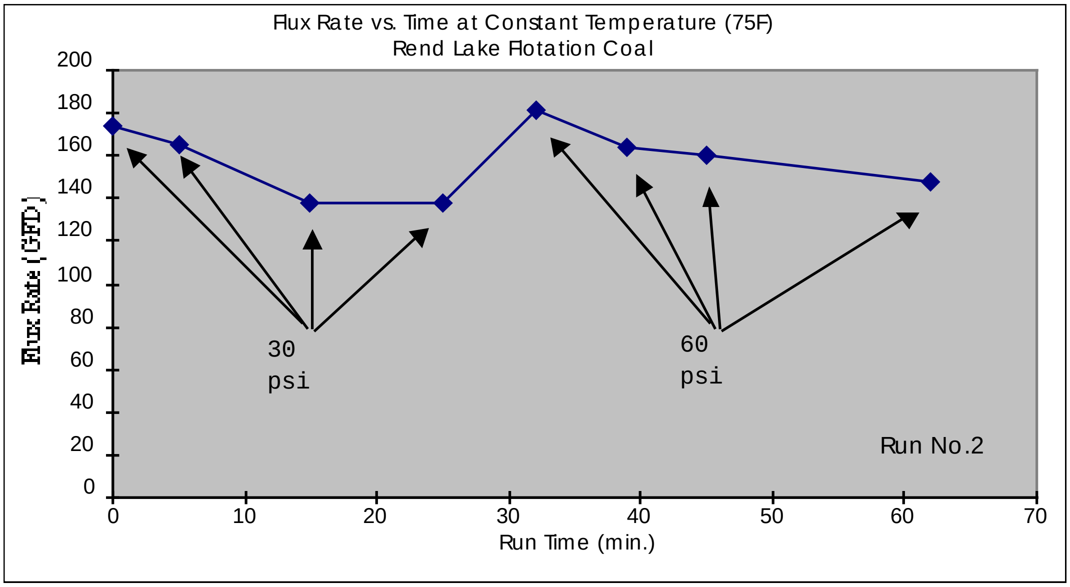

Figure 6

One can see that there is a transient benefit to increasing the filtration pressure, but the effect diminishes with run time. In this case, after 15 minutes, much of the effect is lost. In this case, it is thought that at higher pressures, a thicker sludge bed forms as a result of the higher water removal rate; the sludge bed represents the most significant resistance to water removal, much as it does in conventional filtration.

P-Mode Testing

After the L-tests were completed with RLFC, the machine was re-configured in the P-mode, except with fewer membrane trays. Fewer membrane trays were used considering the previously mentioned feed slurry flow limitations. Table 1 lists pertinent data for an ambient temperature run using the separator configured with 4 membrane trays and a total separation area of 3.30 square feet.

Table 1 - Ambient Temperature Run

Feed Slurry: Rend Lake Flotation Product
Membrane Area: 3.30 sq.ft.
Membrane Material: 0.5 µ Teflon
Date: 12/14/95

Time of Day (hrs.)	Run Time (min.)	Temp TI-06 (°F)	Pressure PI-06 (psi)	1/8 Gallon Flux (sec.)	Flux Rate (GFD)	Product Flow (gpm)
230	0	71	29	25	131	1.7
235	5	72	32	23	142	
240	10	72	32	26	126	
248	18	73	34	25	131	
251	21	73	60	19	172	
300	30	74	54	28	117	
310	40	74	60	29	113	1.33
320	50	74	58	32	102	
330	60	74	60	29	113	1.33

Flux rate was measured by recording the time required to fill a 16 fluid ounce container with separated water (permeate) using a stopwatch; the values in the column labeled "1/8 Gallon Flux" represent the amount of time required to fill such a container in seconds. The observed flux rate was better than previously observed with 7.5 square feet of membrane area (i.e., about 70 GFD), but still was not as high as observed in the L-series testing.

Task C Elevated Temperature Tests

The effect of temperature on water removal rate had been indicated in earlier work. The increase in flux rate had been previously shown to be approximately linear and with almost complete certainty is due solely to the concomitant decrease in slurry carrier viscosity. Tests at higher temperatures were performed with the equipment configured in both the L- and P-modes. As expected, variation in flux rate followed an approximately straight line. Data from this first successful P-mode test is displayed in Table 2.

Table 2 -- "P-Mode Test At Elevated Temperature"

Material: Rend Lake Flotation Product Date 12/14/95
Membrane Area 3.30 sq.ft.
Membrane Material 0.5 µ Teflon (Tetra Tech)

Time (hrs.)	Run Time (min.)	Temp TI-06 (_F)	Pressure PI-06 (psi)	1/8 Gallon Flux (sec.)	Flux Rate (GFD)	Product Flow (gpm)	Total Flow (gpm)	Ampl. (in)
1040	0	70.3	29	30	109	1.7	1.95	0.75
1045	5	71	32	28	117			0.75
Unit Down								
1430	5	71	29	25	131	1.7	2.00	0.75
1435	10	72	32	23	142			1.00
1440	15	72	32	26	126			1.00
1448	23	73	34	25	131			1.00
1451	26	73	60	19	172			1.00
1500	35	74	54	28	117			1.00
1510	45	74	60	29	113	1.33	1.59	1.00
1520	55	74	58	32	102			1.00
1530	65	74	60	29	113	1.33	1.59	1.00
1545	80	95	60	25	131			1.25
1555	90	117	60	20	164			1.00
1605	100	119	64	17	193	2.14	2.58	1.25
1625	120	122	64	17	193			1.00
1640	135	116	60	18	182			1.25
1705	160	150	60	14	234			1.25
1712	167	184	60	10.5	312			1.00
1725	180	175	60	10	328			1.00
1730	185	180	60	10	328			1.00

The values shown in the column labeled "Ampl." represent the measured radial deflection of the membrane stack in inches. The frequency of this vibration was normally about 50 Hz.

The P-mode membrane stack did not achieve the same high flux rate as observed in the L-mode. Data comparing L-mode performance with that of P-mode performance at similar operating conditions is shown in Figure 7.

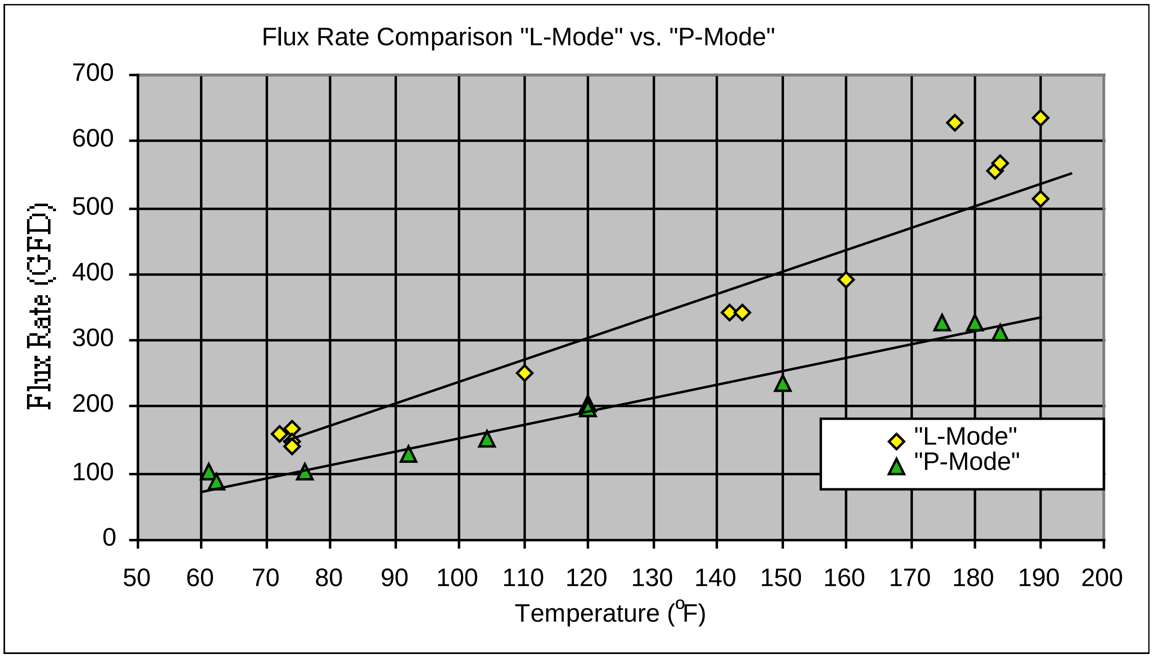

Figure 7

Representatives of New Logic assert that the data obtained from the L-mode testing correlate more closely to the industrial scale equipment than does the P-mode data.

Task D <u>Optimum Vibrational Frequency and Feed Pulse Tests</u>

<u>Vibrational Frequency</u>
The membrane "stack" in a V-SEP separator sits upon a long vertical shaft which is bolted to the center of a heavy base plate which is connected to the floor by four spring-isolators. The spring loaded base is vibrated by an electric motor which imparts radial vibration via an eccentric bearing affixed to the base. The vibration is transmitted through the vertical shaft to the membrane stack. The engineered shaft acts as a torsion bar and twists when radial vibration is applied. When a harmonic frequency is achieved, which depends upon the weight of weight of the membrane stack, the stack vibrates. The magnitude of the radial deflection is modulated by changing the motor rotational frequency about the harmonic frequency.

It was desired to know whether there was a vibrational frequency (i.e., membrane stack radial deflection) which produced best results.

We found no strong correlation between flux rate and radial deflection above a minimum value of 3/4 inches. We did however observe that flux rates dropped dramatically at radial deflections below 0.5 inches. Data relating the variation in flux rate with membrane deflection for L-mode tests are shown in Figures 8 and 9.

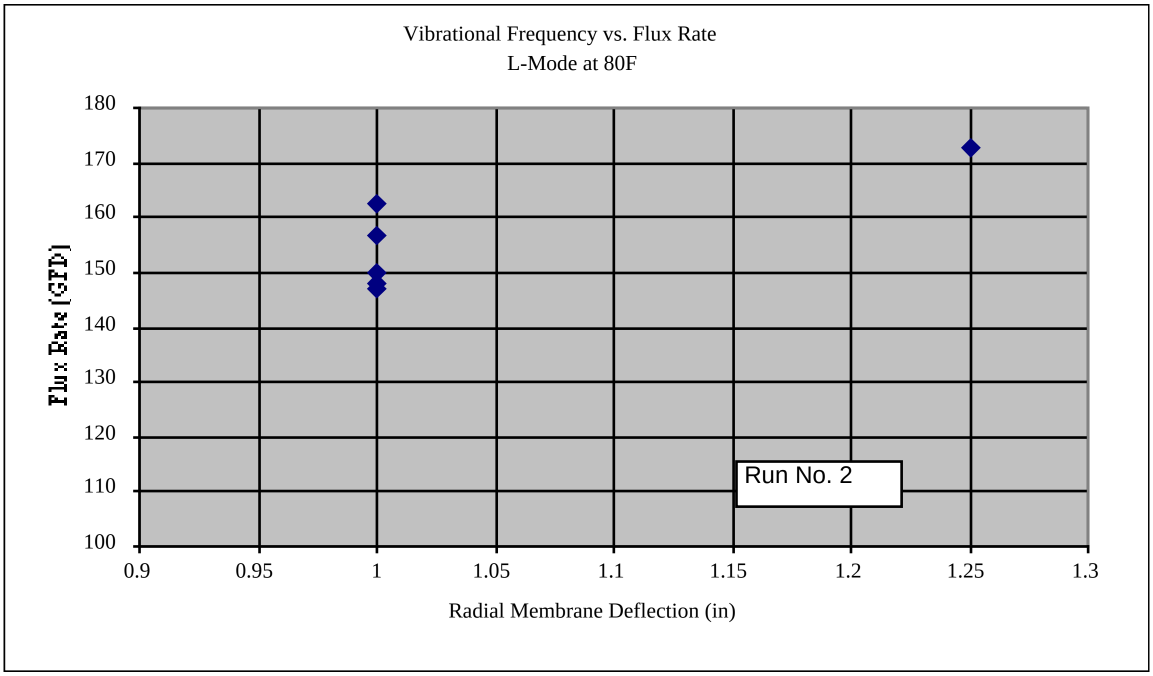

Figure 8

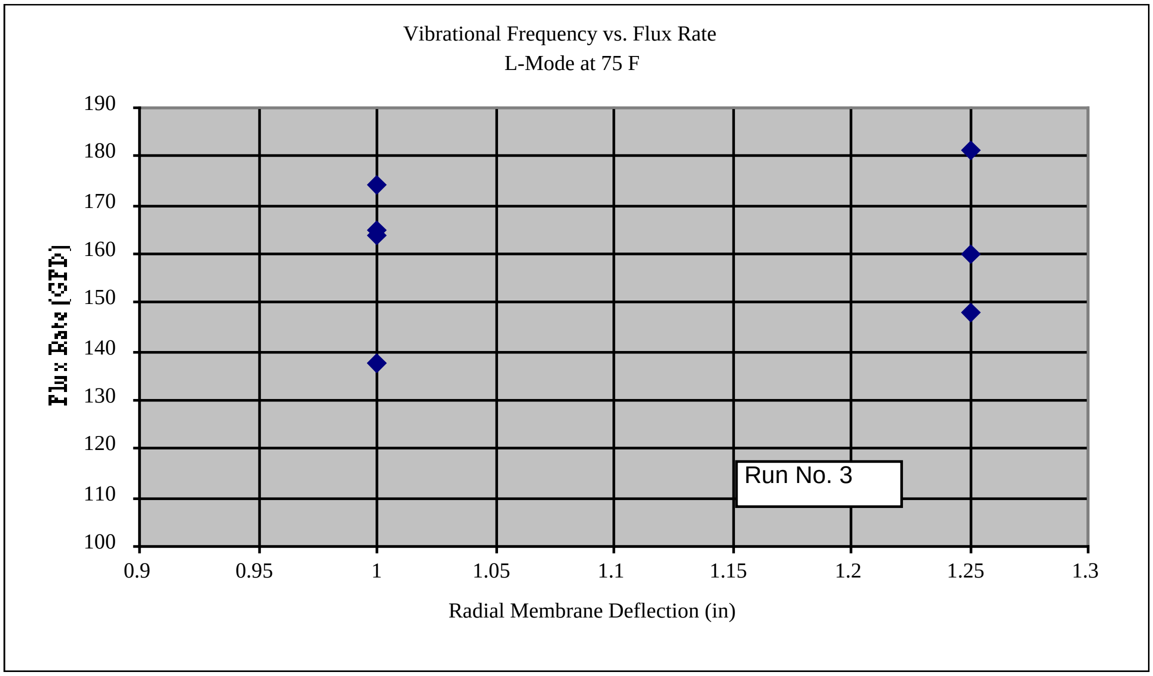

Figure 9

The maximum allowable radial deflection for the Series L/P separator, as indicated by New Logic, International, is 1.25 inches; at vibration greater than this, one risks damage to the equipment. A significant advantage to increasing vibrational power could not be inferred from this data. All subsequent testing was performed at vibrational amplitudes of between 0.75 and 1.0 inches.

Feed Pulse Testing

Feed pulsing tests were to be performed by cycling the feed slurry supply pressure over various timed intervals. The concept is based upon creating a transient pressure/flow disturbance which would upset and sweep away the fines sludge bed which forms along the surface of the vibrating membrane. The sludge bed of fines represents the major resistance in filtration rate. Previous work with the L-mode testing indicated that flux rates could be increased by as much as 20% if such feed slurry supply pressure modulations could be implemented. The increase in flux rate is itself transient and the feed pressure/flow pulse would have to be repeated on a periodic basis.

In the earlier work, the feed pulse was carried out by rapidly cycling the product slurry pressure control valve to zero psig, holding for one second, and then returning to normal operating pressure. It became apparent that this was not possible with the Series L/P pilot scale unit because of the small (0.25 inch ID) piping at the discharge of the separator. When the product slurry pressure control valve (or the bypass around the pressure control valve) was opened, it took 4-5 seconds for the system pressure to fall to a minimum value. Also, at normal flow rates of 3.0 gpm or more and normal operating pressures of 50-70 psig, the pressure in the membrane stack remained relatively high (greater than 30 psig) because of the large pressure drop through the discharge piping. Because neither the pressure/flow changed rapidly nor did the pressure drop to a low value, the effect found in earlier work could not be duplicated.

Task E Process Control Strategy Tests

The following control strategies were developed based on operating experiences with the L-Series and P-Series units. These strategies would be recommended for process automation design in a commercial plant.

a. Preventing Membrane Failure On Low Differential Pressure

One way to destroy a membrane(s) is to vibrate the membrane stack with insufficient trans-membrane pressure differential. This happens when either

- the permeate line is closed (which equalizes pressure on both sides of the membrane, causing it to separate from its support with or without vibration)
- when the slurry flow rate is very low or stopped (which can also cause membrane separation during vibration), or
- any time the differential pressure between the slurry-side of the membrane and the water side of the membrane is less than about 25 psi.

The simple solution to this problem is to install a differential pressure switch (or transmitter) between the product slurry outlet and the permeate outlet ports and interlock the signal to the vibration motor and feed slurry pump contactors. When the vibration and slurry flow are stopped, the risk of damage to the membranes vanishes.

b. Preventing Membrane Failure with No Vibration Present

Another way to damage the membranes in the P-Series Unit is to run high cross-flow rates while the vibration is off and permeate flow is blocked off. We found that the turbulence of the cross-flow alone will tend to separate the membrane from the support even when no vibration is present. Simply opening the permeate valve to create a trans-membrane pressure differential did not suffice since this tended to cause plugging. This is not a problem with other, more typical V-SEP applications with very fine slurries, but because of the coarse particle size, coal slurries tend to rapidly de-water and plug under conditions of no vibration.

Cross-flow-with-no-vibration is a start-up situation; that is, one should not start vibration without flow (see “a” above). The solution involves interlocking the pump with the vibration drive contactor such that both must be on. A short delay timer in the process programmable logic controller (PLC) which starts the vibration within a few seconds of the pump start is the best means of control.

c. Preventing Plugging

During operation, there could be events which cause the onset of membrane stack plugging (e.g., upsets in flows, pressures, etc.). If caught early, there are means to “un-plug” the membrane stack reliably and return the unit to original performance. The means of detecting plugging include:

o Decrease In Vibration Amplitude/Increase In Motor Load

A decrease in vibration amplitude during steady-state generally means that the stack is getting heavier, which generally means that the stack is beginning to plug. The stack does not plug instantaneously, but it can in a matter of minutes. When this happens, the motor load also increases as a result of the increased stack mass.

If permeate withdrawal is continued, the stack further plugs and the V-SEP becomes a very small (and rather expensive) filter press. The reliable way to clear the machine is to:

1. Choke the permeate flow to a very small value while still maintaining the a minimum 20 psid trans-membrane pressure.
2. Reduce the membrane stack vibration to about 1/2 the original radial deflection.
3. Take note of the motor load at the reduced vibration amplitude.
4. As solids are cleared from the stack and are replaced by slurry, the motor load (at the reduced amplitude) will decrease.

5. The indication that the plugging has been eliminated is when the motor load has fallen to a new steady state value. When the motor load is at a minimum, normal operation can be resumed.
6. Final assurance that the machine has become unplugged can be determined when the original motor load and radial deflection are achieved after resuming normal operation.

Detection of incipient plugging can be achieved through PLC monitoring of the motor load and/or optical deflection indication. An increase in motor load or decrease in radial deflection could both trigger an alarm and initiate an anti-plugging sequence. The sequence would reduce the permeate flow by positioning the permeate flow valve while maintaining an adequate trans-membrane pressure. Vibration could be reduced by reducing the vibration drive motor speed either automatically or manually.

- <u>Decrease in Permeate Flow Rate</u>
  A more sophisticated (but more difficult) means of detecting plugging would be to monitor changes in flux rate. Minor fluctuations in permeate flow rate are normal and to be expected; this is what makes this method more problematic. One would have to choose a “threshold” value of permeate flow rate decrease to initiate an automatic membrane stack unplugging sequence. For example, one may encounter normal fluctuations of 10% above or below the normal performance value. In this case, one may choose to have the PLC initiate the un-plugging sequence when the permeate flow rate drops by, for example, 25%.

  One advantage of permeate flow monitoring is that various operator alarms could be initiated to signal potential problems to the operator very early. Such alarms would not represent any significant extra costs since permeate flow meters would be included in the installation in any case.

d. <u>Start-Up Sequencing</u>

During operation of the pilot plant, WTI/CRE found that there are numerous operations that must be simultaneously started and monitored during equipment start-up. They include:

1. Feed slurry pump start.

2. Shortly after pump start, vibration must be started.
   Control Action: Include a vibration start-up interlock timer to start vibration after feed slurry flow is established.
3. Permeate removal must be started (permeate valve opened). Initially, however, the permeate flow should be controlled since high initial flux rates can cause plugging on start-up; this is a problem specific to de-watering coal with V-SEP since the particle size is relatively large when

compared to other V-SEP applications. Initial flux rates of three to four times the steady-state value are commonly encountered; that is, the coal can be completely dewatered to a filter cake within the machine with an uncontrolled start-up. Once steady-state operation has been achieved, the valve can be fully opened. Steady-state operation is achieved after the machine is full of slurry and a steady-state sludge bed has formed. This can take from several minutes to an hour depending upon the application and the number of membranes in the stack.

Control Action: Limit the permeate flow on start-up to less-than-or-equal-to the expected steady-state permeate flow rate using a flow controller on a permeate flow control valve.

4. During start-up, the first liquid out of the separator is normally water. To maintain the required trans-membrane pressure, the product-slurry outlet flow/pressure control valve will normally be choked-down. Unless the valve is modulated, as thickened slurry begins to appear at the V-SEP product slurry discharge valve, the slurry-side pressure increases dramatically. This causes higher transient flux rates and increases the potential for plugging.

Control Action: Control the slurry side pressure with a pressure control valve on the V-SEP product slurry outlet.

e. Improving Flux Rate

The previously mentioned means of increasing the flux rate in the WTI/CRE process include application of elevated temperatures and flow/pressure pulsation. Temperature control in the pilot plant was manual, but is easily automated. Feed slurry flow pulsation is easily accommodated, assuming the product slurry discharge piping is of sufficient size such that it is not a significant restriction to flow, by automatically modulating the product slurry discharge pressure control valve over a timed interval.

Task F Equilibrium Flux Rate at Elevated Slurry Concentration
(Formerly "Long Duration Testing")

After discussions with the ICCI Project Manager, it was felt that some crucial questions regarding equilibrium operation of the plant in the P-mode would be left unanswered if the original Task F course were taken. As a result, the Task F work plan was revised.

Formerly, the Task F work was to consist of two weeks of continuous operation utilizing the pilot plant in the P-mode of operation. The test was to consist of feeding slurry to the separator and returning the product slurry and separated water back to the feed tank in a continuous loop. Testing was to include one week of operation at ambient temperature and one week at an elevated temperature. Operating and performance data were to be taken hourly over the course to the runs. There are several issues which limited the usefulness of such testing. In summary, they include:

a. Some piping within the separator is very small in diameter; about 1/4 inch. At the flow rates used for the test, the velocity of the slurry in these sections ranged from between 22-25 ft/sec. Over the course of testing, this could cause particle size degradation. There is an accompanying decrease in permeate flux rates with decreasing particle size. Since the properties of the feed are continuously changing, the usefulness of any separation performance data is dubious. Therefore, the data obtained would only be useful with regard to physical demonstration of the equipment over the run period.

b. It was demonstrated earlier in the program that the New Logic Series L/P separator was not capable of providing process scale-up data when operating in the “P-mode”. Unit water removal rates in the P-mode are generally lower than that found in L-mode testing by between 20% and 40%.

The particle size degradation problem could have been remedied in a couple of ways: a) change the piping associated with the vendor separator package, or b) feed the plant with a continuous supply of fresh feed and continuous removal of product slurry from the system. Neither of these options was efficable at this point in the test program.
The procedure for accomplishing the revised Task F scope was as follows:

a. A one-barrel sample of Consol Rend Lake Froth Flotation Product feed slurry was prepared. The feed barrel had an initial level of approximately 30 inches and a concentration of 12-16 weight percent. An agitator and separator feed pump suction piping were installed. Feed slurry samples were taken.

b. Slurry was fed to the membrane separator, returning both product slurry and permeate water to the feed barrel. When an equilibrium initial flux rate had been established (i.e., a constant flux rate over a 15 minute interval), the concentration test was started.

c. The permeate line was diverted to a separate barrel while circulating the concentrate back to the feed tank. A sample of the concentrate for each pass was taken.

d. When the level in the feed tank dropped by about five inches, concentration of the feed was stopped by returning permeate back to the feed barrel. The levels in both the feed barrel and permeate barrel were recorded before resuming slurry concentration. This procedure was repeated until the slurry could no longer be concentrated (i.e., became too thick).

e. When the test was completed, a final product slurry sample was taken. All slurry samples were tested for solids concentration.

f. At the end of the slurry concentration, the unit was operated for several hours at the a high slurry loading to observe the unit operation over time at an elevated slurry concentration.

g. The test was repeated at a temperature of 120 ºF.

<u>Task F Experimental Results</u>
Task F work consisted of four runs denoted Run A, B, C, and D. The first three were to measure the relative change in flux rate as slurry solids concentration increased. The last, and most interesting, was to operate the pilot plant at elevated concentration over time.

Run A -- Flux Rate vs. Concentration at Elevated Temperature

For Run A, the V-SEP was operated at the nominal conditions of 120 ºF and 60 psi at the V-SEP discharge. Table 3 gives Run A results. No attempt was made to achieve ultimate loading since the same membranes were to be used in the next set of experiments.

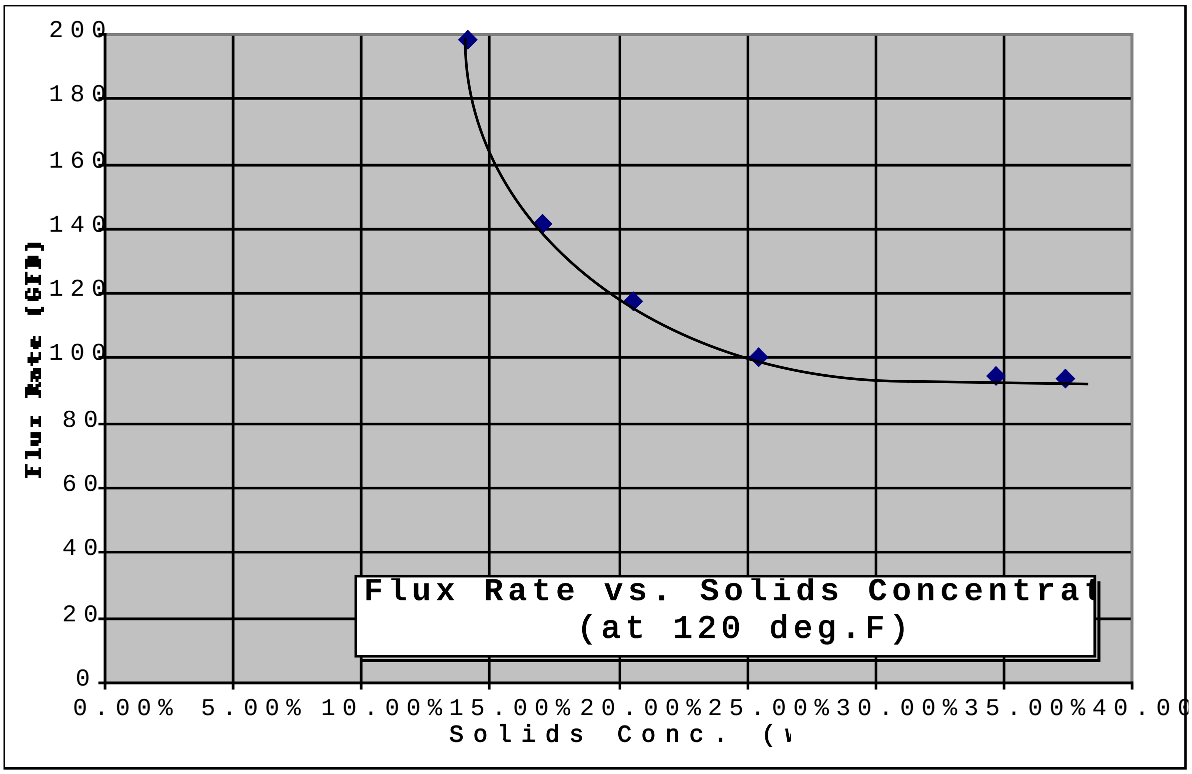

Figure 10

The flux rate dropped rapidly in the initial part of the run. It was suspected that the membranes became damaged during start-up. The results of Run B support this.

Run B -- Flux Rate vs. Concentration at Ambient Temperature
It was apparent that the membrane stack was damaged when unusually low flux rates were noted at the onset. Further damage upon start-up of this run was not suspected.

Table 3 -- Run A Results

4-Tray Concentration of Rend Lake Flotation Product

Membrane Area 3.30 sq.ft. 0.5 µ Teflon No.Trays 4

Date 1/20/96

Run Clock Time	Run Time (min.)	Temp TI-06 (ºF)	Feed Flow (gpm)	Flux Rate (GFD)	Product Flow (gpm)	Product Conc. (wt.%)
420	0	119	3.00	199	2.54	14.11%
430	10	118	3.33	193	2.88	
450	30	124	3.24	165	2.86	
500	40	122	3.09	143	2.76	
530	70	119	2.99	142	2.67	17.07%
540	80	121	2.99	142	2.67	
610	110	121	2.92	118	2.65	20.58%
620	120	117	3.16	108	2.91	
700	160	122	2.86	101	2.63	25.40%
711	171	120	3.03	100	2.80	
720	180	119	2.77	95	2.55	34.71%
730	190	119	2.98	94	2.76	37.42%

Table 4 -- Run B Results

Clock Time (hrs.)	Run Time (min.)	Temp TI-06 (ºF)	Flux Rate (GFD)	Product Flow (gpm)	Slurry Solids (wt.%)	Slurry Inventory (inches)
835	0	65	64	3.02	17.50%	25
845	10	66	40	3.02		25
850	15	66	62	2.88		25
920	45	68	60	2.83		23
950	75	69	61	2.73	18.47%	20
1000	85	69	60	2.73		20
1030	115	70	60	2.82		19
1105	150	72	59	2.70	27.66%	16
1115	160	72	60	2.70		16
1145	190	72	58	2.79		14
1225	230	71	56	2.67	55.20%	3.625
1315	280	69	51	2.67		15
1345	310	69	51	2.73		13
1415	340	70	50	2.63		12
1445	370	72	53	2.70		9
1500	385	73	52	2.75		9
1550	435	74	50	2.73		7.5
1600	445	74	49	2.73		5.75
1620	465	74	50	2.73	44.02%	5

Flux rates remained relatively constant throughout run B. This was also observed in Run D; the most successful run. The slurry was concentrated to 55.2 weight percent by the 230th minute of run time. Because the slurry inventory in the feed barrel dropped to about 3-1/2 inches, water was added back to continue the run and observe the concentration behavior again. The run was continued for an additional 3-1/2 hours before termination.

Inspection of the membranes showed that the failures occurred mainly at the slurry outlet to each membrane tray which damaged 1/2 of the total membrane area. This was a problem with the start-up strategy used and was corrected in subsequent runs. This type of failure is specific to the P-Series V-SEP unit and the mechanism is described earlier in this report.

Run C -- Concentration at Ambient Temperature

Run C was started after replacing the faulty membranes from Runs A and B, but was terminated on start-up due to mechanical failure.

Run D -- Operation at Elevated Concentration Over Time

The optimum start-up strategy for the P-Series machine was demonstrated in this run. The following Table 5, Figure 11, and Figure 12 are from data taken in Run D.

After achieving the target temperature of 120 °F, the flux rate did not drop off significantly with increased solids loading.

Run D was interrupted in the 5th hour of operation due to a leak in the permeate line. The pilot plant was shut-down smoothly, the leak repaired, and the run smoothly re-started.

Immediately upon restarting the run a low flux rate was observed. Without any special care, the flux rate re-established itself to approximately its pre-shut-down value. This is significant since it shows that operation can be restored to original performance after a major upset when proper start-up and shut-down procedures are followed. The procedure for automating the start-up and shut-down procedure is covered in “Task E -- Process Control Strategy Tests.”

The run was terminated after 11-1/2 hours of run time due to a pump failure.

Table 5 -- Run at Elevated Slurry Concentration (Run D)

Membrane Area: 4.95 sq.ft. No. Trays: 6
Membrane Material: 0.5 µ Teflon
Date: 22-Jan-96

Time (hrs.)	Time (min.)	Temp TI-06 (°F)	Pressure PI-06 (psi)	1/8 Gallon Flux (sec.)	Flux Rate (GFD)	Product Flow (gpm)	Solids Conc. (wt.%)
1945	0	61	41	21.3	103	2.93	12.81%
2005	20	62	45	24.5	89	2.94	
2015	30	76	45	20.95	104	2.94	
2030	45	92	45	16.75	130	2.82	
2045	60	104	45	14.5	151	2.84	
2100	75	120	45	11.1	197	2.80	
2115	90	120	45	10.6	206	2.79	
2145	120	120	42	11.1	197	2.78	
2215	150	120	42	11.1	197	2.78	
2235	170	122	40	11	199	2.86	18.21%
2250	185	120	40	11.5	190	2.76	
2315	210	119	40	12	182	2.86	
2330	225	120	40	14	156	2.84	24.21%
2350	245	120	40	13.4	163	2.84	
5	260	120	42	14.1	155	2.79	30.67%
20	275	119	44	14.2	154	2.67	
35	290	120	62	13	168	2.86	
40	295	120	62	12.3	178	2.83	
50	305	120	65	12.3	178	2.90	41.36%
100	315	121	65	12.8	171	2.90	
120	335						
135	350	117	50	19.3	113	3.13	
200	375	123	46	13.2	165	2.79	
220	395	120	56	13.4	163	2.69	
300	435	120	58	14	156	2.82	
400	495	120	55	14.1	155	2.88	
500	555	131	61	12.7	172	2.97	
600	615	120	56	14	156	3.03	

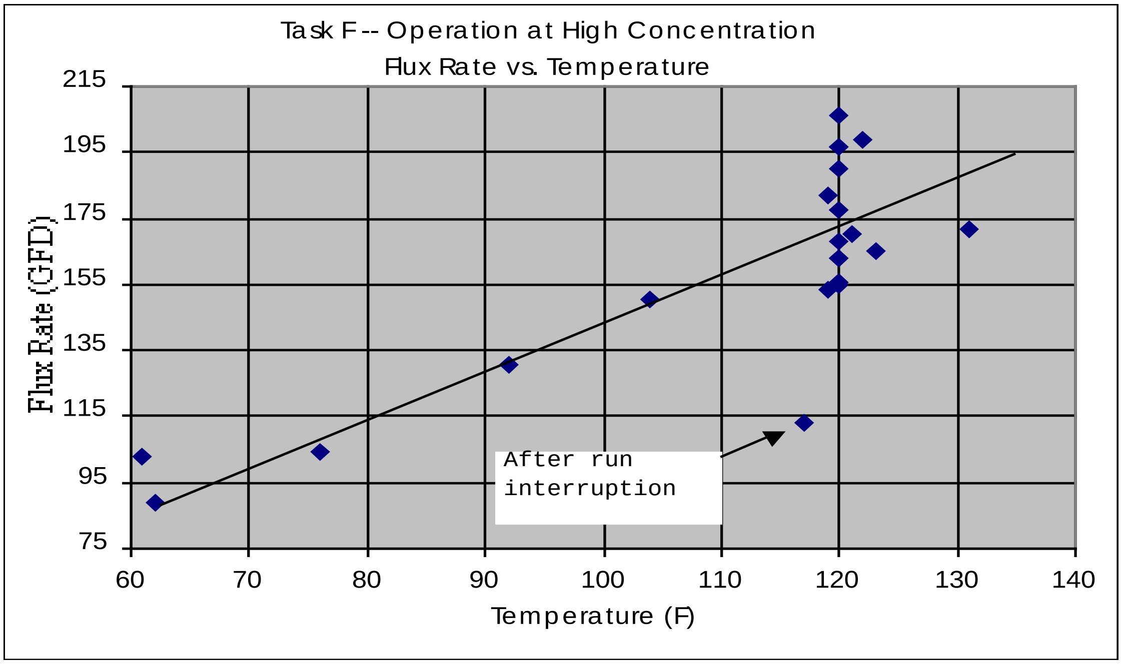

Figure 11

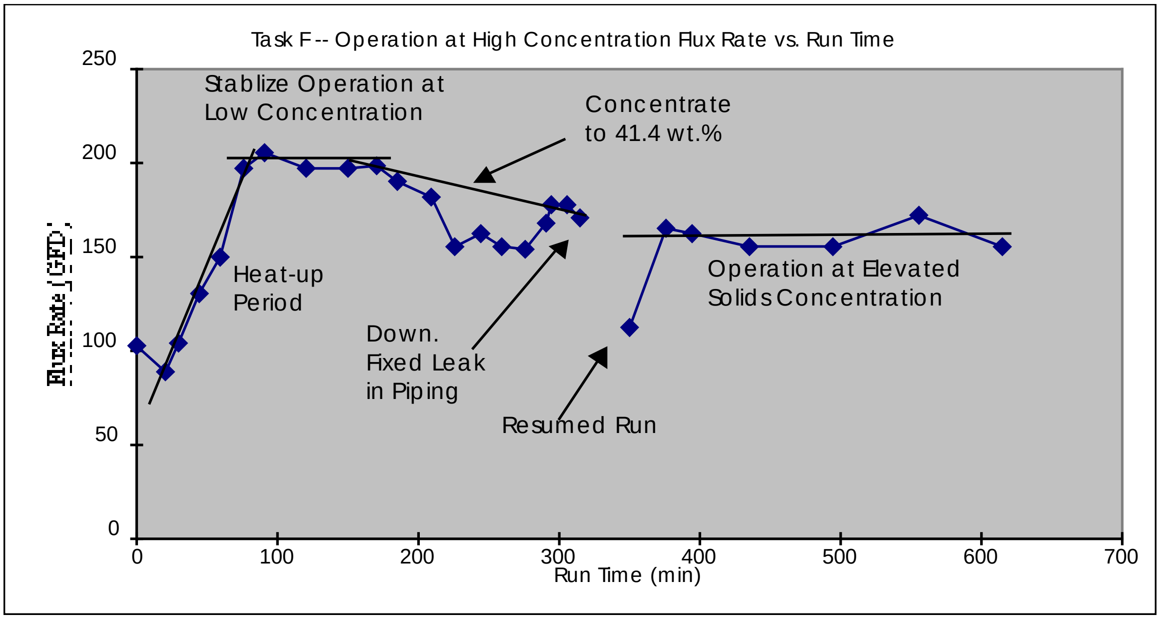

Figure 12

Task G   <u>Tailings Concentration</u>

Task G work was to be directed at production of a tailings paste. Unfortunately, the material we received was of a very low solids concentration; a little over 1.0 weight percent solids.

An attempt was made to concentrate a 55 gallon barrel of tailings mud from the Rend Lake Preparation Plant. Water was removed from the slurry using the pilot plant equipment configured in the P-mode. When the volume had been reduced to practically nil in the feed barrel, the run had to be stopped. Because of the low initial solids loading, the final concentrate had a concentration of only about 3.5 weight percent.

Representatives of Consol Coal Company indicated that the feed material we received was not typical and should have had a solids concentration of 5-7 weight percent. As a result, tailings paste production was not successful.

One of the more interesting results of the L-testing was the relationship between cross-flow rate and flux rate. The cross flow rate is the slurry flow rate across the membrane surface and exiting as product slurry. This relationship is shown in the Figure below.

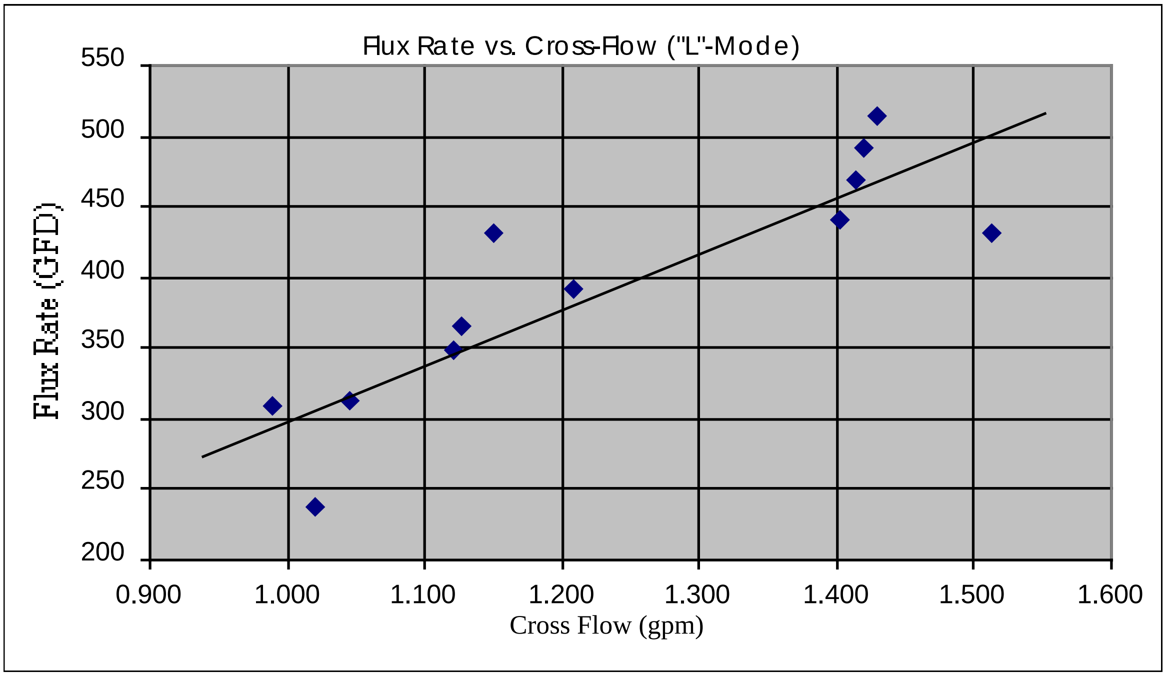

Figure 13

This phenomena became apparent during testing with the Rend Lake Flotation concentrate. The cross flow rate across the membrane surface is a function of tray spacing. The flow/flux relationship will be discussed further in the final report.

Task H Destec IGCC Fuel Evaluation

Destec evaluates slurry fuels for their IGCC technology by modeling gasifier performance based upon the parameters of slurry concentration and coal properties from the dry coal proximate and ultimate analyses.

The dry coal analyses reported to Destec were as follows:

Ultimate Analysis		Proximate Analysis		
C	78.6 %	Vol. Matter	35.1	%
H	5.0 %	Fixed Carbon	59.2	%
N	1.8 %	Ash	5.7	%
O	7.8 %	HHV	13,782	Btu/lb
S	1.15%			

Table 6 displays the results of two model runs provided by Destec for slurries with solids concentrations of 50.0 wt.% and 61.9 wt. % solids. Both scenarios compare favorably with standard nominal conventional power generation heat rates of about 10,000 BTU/KWHe. There is, however, an obvious benefit to higher loading as can be seen by the 11% improvement in efficiency for the higher solids concentration.

Table 6 -- Destec Slurry Fuel Performance Model Results

ESTIMATED PERFORMANCE FOR FLOTATION-CLEANED
COAL FINES SLURRY(1)

	Slurry Solids, wt.%	
	50.0	61.9
Coal Fines (Dry), TPD	2363	2107
Oxygen Required (95%), TPD	2672	2135
Slag Product (dry), TPD	135	120
Sulfur Product	27.2	24.2
Syngas Properties		
Dry Composition		
H2	36.05	32.43
CO	43.34	51.29
CO2	16.48	10.84
CH4	1.15	2.52
H2S (ppm)	20	23
COS (ppm)	30	30
N2	1.69	1.73
Ar	1.28	1.18
Dry Molecular Weight	20.31	20.42
Moisture Content, vol. %	30.05	23.50
Heating Value (dry), BTU/SCF		
HHV	267	295
LHV	248	276
Net Power, MW	301.2	302.4
Heat Rate (HHV), BTU/KWHR	9013	8003

(1) Based on Destec's coal gasification process supplying Syngas to a combined cycle plant utilizing an advanced 200 MW gas turbine.

5.0 Preliminary Economics

Table 7

Plant Operating Criteria	1000000	tpy (coal basis) Slurry Fuel Plant			
	Feed	Product			
	(tph)	(tph)			
Coal	114.2	114.2			
Water	456.8	76.1			
Total	571.0	190.3			
Solids Content	20%	60%			
Water Removed		1,521	gpm		
		Heated Feed		Un-Heated Feed	
Flux Rate		200	GFD	100	GFD
Area Required		10,954	sq.ft.	21,909	sq.ft.
No. of Machines (20% spares)		13		26	
Installed Cost of Major Equipment		$3,191,971		$5,783,942	
(Including pumps, valves, instruments, tanks, agitators)					
Amortized Capital Cost		$842,034	/yr	$1,525,789	/yr
No. years	5				
Interest Rate	10.0%				
Operating Costs					
Labor, Utilities		$1,000,000		$1,000,000	
Heat($/yr)		$305,268	/yr	$0	/yr
Coal Fines (at $0.80/mmBtu)		$21,608,467	/yr	$21,608,467	
Fuel Revenue (@ $1.00/MMBtu)		$27,010,584	/yr	$27,010,584	/yr
Net Revenue		$3,254,815	/yr	$2,876,327	/yr

A rough economic analysis of the technology is provided here to give an indication of the order-of-magnitude cost for a WTI/CRE facility to produce CWSF from coal fines from a generic source (e.g., prep plant fines, pond fines, milled slurry). Such a plant could have a near infinite number of configurations, so it has been assumed that major equipment includes V-SEP's, pumps, tanks, agitators, and instrumentation. Application specific equipment such as cyclones or other classifiers are not included. These costs have been lumped into one capital cost per installed V-SEP. A summary of all the assumptions and results are displayed in Table 7.

Excluded from the costs are engineering, building and infrastructure, freight, taxes, permitting, and contractor costs. Included in the estimate is a comparison of the cost of heating the feed slurry from 68 to 102 ^{o}F. In this estimation, it is assumed that the cost of a 375 bhp boiler and associated plate and frame heat exchangers add $300,000 to the capital cost. This cost is offset by a $2.9 MM savings in V-SEP and associated equipment. A net annual amortized capital cost savings of about $675,000 is offset by an increase in operating cost (boiler fuel) of $305,000 per year for a net annual revenue increase of about $370,000/year. If waste heat is readily available, the heated feed option becomes even more attractive.

CONCLUSIONS AND RECOMMENDATIONS

1. The application of heat to improve de-watering performance was demonstrated in this program. Figure 14 below indicates the relative improvement in performance with temperature.

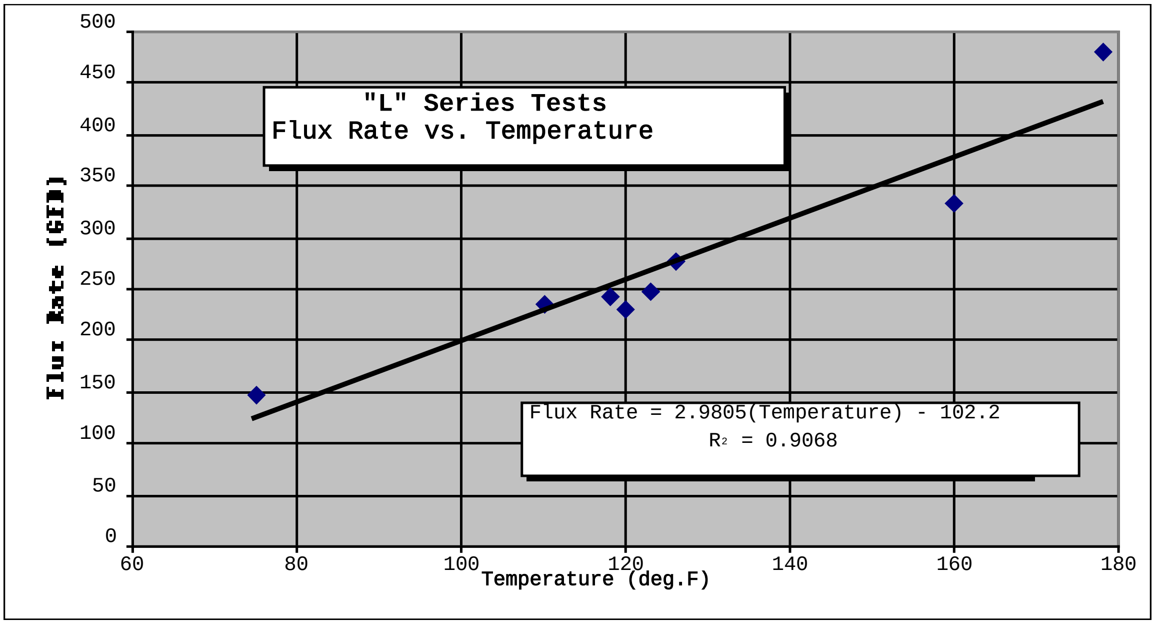

Figure 14

Using the equation shown in Figure 14, a flux rate of 100 GFD is predicted at 68 °F. Equipment costs are cut in half by elevation of operating to 102 °F. In an installation to produce 1.0 MMTPY (coal basis) CWSF, the cost to raise the feed to this temperature is generally more than offset by the savings in capital equipment. If waste heat is available, the decision to heat the feed is unquestionably justified. In a new installation, direct steam injection and heat recovery are recommended.

2. The New Logic Series “P” is not an appropriate unit for obtaining scale-up data for larger slurry concentration facilities.

There are significant differences between the Series “P” (denoting pilot scale) and both the Series “L” (laboratory) and the Series “I” (industrial scale) equipment. The flow patterns in the membrane stack do not match either unit. The flow patterns in the Series “P” create operating problems which are distinctly different from either of the other models.

The Series “L”, which has a flow regime which is similar to that of the “I” unit is much easier to operate. It is also claimed by New Logic International that the laboratory unit is scalable to the commercial scale, whereas the Series “P” is not. This conclusion could only reasonably be justified by further testing at the vendor facility.

3. It was found that vibrational frequency (i.e., vibration amplitude) had little effect on de-watering performance in either the pilot or laboratory apparatus above a minimum value. In the pilot unit, it was found that when vibration was decreased below about 0.5 inches (as measured at the full diameter of the membrane stack), flux rates fell off dramatically. This was attributed to the inability of the low vibration to clear solids cake formation along the membrane surface. When vibration was increased above this value, the membranes would disrupt the cake and flux rates could be re-established. In general, smoothest operation was achieved above 0.75 inches of stack deflection.

   The maximum allowable membrane stack vibration is a function of the standard vendor design. The vendor recommends operation at or below the maximum allowable design value. No further investigation into the effect of vibration appears warranted.

4. The effect of feed pulsing could not be established in the pilot configuration during this test program. The main cause of this was the small diameter piping included with the Series "P" V-SEP package which would not allow for rapid pressure/flow pulsations because of flow restriction. Improved water removal performance as a result of feed pulsing has, as yet only been observed in the laboratory (Series "L") configuration.

   It is recommended that future pilot programs or commercial development address the need for larger system piping and flow paths in the vendor supplied equipment to take advantage of the potential benefits of feed/pressure pulsation.

5. Observations during operation of the pilot plant suggested several operational issues which could be addressed by process control. Included were:

   a. Means of preventing membrane failure as a result of general plant upsets.
   b. Means of preventing membrane failure during routine start-up and operation.
   c. Automated Start-Up Procedures
   d. Means of Preventing Machine Plugging
   e. Automated Means of Improving De-watering Performance

   Future pilot plant and commercial development projects should include, at a minimum, the necessary instrumentation and controls for smooth automatic start-up and shut-down procedure as outlined in "Task E" of this document.

6. Task F investigated equilibrium flux rate at elevated concentrations. In the last, and most significant test, it was found that:

   a. Flux rate did not drop dramatically as concentration increased to high loading. In other V-SEP applications, where the particle size is normally much smaller, a steady drop in flux rate is usually observed. The vendor claims that this drop is normally associated with increasing slurry viscosity. It is felt that, because of the relatively large particle size of the coal feedstock, this effect was not evident.

b. Flux rates could be re-established if orderly shut-down and re-start-up procedures are followed.

7. No significant effect of increased system pressure on flux rate was found. This confirms the results found in earlier "L" Series test work. One explanation for this is that increased system pressure leads to increased slurry density at the membrane surface which increases the "cake" resistance to permeate flow. The effect is not well understood and could be a function of the coal particle geometry.

   This effect may be slurry specific. The vendor indicates that there is some benefit to increased pressure with certain other materials they have tested.

   It is recommended that the effect of pressure be investigated for each new slurry to be processed before designing a plant.

8. Consol suggested that this technology may prove useful in de-watering tailings muds to either provide a tailings paste for mine backfill or as an improved feed to existing filtration equipment. Testing of tailings mud in this program was not successful due to the ultra-low solids content (less than 1.0 wt.%) and apparent fineness of the muds received from Consol's Rend Lake preparation plant. Limited testing with the material showed that de-watering performance of the equipment did not appear to be economically interesting. However, this assertion is somewhat dubious in the absence of testing with a more representative sample.

9. Model results of CWSF performance in Destec's IGCC technology at solids contents of 50 and 62 weight percent solids both showed low heat rates as compared to normal pulverized coal power plant performance. IGCC heat rates of about 9,000 and 8,000 Btu/KWH respectively compare favorably with 10,000 Btu/KWH or more found in conventional power plant practice.
   For a given coal fines stream, the maximum attainable solids loading may only be 50-55 wt. %. If so, there are numerous ways to augment the solids loading to achieve a 60% or better coal loading. Normally, the ultimate solids loading is a function of both solids density and particle size distribution. For example, suppose the particle size of a particular recovered fines slurry is such that only a 55% loading is attainable. Coarser size fractions (e.g., -28 mesh x 100) could be mixed with the slurry to increase the solids loading. In this case, the addition of 0.12 lb of coarse coal per pound of slurry would bring the loading up to 60%.

<u>Acknowledgments</u>

The help and guidance of Dr. Ken Ho of the Illinois Clean Coal Institute is gratefully acknowledged. His interest and innovative thought processes proved invaluable in the execution of this project.

The authors also wish to thank Dr. Anthony Fonseca and Mr. Randy Kosky of Consol Inc. For providing support to this project as well as Mr. David Breton of Destec Energy for his timely owkr in modeling the fuel characteristics of the coal slurry fuels.

Finally, many thanks to Mr. Henry Ehrlinger for his support and efforts to get this project off the ground and moving forward.

DISCLAIMER STATEMENT