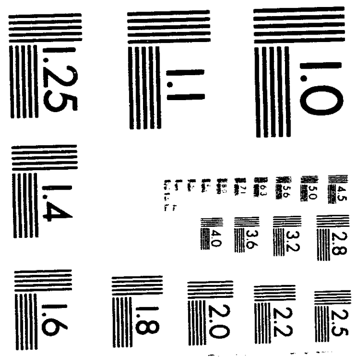

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DOE/ID/13132-T1
(DE94007013)

IMPROVED ELECTROACOUSTIC DEWATERING (EAD) BELT PRESS FOR FOOD PRODUCTS

Phase III

Technical Progress Report

February 1994

Work Performed Under Contract No. FC07-91ID13132

For
U.S. Department of Energy
Office of Industrial Technologies
Washington, D.C.

By
Battelle
Columbus, Ohio

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Technical Progress Report

February 1994

Work Performed Under Contract No. DE-FC07-91ID13132

Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Sponsored by the Office of the Assistant Secretary
for Energy Efficiency and Renewable Energy
Office of Industrial Technologies
Washington, D.C.

Prepared by
Battelle

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SUMMARY

The food processing industry is a large user of energy (0.15 to 0.18 quad in 1986) for evaporative drying partly due to the limited effectiveness of conventional mechanical dewatering machines. Battelle's electroacoustic dewatering (EAD) process has been shown to improve the performance of mechanical dewatering processes for several food products, such as corn fiber, by superimposing electric and ultrasonic fields. A two-phase developmental program, co-funded by DOE/OIT and industry, showed the potential to save 0.027 to 0.035 quad/yr energy by 1995 through the full implementation of EAD in the food processing industry. The Phase II results suggested that EAD should be used as a post dewatering device to realize the full benefit of EAD. Based partly on these results, Ashbrook-Simon-Hartley (Ashbrook), Battelle's EAD licensee and cost-sharing industrial partner, built an EAD belt press prototype for testing on sewage sludges. This report covers a Phase III effort funded by DOE/OIT, under a cooperative agreement, for demonstrating the EAD prototype on corn wet milling products, namely corn fiber and corn gluten.

The Phase III was originally designed to cover three tasks: prototype preparation and planning (Task 1); on-site (field) testing (Task 2); and energy conservation and economic analysis (Task 3). However, only Task 1 was performed as Ashbrook was unable to provide the technical and financial resources necessary to successfully carry out field testing. This report, therefore, concerns only Task 1, which concerned prototype modifications, bench-scale testing, site selection, and shakedown (readiness) testing of the prototype.

Since, the Phase II effort involved the use of an EAD machine that combined mechanical predewatering and EAD post dewatering in one, the feed to the machine was a dilute one (i.e., 17 percent solids for corn fiber slurry and 11-16 percent solids for corn gluten slurry). But the target feed for Phase III EAD prototype was of the order of 25 to 35 percent, obtained after predewatering in a centrifuge or a screw press. Therefore, it was necessary to reexamine the EAD performance in the laboratory, and to modify and check the prototype to insure readiness of the machine prior to field testing. It was also necessary to reexamine the availability of a test site. These activities were completed in this Phase III program and are discussed in this report.

The primary effort in Phase III was on corn fiber rather than corn gluten because of a larger energy conservation potential for corn fiber EAD. Bench-scale tests were conducted on corn fiber samples from two plants: American Fructose, Decatur, Alabama; and American Fructose, Dimmitt, Texas. The EAD variables included voltage, ultrasonic wattage, residence time, and pressure. The EAD behavior of these predewatered materials was generally comparable to the EAD behavior of more dilute feedstocks tested in previous phases. The voltage, actually voltage gradient, and ultrasonic wattage were the most important variables. Both feedstocks behaved similarly, though the level of post dewatering achieved with the Decatur sample was higher than for the Dimmitt sample. This was partly because the Dimmitt sample is harder to dewater due to finer grinding of the corn fiber, and possibly also because the Dimmitt sample was allowed to stand (age) longer, in a pile, after predewatering than the Decatur sample was. In fact, the bench-scale tests showed a clear, negative impact of aging of sample on performance of EAD, possibly because the sample picked up air and lost some of its conductivity. But, while either site was suitable for EAD testing, the Dimmitt site was tentatively selected because of previous (Phase II) efforts at this site and because the Dimmitt material is harder to dewater, and, therefore, a better test of EAD effectiveness. The actual increase

in solids content observed in bench-scale tests for the Dimmitt material was 5 to 8 percent; however, it is believed that the use of fresh material in field tests will help achieve the targeted 8 to 11 percent increase in solids content.

A major part of the bench-scale testing also concerned the testing of new polymer belts as well as a new copper-poly belt which could replace two of the three belts used previously on sludge testing. The reason for trying copper-poly belt was that it represented a major opportunity for EAD press capital cost reduction. These alternative belts performed satisfactorily in the bench tests.

A number of modifications were made to the EAD prototype based on the bench-scale tests. The prototype performance was then checked out through two readiness (shakedown) tests. All sub-systems were found to perform as designed. However, the design pressure of about 4 psi was considered suboptional for corn fiber; it was not possible to modify this prototype to achieve higher pressure. Also, while the previous, three-belt (two polymer belts and one stainless steel, cathode belt) system performed as designed, the more attractive two-belt (copper-poly belt) system was not mechanically satisfactory. The problem with the copper-poly belt was that the seam, needed to make an endless belt, did not hold under tension. Putting an epoxy at the seam was attempted but failed apparently because of inadequate on-site curing of the epoxy. At this point, it was necessary either to launch an additional developmental effort to make the more economical two-belt system work or to revert back to the proven, but expensive, three-belt system. Unfortunately, Ashbrook felt that the two-belt system was critical for the economic viability of the process but was unable to commit the technical and financial resources necessary to carry out an additional developmental effort. Therefore, the plans for field testing were abandoned.

The bench-scale tests on corn gluten were quite encouraging and showed that EAD was attractive in dewatering corn gluten slurry from an initial 30 percent to over 43 percent solids level. This represents a 25 percent energy savings potential, comparable to that projected for corn fiber or corn gluten EAD in Phase II efforts on a more dilute slurry. The bench-scale efforts suggested that the earlier (Phase II) projections for energy conservation in corn wet milling industry on implementation of EAD were reasonable, i.e., 8.5×10^{12} to 12.8×10^{12} Btu/yr (1995 basis) savings are potentially achievable.

ACKNOWLEDGEMENT

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Phase III Report
on
Improved Electroacoustic Dewatering Belt Press for Food Products
to
U. S. Department of Energy Idaho Operations Office

November 30, 1993

1.0 INTRODUCTION

The food processing industry is a large user of energy (0.15 to 0.18 quad in 1986) for evaporative drying partly due to the limited effectiveness of conventional mechanical dewatering methods. Battelle's electroacoustic dewatering (EAD) process has been shown to improve the performance of mechanical dewatering methods for several food products, such as corn fiber, by superimposing electric and ultrasonic fields[1]. It has been estimated that there is a potential to save 0.027 to 0.035 quad/yr by 1995 through the full implementation of EAD in the food processing industry. A two-phase developmental program, co-funded by DOE/OIP and industry, to demonstrate the benefits of EAD was carried out in cooperation with the food processing industry, the National Food Processors Association (NFPA), and two equipment vendors (Ashbrook-Simon-Hartley and FMC). In Phase I, laboratory scale studies were carried out on a variety of food suspensions including corn fiber, corn gluten, and apple pomace[2]. In Phase II, scaled-up, continuous tests were carried out in a small belt press and a screw press, both modified with EAD hardware. The Phase II test results suggested that EAD should be used as a post dewatering device and several mechanical and EAD design changes were necessary to realize the full benefits of EAD[3,4].

Based on the published Phase II results, a post dewatering, stand-alone, longer residence time, EAD belt press was designed and built by Ashbrook-Simon-Hartley (Ashbrook). The prototype was successfully tested on sewage sludges[5], which led to the selection of the EAD belt press for the "Product of the Year" award in 1990 by the American Filtration Society. Based on this success, Ashbrook felt that the improved EAD belt press could be successfully employed in food processing applications, such as for dewatering of corn fiber and corn gluten slurries. Therefore, Battelle applied for financial assistance from DOE, Office of Industrial Technology (DOE/OIT) to demonstrate this improved EAD belt process prototype with cost sharing and technical resources provided by Ashbrook.

2.0 OBJECTIVE AND SCOPE OF PHASE III

The objective of Phase III was to demonstrate the economic viability of the improved EAD belt press for enhanced postdewatering of corn products, specially corn fiber slurry.

The work plan consisted of the following tasks:

- Task 1. Prototype Preparation and Planning
- Task 2. On-site (Field) Testing
- Task 3. Energy Conservation and Economic Analysis.

Unfortunately this effort was prematurely terminated near the end of Task 1 as Ashbrook dropped from the program due to inability to supply the technical and financial resources necessary to demonstrate the satisfactory mechanical performance of a less expensive belt system and then to carry out Task 2. Therefore, this report only concerns Task 1.

3.0 RESULTS AND DISCUSSION

The following Task 1 activities were carried out in Phase III:

(1) Analysis of Belt Press Design Requirements

(2) Feedstock and Site Selection

(3) Equipment Modifications and Readiness Testing.

Each one of these activities is described below in detail.

3.1 Belt Press Design Analysis

3.1.1 The EAD Concept and Potential

The EAD process utilizes conventional mechanical presses, such as vacuum or pressure filtration, in combination with electric and ultrasonic (acoustic) fields. A synergistic effect of combining electric and ultrasonic fields was discovered by Battelle and is the basis of several U.S. and foreign patents and patent applications[1,6]. It is believed that the application of a direct-current electric field pumps water from open pores and capillaries due to electro-osmosis. The water is then pulled away from the filter surface by mechanical means (vacuum or pressure). The ultrasonic field aids the electric field and mechanical dewatering process by releasing tightly held bulk and capillary water and consolidating the filter cake to maintain a liquid continuum[2].

In a typical application of EAD, a filter cake, dewatered by conventional mechanical means, is post dewatered by EAD. This helps reduce or eliminate capital- and energy-intensive thermal drying thus lowering the operating cost and leading to energy conservation. This is depicted in Figure 1 where corn fiber is dewatered by a screw press to about 35 percent solid level. The material is then postdewatered with EAD to 46 percent level; i.e., increasing the solids content by 11 percent, which was projected for the improved (1.2 m wide) EAD belt press based on the Phase II results with a 0.5 m wide EAD belt press. Based on the range of conditions used in Phase II, the energy conservation potential of EAD for corn wet milling, i.e., for corn fiber and corn gluten dewatering, was estimated at 8.5×10^{12} to 12.8×10^{12} Btu/yr (1995 basis). A comparison of these two corn products showed that about two-thirds of the energy conservation potential could be attributed to corn fiber application. Therefore, corn fiber was chosen as the primary material for Phase III testing.

3.1.2 Improved EAD Prototype Design

The results from the Phase II PRU tests on apples and corn fiber slurry indicated that the best place to apply EAD is after the high-throughput predewatering is completed. Furthermore, it was found impractical to get the desired EAD effect without either sacrificing the throughput of existing belt presses or extensively altering the overall dimensions, especially increasing the support frame size and strength. For this reason Ashbrook, with help from Battelle, built a post-dewatering, "stand-

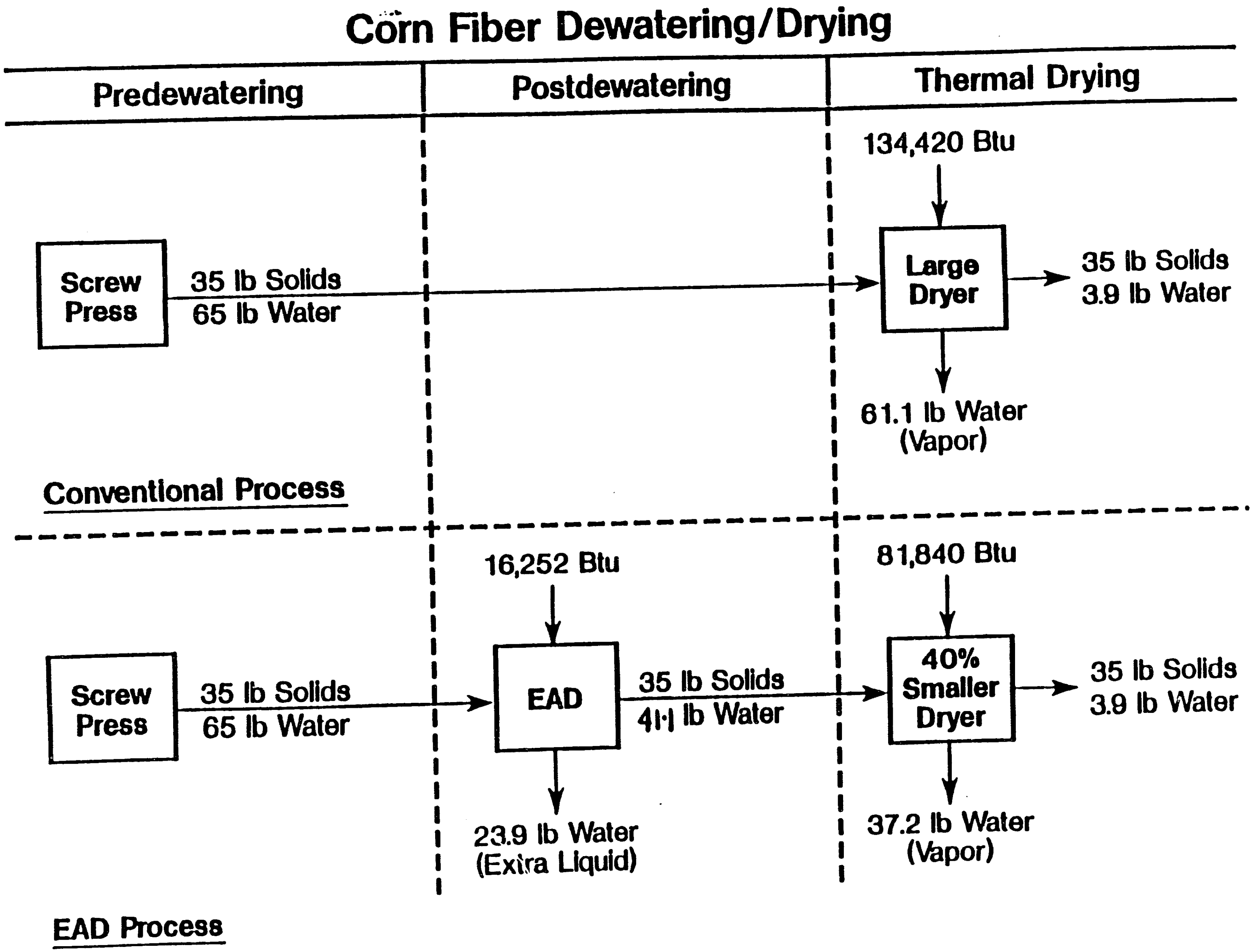

FIGURE 1. TYPICAL ENERGY USE FLOWSHEET FOR CORN FIBER DEWATERING AND DRYING (EAD PROCESS PROJECTED TO USE 27 PERCENT LESS ENERGY)

alone" belt press EAD prototype. This prototype detailed in Figures 2, 3, and 4 was successfully tested, prior to start of this (Phase III) project, on several sewage sludges and can be used with a variety of currently installed and operational predewatering units such as belt presses, screw presses, and centrifuges. The details of the patented design[6], prior to modifications on this project, are given below.

3.1.2.1 Overall Specifications. The overall specifications for the 1.2 meter wide belt EAD prototype are listed in Table 1. A 1.2 meter width was chosen in order to give a reasonable expansion of cake width (3.7 times that for PRU) while keeping the cost of the demonstration program reasonable. The effective cake width for this prototype is about 1.1 meter which should reduce the edge effect encountered in the PRU (Phase II), especially wetting of the cake at the edges.

The most commonly used belt widths are 2 to 2.5 meters, but belt widths as small as 1 meter and as large as 3 meters are also used. Since the EAD unit is essentially a single-roll unit, using belts in the 2 to 2.5 meter range should be no problem.

A 1.3 meter diameter roll was chosen to keep the belt tension reasonable while maintaining a reasonable pressure but still achieving maximum EAD contact length possible. The maximum pressure on cake is 4 psi compared with 3.9 psi used in PRU tests and 7 psi used in the batch tests. The pressure should have a positive effect on delta solids or delta EAD, defined as the increase in solids content due to EAD, but a larger positive effect on mechanical dewatering of corn fiber. The EAD contact length is 2.7 meters compared to 0.4 meter for the 9th roll in PRU. This makes longer residence time possible without reducing belt speed or throughput.

The normal belt speed for belt presses are in the 2 to 6 m/min range. On the other hand, the prototype has a variable drive that gives a belt speed of 0.75 to 3 m/min. If necessary, the belt speed can be increased simply by changing the variable drive.

The Phase II economic analysis for corn fiber dewatering showed the need to maximize throughput even if delta solids decline below the 10 percent level, say to about 8 percent. The current design will allow a 12-fold increase in total throughput and a 4.5-fold increase in throughput per unit anode drum width.

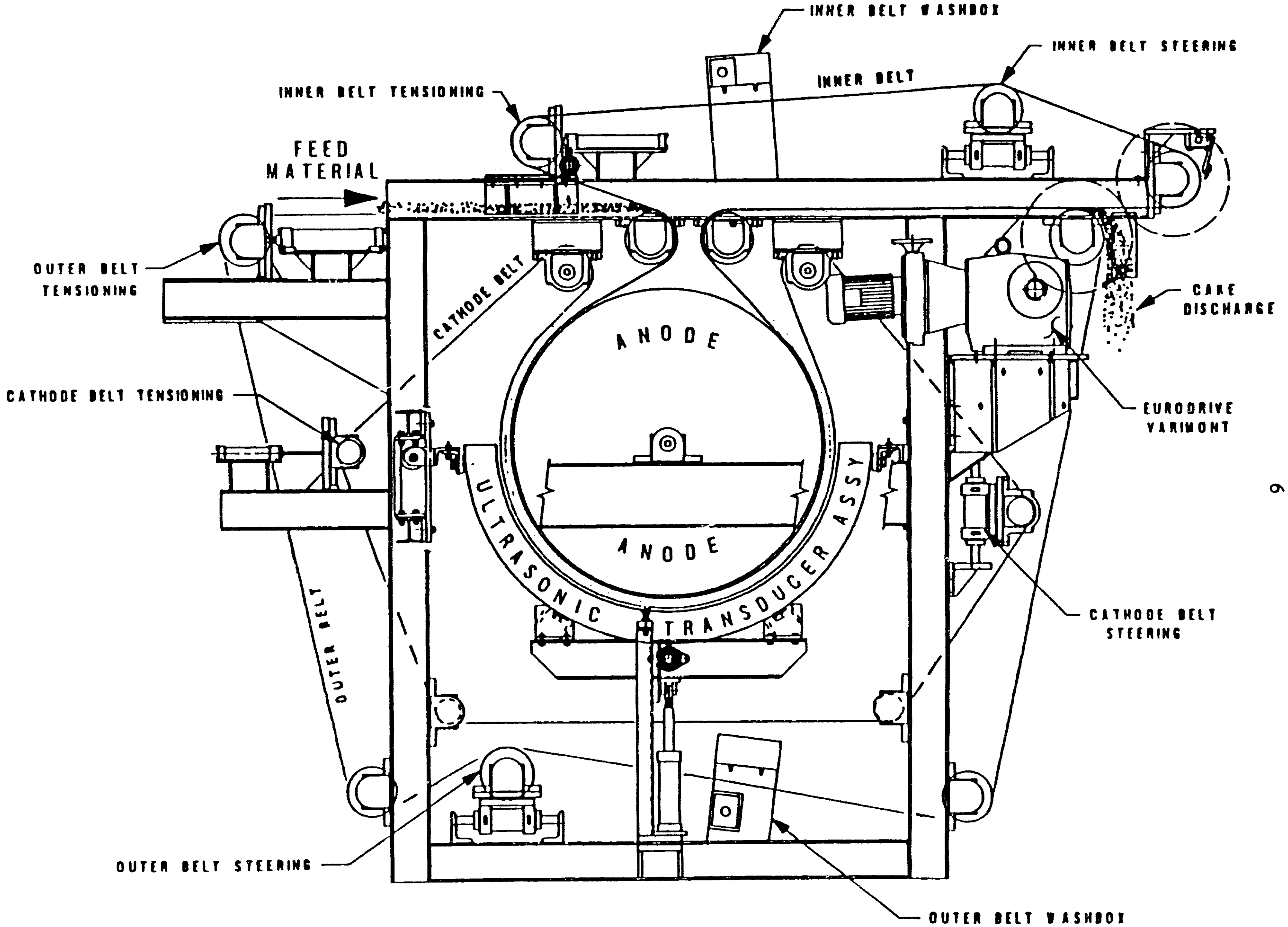

FIGURE 2. SCHEMATIC OF BELT PRESS EAD PROTOTYPE

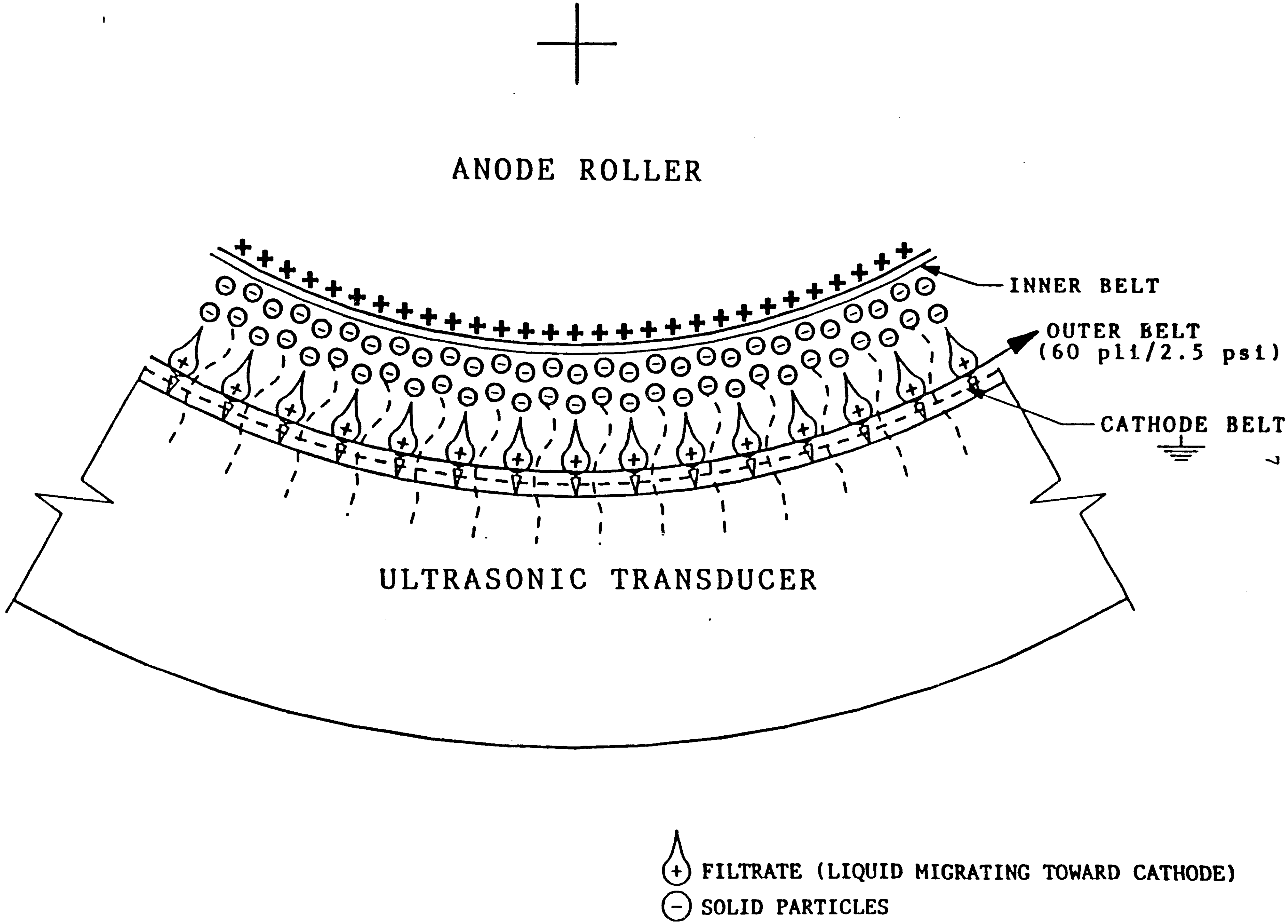

FIGURE 3. BELT PRESS EAD PROCESS CONCEPT

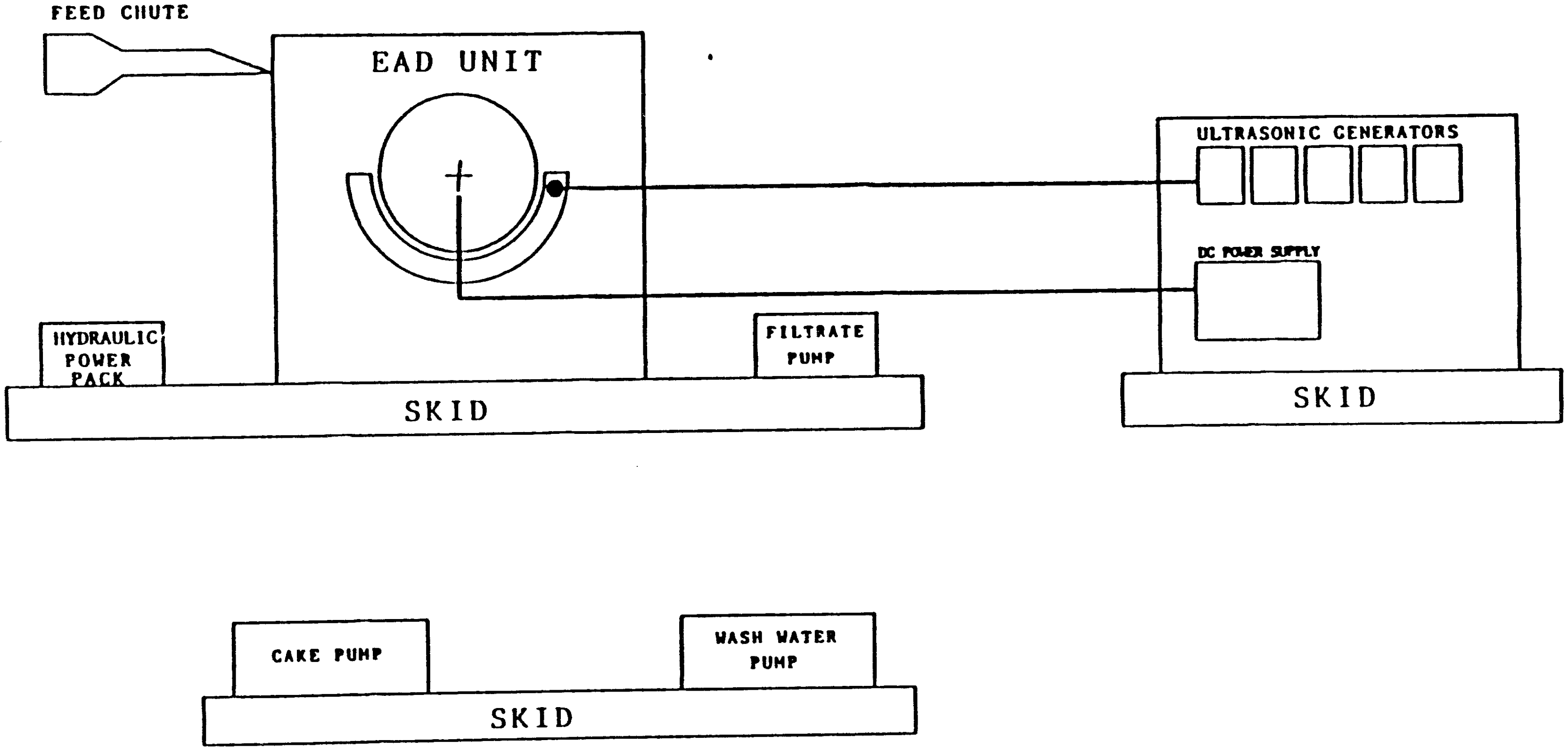

FIGURE 4. SKID-MOUNTED BELT PRESS EAD PROTOTYPE SYSTEM

Table 1. Overall Specifications of 1.2 Meter Belt EAD Prototype (Prior to Modifications in Phase III) Compared to PRU (Phase II) Test Conditions for Corn Fiber

Design Parameters	Design Values	
	Prototype	PRU
Maximum cake pressure, psi	4	3.9
Maximum cake thickness at inlet, inch	0.75	1.3
Maximum cake thickness at outlet, inch	0.60	1.0
Belt speed, m/min	0.32-1.60	0.33-2.0
Anode roller diameter, m	1.3	0.36
EAD contact length, m	2.7	0.4 (3rd or 9th roll)
EAD residence time, min	1.7-8.4	0.2-1.2 (3rd or 9th roll)
Cake width, m	1.1	0.3
Ultrasonic plate width, m	1.1	0.4
Cathode belt width, m	1.1	Belt not used
Corn fiber throughput at 3/8-in. cake thickness, and 2 min. residence time, lb(DS)/hr	842	68 (3rd + 9th rolls)
Voltage range, volts	0-120	0-120
Current capacity, amps	1600	200 (3rd or 9th roll)
Ultrasonic capacity, kw	9.6	1.6 (3rd or 9th roll)
Ultrasonic intensity, watts/cm^2	0.41	1.0

3.1.2.2 Improvement of Ultrasonic Coupling Efficiency. The ultrasonic efficiency depends on two major variables:

1. Coupling efficiency – i.e., fraction of ultrasonic energy generated at the surface of the plate which is transmitted into the cake.
2. Conversion efficiency – i.e., efficiency of converting electrical to ultrasonic energy at the surface of the plate.

The new seal design for the EAD rolls, demonstrated in Phase II, significantly improved the coupling efficiency of ultrasonic energy. The coupling efficiency was further increased by minimizing formation of gaseous films (product of electrolysis) by continuously circulating the filtrate through the annular gap between the cathode belt and the curved ultrasonic plate (Figure 3). The annular gap was minimized to help reduce reflections due to impedance mismatch at the solid-liquid and the liquid-solid interface of the vibrating plate, filtrate and the polymeric belt. We hope to eliminate the cathode belt eventually and control the cake thickness more precisely so that the polymeric outerbelt can be coupled to the vibrating ultrasonic plate by a thin film of filtrate. This would be a significant improvement over the present design.

For the prototype, a new half cylindrical vibrator was designed with appropriate boundary conditions and seal for the filtrate to maximize both conversion and coupling efficiency.

The present ultrasonic vibrating plate and seal design have evolved through several steps during the Phase II testing and prototype testing with sludges. Due to the cost and time constraint the Phase II vibrating plates were fabricated by welding one of the edges of two half sections, each with about 67 degree sector angle. Due to change in the boundary condition from free end to welded (clamped) end, the resonance of this welded plate changed and was, therefore, far from optimum. We believe the conversion efficiency of the present prototype system, which is designed as a single curved plate, is significantly more efficient. And, as mentioned earlier, the conversion efficiency can be further improved by improving the ultrasonic seal design.

The ultrasonic plate is driven by 96 transducers. However, through a special circuit design we have been able to use several combinations of these to determine the optimum number and locations for these for various materials and throughputs. The rated maximum power input is 9,600 watts which is supplied by 6 ultrasonic generators as opposed to only one used on a roll in the PRU. The effective surface area is about 2.35 m^2.

To estimate transmission of ultrasonic intensity (I_o) into various materials, we did an impedance analysis using the following values for the specific acoustic impedance Z:

Z_{steel} = 47×10^6 MKS Rayls

Z_{water} = 1.5×10^6 Rayls

$Z_{Belt/Cake}$ = 3×10^6 Rayls.

Acoustic impedance of the cake is expected to increase with dewatering, making acoustic energy transmission easier, however, the attenuation through the cake also increases with dewatering. Our calculations show that at zero fluid gap, about 23 percent of I_0, i.e., 0.11 watts/cm^2 is coupled into the belt/cake.

As we increase the fluid gap to 1/8-in, 1/4-in, and 1/2 in, the energy coupled into the belt/cake decreases by 14.5, 40, and 70 percent, respectively, of the 23 percent, e.g., for 1/4 inch fluid the available intensity in the cake is about 0.07 watts/cm^2. We expect the fluid gap to vary from just under 1/8-in at the inlet to roll and just over 1/4-in at the outlet, which is far less than possible with the PRU. The resulting intensity in cake is projected to be 0.07 to 0.10 watts/cm^2. Under these conditions, the sludge dewatering tests showed that the optimum ultrasonic input power for the prototype was in the range of 1.7 to 6 kw. On the other hand, bench-scale (i.e., 45 cm^2 filter area for batch tests) results showed an optimum at 20-25 watts of ultrasonic transducer output power. This meant that, in the case of sludge dewatering, the optimum ultrasonic intensity for the prototype based on the generator input power was 2 to 7 times less than the optimum intensity in the bench tests based on the generator output power. Such a scale-up relationship for corn fiber and corn gluten will not be known until field tests (Task 2) are carried out and 9.6 kw input power for the prototype is considered adequate in the meantime.

3.1.2.3 Electrodes. The anode is made of the same material and coating as the PRU (Phase II) EAD rolls, which did not experience any deterioration based on a surface evaluation procedure specified by Engelhard.

A wire mesh, moving cathode belt was used for sludge dewatering to obtain good electrical contact of the cathode and the outer polymer belt and to minimize cathode wear. An alternate cathode system consisting of a conducting polymer belt was identified, but not field tested before start of Phase III. The use of this new belt will eliminate the need for the wire mesh cathode belt and associated equipment (belt washing, belt tracking, belt tension, etc.), thus, reducing the cost of the EAD belt press.

3.1.3 Previous Design Versus Corn Dewatering Needs

The previous prototype design versus the needs of this project are discussed below.

3.1.3.1 Electrostatic Voltage and Current Density. The direct-current power supply is capable of delivering 0-120 volts and 0-1600 amps. In Phase II tests with corn fiber, the highest voltage used was 90 volts and the largest voltage gradient was 480 volts/inch at a cake thickness of 0.125 in. The designed voltage range and voltage gradient range are sufficient for our intended tests on the prototype (i.e., 120 volts and 1,000 volts/inch at 0.125-in. cake thickness). At 1600 amps, the current density will be 46 amps/ft^2. The voltage gradient is the driving force and the current consumption depends on conductivity of cake, which is expected to be less for the drier feed. We believe the design values for both voltage and current are sufficient for optimum results. In the most recent tests of the prototype with coal slurry and industrial sludge, the direct-current power supply performed as per specifications with respect to current delivered; the maximum voltage in these tests was limited to 100 volts by experimental design.

3.1.3.2 Ultrasonic Power and Sector Combinations. As discussed previously, the previous design has six independently controllable sectors. Each sector is connected to a power supply rated at 1.6 kw for a total of ultrasonic power of 9.6 kw. All the six sectors of the ultrasonic plate can be activated independently. With this design, the ultrasonic intensity at different stages of dewatering can be controlled to optimize the level of dewatering and operating power requirements. If necessary, ultrasonic power supplies can be upgraded to a total of 10.8 kw from 9.6 kw.

3.1.3.3 Cake Residence Time and Cake Thickness. Belt speed motor control has a turndown ratio of 5. The speed control at present is capable of cake residence times of 1.7 min. to 8.4 min. (1.6 m/min. to 0.32 m/min. belt speeds) for a contact length of 2.7 m. For corn fiber dewatering, it will be necessary to modify the speed control to achieve residence times of 0.8 min. to 4.0 min., which corresponds to a belt speed range of 0.68 m/min. to 3.40 m/min. With respect to cake thickness, the prototype is designed to handle 0.125-in. to 0.75-in. To date, the prototype has been tested to handle other materials of this thickness range. The trade off is between throughput and heating of the cake, with cake heating a critical criterion, the optimum thickness may not be 0.75-in. as observed with coal slurry.

3.1.3.4 Feed Pump and Feed Spreader. Prototype tests have been conducted for other materials such as coal slurry at a maximum of 63 percent solids and sludge at 23 percent solids using a Moyno pump. At the fastest belt speed (3.40 m/min) and the largest cake thickness (0.75-in.), the feed pump should deliver 18 gallons/min, which is well within the range of the Moyno pump. However, the uncertainty here is the material handling characteristics of corn fiber due to the high solids content of the feed (30-35 percent); this was not a problem in Phase II where the solids content of the feed was only 17 percent and the EAD belt press had a conventional mechanical dewatering section. The pump needs to be tested for its ability to deliver the feed slurry to the feed hopper. In the unlikely event it is not performing as expected, a screw conveyor can be used for prototype testing. The feed spreader needs to be tested for its ability to spread feed cake evenly along the belt width at the required feed rates. Again, there is some uncertainty due to the high solids content.

3.1.3.5 Cake Heating, Temperature and Cooling. Preliminary heat transfer calculations indicate that the primary mode of heat removal is convection of heat by the filtrate. Conduction through the cake plays only a minimal role in heat removal for cake thicknesses greater than 0.125 in. The above results are based on assumptions of uniform heat dissipation due to electrical resistance heating along the cake thickness and contact length. Heat generated from the ultrasonic vibration is significantly lower and is neglected.

Adiabatic temperature rise calculations based on total energy input indicate a temperature rise of 36 to 41 F for cake thicknesses of 0.25-in. to 0.75-in. It should be noted that the adiabatic temperature rise calculations are based on energy consumption values from batch tests of corn fiber slurry containing 27 percent solids dewatered to a final 34 percent solids. In the planned tests in Phase III, solids content is in the range of 30-45 percent. Dewatering rate is directly proportional to the applied voltage gradient. For specific voltage, the higher the solids content, the smaller the conductivity and current and, hence, smaller the energy consumption per pound of filter cake. We expect that the adiabatic heat rise calculations are on the conservative side and the actual temperatures rise for the drier cake is smaller.

Gelatinization becomes a problem either due to non-uniformities in heating or if the feed itself has an inlet temperature of substantially higher than 100 F. In that case, the only two practical options may be to precool the feed slurry or to reduce the energy input at the expense of dewatering. One of the main goals of Phase III work is to establish the optimum amount of dewatering and the optimum experimental conditions to achieve it. We need to establish the correct combination of voltage, ultrasonic power, cake residence time and thickness to achieve the required dewatering, without gelatinizing the cake.

3.1.3.6 Fluid Seal, Fluid Leakage and Belt Properties. In prior tests, fluid leakage between the cathode belts and ultrasonic plate was a source of concern. Air gaps between the belt and ultrasonic plate decrease the transmission of ultrasonic energy to the cake, thus, decreasing the dewatering. The EAD belt press equipment vendor believes that the leakage was through the edges of the belt itself and not through the seal. This is based on their observation that the leakage continued unabated, even when an inflatable rubber seal was applied at the maximum inflatable pressure. The new polymeric outer belt, used along with a third metallic belt, as well as the alternate cathode/outer belt is such that the edges of the belt have a different weave of no porosity that should minimize the fluid leaks. Small fluid leaks are not a problem so long as the cavity between the belt and the ultrasonic plate is always full. Replacing two outer belts with one should specially improve the sealing abilities and minimize fluid leakage.

3.2 Feedstock and Site Selection

As discussed earlier, the Phase III EAD belt press design is based on the concept of post dewatering, i.e., utilizing a corn fiber feed with a solids content of 25-35 percent. The previous (Phase II) field testing, however, was based on the use of a dilute (17 percent solids) feed. It was, therefore, necessary to re-examine several corn feedstocks and the associated test sites. After examining three corn processors, it was decided to work with American Fructose Corporation, and two of their plants located in Dimmitt, Texas, and Decatur, Alabama, were selected for bench-scale testing.

The objective of this phase of the research was twofold:

(1) To select the material and field test site suitable for demonstration of EAD of corn fiber slurry at a commercial corn processing plant, and

(2) To briefly explore the limits of dewatering by varying the independent variables (such as voltage, ultrasonic wattage, residence time and cake thickness) to their extremes.

This would let us determine, in the laboratory (bench-scale), if the predewatered material behaves similar to the more dilute material used in Phases I and II as far as the effect of EAD parameters is concerned and to help better plan the field test conditions. The majority of the laboratory tests were conducted with corn fiber. A few tests were done on corn gluten at the end.

3.2.1 Corn Fiber Testing

Corn fiber samples from two plants were tested:

(1) American Fructose in Dimmitt, Texas, and

(2) American Fructose in Decatur, Alabama.

Corn fiber product from two different stages in the dewatering process were tested:

(1) Product of Mercone centrifuge, and

(2) Product of screw press.

The following range of independent variables were tested; voltage from 0 to 120 volts; residence time from 1 to 3 minutes; and ultrasonic wattage from 0 to 45 watts (0 to 1.0 watts/cm^2). In most tests, pressure was 5 psi, though some tests were performed at 7 psi to determine the effect of pressure. A key part of the testing concerned the selection of belts. All tests were conducted in a bench-scale EAD unit, comprising a 45 cm^2 filter area, operated in a batch mode[(2)].

A total of 70 tests were conducted on various corn fiber samples. Raw data with all the independent variables, material source and percent dewatering are shown in Tables 2 through 4. The data in Tables 2 and 3 are for tests performed with corn fiber product out of a Mercone centrifuge used at the Decatur Plant, with a typical initial solids content of 21.5 percent. On the other hand, Table 4 shows tests performed with corn fiber product of a screw press used at the Dimmitt Plant, with a typical solids content of 26.3 percent. One test was also performed on screw press product from Decatur that had a solids content of 38.9 percent (Table 4).

Table 2. Experimental Data on Dewatering of Corn Fiber Product of a Mercone Centrifuge (Initial Solids ≅ 21 percent)

TEST #	TEST DATE	SAMPLE WEIGHT GRAMS	APPLIED VOLTAG VOLTS	AVERAGE CURRENT AMPS	U/S POWER WATTS	ELEC. TIME MIN	APPLIED PRES. PSI	INITAL SOLIDS %	FINAL SOLIDS %	DELTA SOLIDS %	MAX SAMPLE TEMP., F	LIQUID REMOVE GRAMS	ENERGY KW.HR/ LB.FILT.	FILTER BELT TYPE	MATERIAL SOURCE
1	11-7-91	50.08	0	0.000	0	0.0	5	20.34	23.65	3.31	68	7.01	0.000	CU-POL	DECATUR
2	11-7-91	60.03	50	0.934	0	3.0	5	20.34	23.21	2.87	95	7.42	0.143	CU-POL	REC'D
3	11-7-91	60.09	50	0.983	15	3.0	5	20.34	24.64	4.30	105	10.49	0.113	CU-POL	11-07-91
4	11-7-91	60.04	75	1.385	0	3.0	5	20.34	27.18	6.84	139	15.11	0.156	CU-POLY	
5	11-7-91	60.66	75	1.469	15	3.0	5	20.34	26.29	5.95	150	13.73	0.187	CU-POLY	
1	12-18-91	90.14	0	0.000	0	0.0	5	21.49	23.92	2.43	69	9.16	0.000	TETKO	DECATUR
2	12-18-91	90.10	100	2.363	0	2.0	5	21.49	27.05	5.56	157	18.52	0.193	TETKO	REC'D
3	12-18-91	90.13	100	2.605	30	2.0	5	21.49	30.65	9.16	180	26.94	0.150	TETKO	12-18-91
4	12-18-91	90.07	100	2.730	0	2.0	5	21.49	31.07	9.58	190	27.77	0.149	CU-POLY	
0	12-19-91	90.21	0	0.000	0	0.0	5	21.49	23.38	1.89	73	7.29	0.000	TETKO	
11	12-19-91	90.08	0	0.000	0	0.0	5	21.49	24.49	3.00	75	11.03	0.000	TETKO	
1	12-19-91	90.08	100	2.458	15	2.0	5	21.49	25.63	4.14	154	14.55	0.259	TETKO	
2	12-19-91	90.06	100	2.585	30	2.0	5	21.49	27.46	5.97	163	19.58	0.204	TETKO	
3	12-19-91	90.06	100	2.588	45	2.0	5	21.49	28.31	6.82	178	21.70	0.187	TETKO	
4	12-19-91	90.17	80	2.024	15	2.0	5	21.49	25.67	4.18	132	14.68	0.170	TETKO	
5	12-19-91	90.2	80	2.038	30	2.0	5	21.49	26.10	4.61	134	15.94	0.160	TETKO	
6	12-19-91	90.1	80	2.011	45	2.0	5	21.49	25.51	4.02	141	14.20	0.181	TETKO	
7	12-19-91	90.2	80	2.067	15	3.0	5	21.49	27.64	6.15	154	20.07	0.190	TETKO	
8	12-19-91	90.3	80	1.952	30	3.0	5	21.49	29.00	7.51	155	23.38	0.157	TETKO	
9	12-19-91	90.3	100	3.034	30	1.0	5	21.49	25.83	4.34	150	15.18	0.154	TETKO	
10	12-19-91	90.2	100	2.980	45	1.0	5	21.49	26.10	4.61	146	15.93	0.146	TETKO	
9	12-20-91	90.3	0	0.000	0	0.0	5	21.49	24.69	3.20	88	11.70	0.000	CU-POLY	
1	12-20-91	90.3	80	2.368	15	2.0	5	21.49	26.52	5.03	146	17.12	0.170	CU-POLY	
2	12-20-91	90.1	80	2.496	30	2.0	5	21.49	26.27	4.78	153	16.39	0.190	CU-POLY	
3	12-20-91	90.3	80	2.482	45	2.0	5	21.49	26.66	5.17	156	17.51	0.179	CU-POLY	
4	12-20-91	90.2	80	2.509	15	1.0	5	21.49	24.14	2.65	132	9.90	0.156	CU-POLY	
5	12-20-91	90.3	80	2.479	45	1.0	5	21.49	25.25	3.76	115	13.44	0.117	CU-POLY	
6	12-20-91	90.2	80	2.248	15	3.0	5	21.49	27.53	6.04	164	19.79	0.209	CU-POLY	
7	12-20-91	90.2	80	2.184	30	3.0	5	21.49	28.65	7.16	173	22.53	0.182	CU-POLY	
8	12-20-91	90.1	80	2.277	0	2.0	5	21.49	26.13	4.64	149	15.99	0.172	CU-POLY	
10	12-20-91	90.2	100	3.735	0	1.0	5	21.49	26.66	5.17	174	17.49	0.161	CU-POLY	
11	12-20-91	90.2	100	3.499	30	1.0	5	21.49	26.90	5.41	150	18.13	0.148	CU-POLY	
12	12-20-91	90.3	100	3.491	45	1.0	5	21.49	27.54	6.05	171	19.84	0.136	CU-POLY	

Table 3. Experimental Data on Dewatering of Corn Fiber Product of a Mercone Centrifuge (Initial Solids = 27.5 percent)

TEST #	TEST DATE	SAMPLE WEIGHT GRAMS	APPLIED VOLTAG VOLTS	AVERAGE CURRENT AMPS	U/S POWER WATTS	ELEC. TIME MIN	APPLIED PRES. PSI	INITAL SOLIDS %	FINAL SOLIDS %	DELTA SOLIDS %	MAX SAMPLE TEMP, F	LIQUID REMOVED GRAMS	ENERGY KW.HR/ LB.FILT.	FILTER BELT TYPE	MATERIAL SOURCE
1	11-18-91	60.04	80	0.690	0	3.0	5	27.50	27.89	0.39	112	0.84	1.491	IFC#6093	DECATUR
2	11-18-91	50.21	80	0.775	15	3.0	5	27.50	30.02	2.52	118	5.05	0.292	IFC#6093	REC'D
3	11-18-91	60.21	100	0.931	15	3.0	5	27.50	31.61	4.11	142	7.83	0.278	IFC#6093	11-15-91
4	11-18-91	60.16	100	0.930	25	3.0	5	27.50	35.40	7.90	144	13.43	0.166	IFC#6093	
5	11-18-91	60.06	100	1.050	15	3.0	7	27.50	35.91	8.41	147	14.07	0.174	IFC#6093	
6	11-18-91	90.08	100	0.800	15	3.0	7	27.50	35.58	8.08	127	20.46	0.092	IFC#6093	
7	11-18-91	90.15	100	0.830	35	3.0	5	27.50	36.50	9.00	126	22.23	0.092	IFC#6093	
8	11-18-91	90.19	120	1.107	15	3.0	7	27.50	40.57	13.07	143	29.06	0.106	IFC#6093	
1	11-20-91	90.16	100	1.221	25	3.0	5	27.50	34.04	6.54	135	17.32	0.166	IFC#6093	
2	11-20-91	90.13	120	1.632	25	3.0	5	27.50	33.30	5.80	172	15.70	0.290	IFC#6093	
3	11-20-91	90.02	100	1.336	25	3.0	7	27.50	36.31	8.81	146	21.84	0.144	IFC#6093	
4	11-20-91	90.06	120	1.693	25	3.0	5	27.50	33.33	5.83	207	15.75	0.300	CU-POLY	

Table 4. Experimental Data on Dewatering of Corn Fiber Product of a Screw Press

TEST #	TEST DATE	SAMPLE WEIGHT GRAMS	APPLIED VOLTAG VOLTS	AVG. CURRENT AMPS	U/S POWER WATTS	ELEC. TIME MIN	APPLIED PRES. PSI	INITIAL SOLIDS %	FINAL SOLIDS %	DELTA SOLIDS %	MAX SAMPLE TEMP, F	LIQUID REMOVED GRAMS	ENERGY KW.HR/ LB.FILT.	FILTER BELT TYPE	MATERIAL SOURCE
1	01-03-92	90.1	100	0.872	0	2.0	5	29.67	31.45	1.78	101	5.10	0.258	CU-POLY	DIMMITT
2	01-03-92	90.0	120	1.130	0	3.0	5	29.67	32.10	2.43	130	6.82	0.451	CU-POLY	REC'D
3	01-03-92	90.2	120	1.219	30	3.0	5	29.67	32.56	2.89	143	8.00	0.431	CU-POLY	01-03-92
4	01-03-92	90.1	120	1.154	30	3.0	5	29.67	32.91	3.24	141	8.87	0.370	IFC#6012	
5	01-03-92	78.2	120	1.324	30	3.0	5	23.67	32.40	2.73	149	6.59	0.568	IFC#6093	
6	01-03-92	90.3	120	1.211	15	3.0	5	29.67	32.87	3.20	149	8.79	0.383	IFC#6093	
7	01-03-92	90.2	120	1.241	15	3.0	7	29.67	34.31	4.64	151	12.20	0.282	IFC#6093	
9	01-03-92	78.2	120	1.348	15	3.0	5	29.67	33.62	3.95	169	9.19	0.407	IFC#6093	
10	01-07-92	60.2	120	1.522	30	3.0	15-5	38.93	48.14	9.21	184	11.52	0.371	CU-POLY	DECATUR
3	01-09-92	90.3	120	1.396	15	3.0	5	27.32	33.07	5.75	152	15.70	0.246	CU-POLY	DIMMITT
5	01-09-92	90.1	120	1.423	15	3.0	5	27.32	32.42	5.10	151	14.18	0.278	IFC#609	REC'D
6	01-09-92	90.3	120	1.440	0	3.0	5-5	27.32	33.34	6.02	152	16.31	0.240	CU-POLY	01-09-92
7	01-09-92	90.4	120	1.390	15	3.0	5-5	27.32	34.64	7.32	150	19.10	0.202	CU-POLY	
8	01-09-92	90.1	120	1.478	15	3.0	7	27.32	32.82	5.50	165	15.10	0.271	CU-POLY	
10	01-09-92	90.4	120	1.380	15	3.0	15-5	27.32	36.43	9.11	175	22.60	0.169	CU-POLY	
1	01-17-92	90.16	0	0.000	0	0.0	5	26.31	27.32	1.01	67	3.33	0.000	CU-POLY	DIMMITT
2	01-17-92	90.16	40	0.427	0	3.0	5	26.31	27.34	1.03	75	3.40	0.114	CU-POLY	REC'D
3	01-17-92	90.30	80	0.954	0	3.0	5	26.31	28.25	1.94	98	6.20	0.279	CU-POLY	01-16-92
4	01-17-92	90.34	120	1.608	0	3.0	5	26.31	30.52	4.21	155	12.46	0.351	CU-POLY	
5	01-17-92	90.37	120	1.629	8	3.0	5	26.31	30.60	4.29	154	12.67	0.353	CU-POLY	
6	01-17-92	90.31	120	1.657	15	3.0	5	26.31	30.80	4.49	180	13.17	0.348	CU-POLY	
7	01-17-92	90.37	120	1.678	30	3.0	5	26.31	31.20	4.89	180	14.16	0.332	CU-POLY	
8	01-17-92	90.34	120	1.692	45	3.0	5	26.31	31.02	4.71	184	13.72	0.351	CU-POLY	
9	01-17-92	90.33	120	1.903	30	2.0	5	26.31	30.14	3.83	149	11.48	0.309	CU-POLY	
10	01-17-92	90.36	120	1.893	30	1.0	5	26.31	29.25	2.94	117	9.08	0.194	CU-POLY	

The main variables tested were the electric voltage, residence time, and ultrasonic wattage. In addition, during the testing process, it was found that aging of the product and applied pressure had significant effects on the amount of dewatering (delta solids, i.e., the increase in solids content), so some tests were performed to quantify these effects. Since it was desired to replace the outer polymer belt and the stainless steel cathode belt on the EAD prototype with a new single copper-polymer cathode belt, some laboratory tests were performed to determine any unforeseen effects due to the new cathode belt. Effect of each variable on electroacoustic dewatering (EAD) performance and energy consumption is described below.

Effect of Voltage. Applied voltage across the filter cake, for a given cake thickness, is the most significant variable in EAD. Figure 5 shows a representative EAD performance (delta solids) as a function of applied voltage for corn fiber. The data are from test numbers 1 through 4 on 01/17/92 for corn fiber product of a screw press with 26.3 percent initial solids. The effect is monotonic with the slope indicating that relative gain in delta solids per unit increment in applied voltage is better at higher voltages. These results show that the general EAD behavior of the more dewatered materials used in this phase is comparable to the EAD behavior of the dilute materials used in Phase I and Phase II.

Effect of Residence Time. Figure 6 shows the effect of residence time on delta solids from two sets of experiments; one for a product of Mercone centrifuge and another for a product of a screw press. The effect is essentially linear, monotonically increasing with residence time. However, the energy consumption per pound of removed filtrate also increases, indicating that there may be an optimum with respect to processing rate and energy consumption. This can be determined later after the field tests, when complete energy consumption analysis is performed.

Effect of Ultrasonic Power. Figure 7 shows the effect of ultrasonic power on EAD performance for two sets of experiments. The range of ultrasonic wattage is from 0 to 45 watts (0 to 1 W/cm^2). It should be noted that on the prototype belt press, the maximum ultrasonic wattage is 0 to 0.5 W/cm^2, exactly half the maximum value used in the laboratory tests. Laboratory tests were conducted at high wattage to find the limits of ultrasonic effect. Typically, the ultrasonic effect reaches a maximum around 0.66 W/cm^2 (30 watts in the bench-scale apparatus with an area of

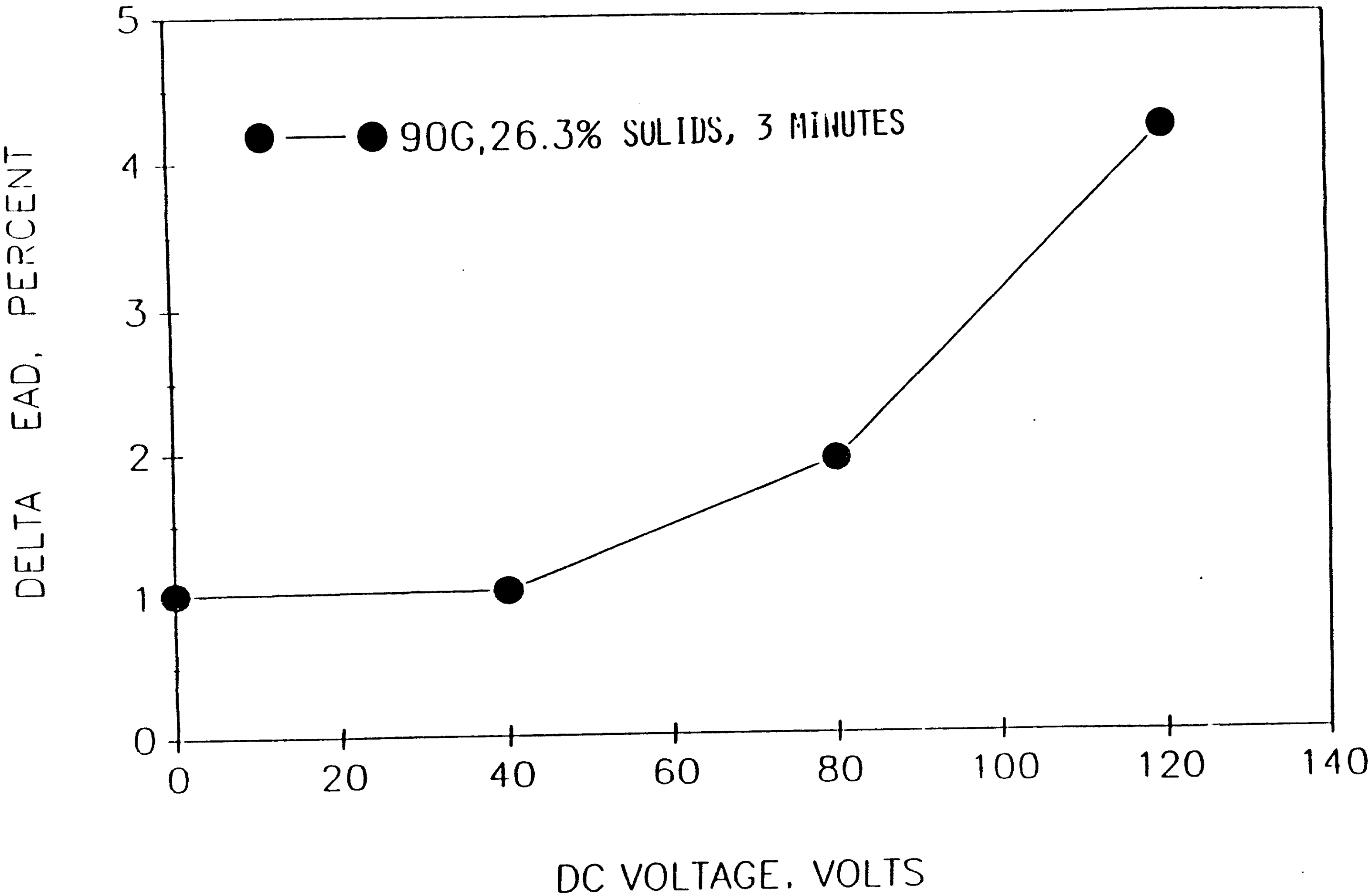

FIGURE 5. EFFECT OF VOLTAGE ON EAD PERFORMANCE. DATA FROM TEST NUMBERS 1, 2, 3, AND 4 ON 01/17/92 FOR DIMMITT PRODUCT FROM A SCREW PRESS

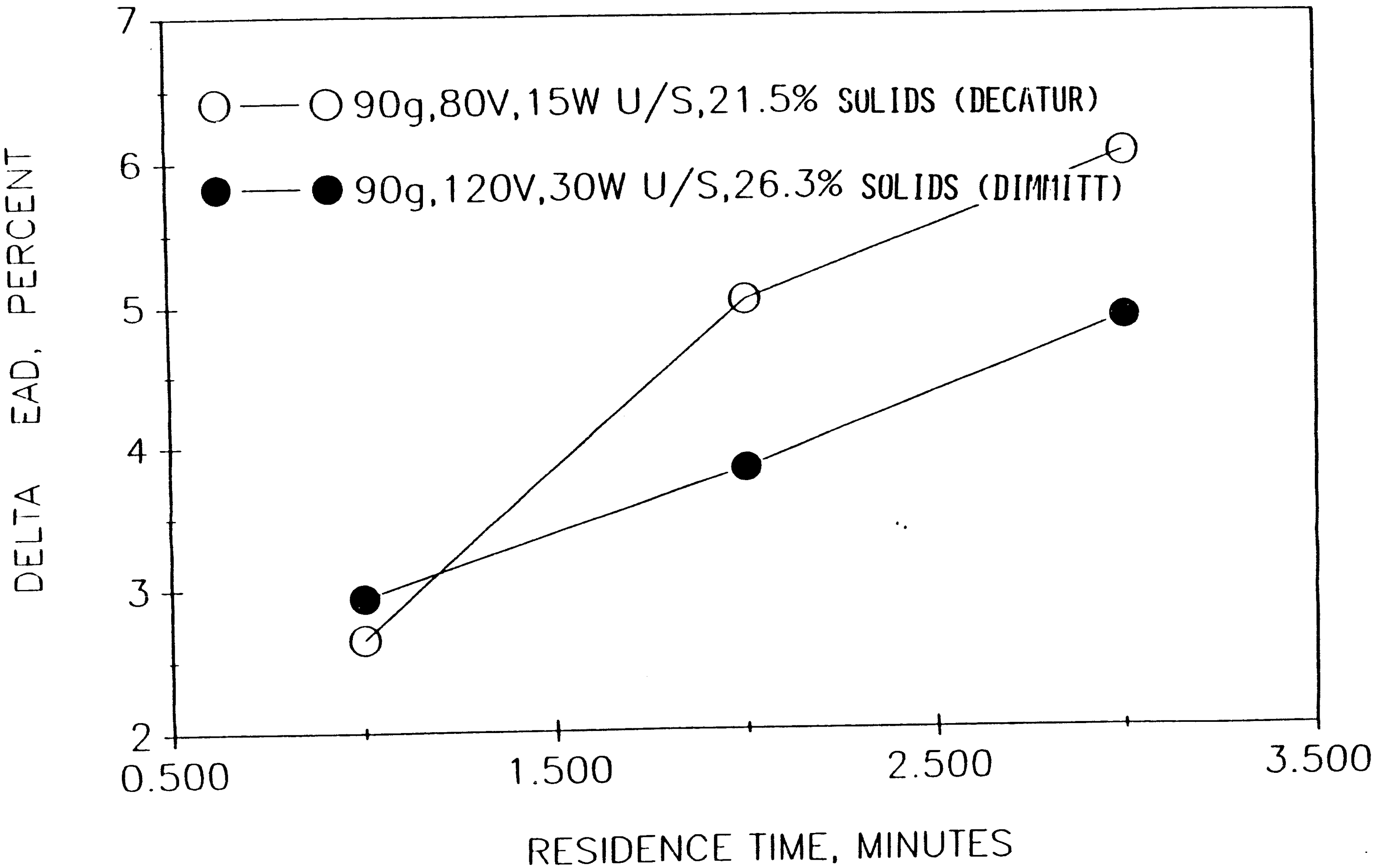

FIGURE 6. EFFECT OF RESIDENCE TIME ON EAD PERFORMANCE. DATA FROM TEST NUMBERS 1, 4, AND 6 ON 12/20/91 (DECATUR PRODUCT FROM A MERCONE CENTRIFUGE; 21.5 PERCENT FEED SOLIDS) AND 7, 9, AND 10 ON 01/17/92 (DIMMIT PRODUCT FROM A SCREW PRESS; 26.3 PERCENT FEED SOLIDS)

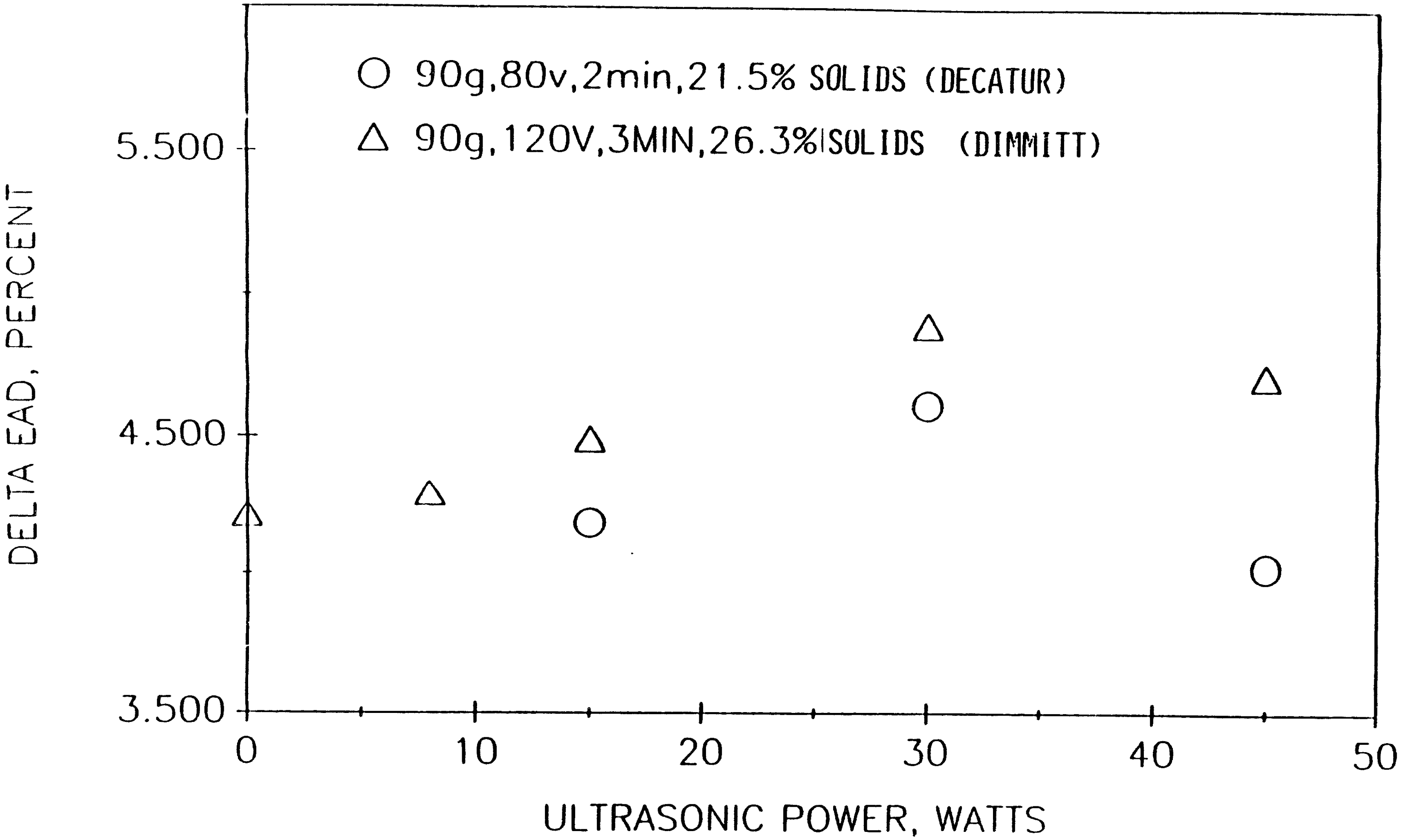

FIGURE 7. EFFECT OF ULTRASONIC POWER ON EAD PERFORMANCE. DATA FROM TEST NUMBERS 4, 5, AND 6 ON 12/19/91 (DECATUR PRODUCT FROM MERCONE CENTRIFUGE; 21.5 PERCENT FEED SOLIDS) AND 4, 5, 6, 7, AND 8 ON 01/17/92 (DIMMIT PRODUCT FROM SCREW PRESS; 26.3 PERCENT FEED SOL!DS)

45 cm^2). In these tests, ultrasonic contributed approximately 25 percent of the total EAD effect. Moreover, since ultrasonic contributes only a small amount to the total power consumption, its effect is only beneficial without any undesirable effects such as heating of the filter cake. As can be seen from test numbers 6, 7, and 8, on 01/17/92, final temperature of the filter cake is almost constant while delta solids went up by one percent from 15 to 30 watts of ultrasonic wattage. Energy consumption per pound of removed filtrate also decreased with increasing ultrasonics. The above results show that, as in the case of more dilute corn fiber feedstrokes, ultrasonic energy is an important contributor to the EAD performance of more predewatered feedstocks.

Effect of Belt Material. Previously, the prototype EAD belt press had a polyester belt serving as the outer belt and a metal belt beneath it, serving as the cathode belt. In a new version, a single belt made of copper-polyester performs the dual role of the outer belt and the cathode belt. Experiments were performed to determine if this change has any detrimental effect on EAD performance. Figure 8 shows two sets of data with all independent variables being the same except for the belt material. Both the polyester belt (Tetko) and copper-polyester belt gave similar EAD results indicating no degradation of performance due to the use of copper-polyester belt. We expect the performance of the copper-polyester belt is, in fact, better if the effects of aging of corn fiber slurry are taken into account (see discussion below on corn fiber aging). The average current obtained using the copper-polyester belt was always higher indicating less overall electrical resistance and better EAD results. In addition to testing the new cathode belt, a number of tests were also conducted with the Decatur sample to compare two types of polymer belts for using next to the anode (i.e., inner polymeric belt). The results in Tables 2 and 3 show essentially no difference between these two belts.

Effect of Aging of Corn Fiber. The ability to dewater corn fiber appears to decrease with increasing age of product. An example is the EAD results of test number 3 on 12/18/91, and test number 2 on 12/19/91. A reduction of 35 percent in delta solids was obtained when the corn fiber was tested one day older. This is not a concern during field tests since the product to be tested is fresh from previous steps of dewatering. However, it does affect the bench-scale (laboratory) results since the product is at least one day old or older by the time it is tested in the laboratory. Thus, we expect the results of field tests to be better than those obtained in the laboratory. A likely reason for this aging effect is that the sample picked up air and this created more void space.

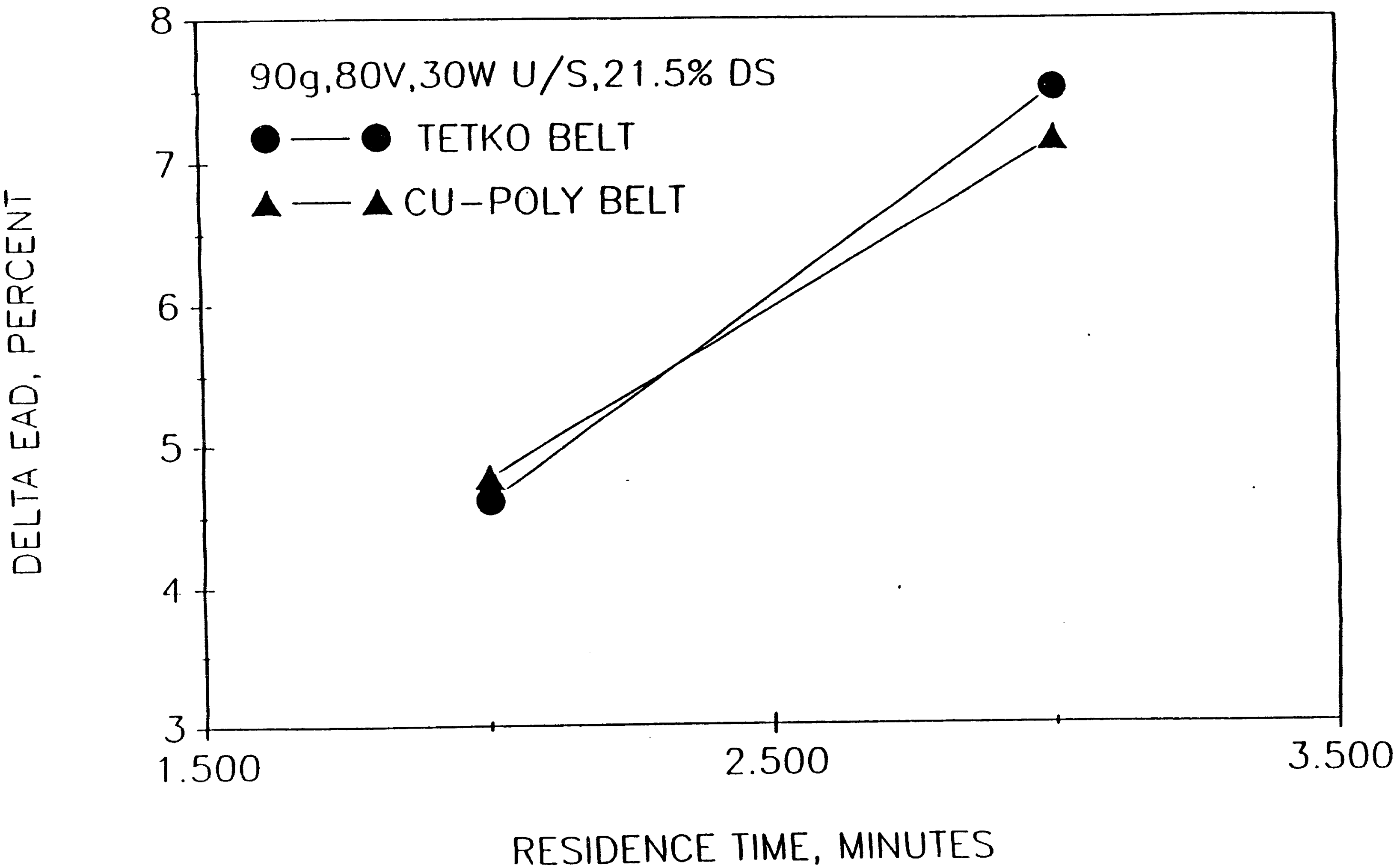

FIGURE 8. EFFECT OF BELT MATERIAL ON EAD PERFORMANCE. DATA FROM TEST NUMBERS 5 AND 8 ON 12/19/91 AND 2 AND 7 ON 12/20/91 (DECATUR PRODUCT FROM A MERCONE CENTRIFUGE)

Effect of Pressure. Void space in the corn fiber filter cake decreases the conductivity of the cake, reducing the amount of dewatering. Since the present tests were conducted with drier cake than Phase II tests (17 percent dry solids versus 21-30 percent dry solids), void space effect is more pronounced in the present tests. Increasing the pressure reduces the air gaps, enhancing EAD performance. By increasing the pressure from 5 psi to 7 psi almost a greater than 50 percent increase in EAD performance can be obtained, as shown in Table 5. Another example is test number 10 on 01/07/92. Here, a pressure of 15 psi was applied to the filter cake from a screw press for 30 seconds and then the pressure was reduced to 5 psi for a normal EAD test run of 3 minutes (Table 4). The sample which was initially 38 percent dry solids was dewatered to 48 percent dry solids group, a delta solids EAD of 9.2 percent, which is about twice that achieved for other screw press materials (Table 4). We believe that this high level of dewatering was obtained because the 15 psi pressure for 30 seconds reduced the void space to a large extent. It is clear that field tests should be performed at the highest permissible pressures with the belt strength capabilities determining the limit. In addition, sheering action in the prototype belt press should also help in removing the trapped air in the filter cake.

Energy Consumption. The energy consumption measured in terms of kilowatt hours per pound of removed filtrate has been quite high for the present corn fiber tests. In fact, relative to a few laboratory simulation tests performed with more dewatered (27.3 percent solids) material in Phase II (11/22/88), the energy consumption is higher by a factor of about two. We expect that it is due to two reasons:

(1) Phase II tests were performed at a higher pressure, at 7 psi versus the present 5 psi, and

(2) The method of sample preparation.

As discussed under the "effect of pressure", even an additional 2 psi results in almost a 50 percent gain in EAD performance. The present tests were conducted at the lower (5 psi) pressure values because it is more representative of the attainable pressures in the field tests with the prototype belt press. Furthermore, in Phase II tests, the corn fiber was predewatered to 27.3 percent dry solids using a bench scale belt press. This in effect compressed the filter cake, removing the air gaps and thus increasing the effective conductivity. In the present tests, no such pressing was performed and the material in its fluffy form was subjected to EAD. During the field tests, we expect that pumping

Table 5. Effect of Applied Pressure on EAD of Corn Fiber

DATE	SAMPLE SIZE (g)	PRESSURE (psi)	VOLTAGE VOLTS	U.S. WATTS	INITIAL SOLIDS %	ΔS	ENERGY KWHR/LB FILTRATE
11/18/91	60	5	100	15	27.5	4.1	0.278
11/18/91	60	7	100	15	27.5	8.41	0.174
11/20/91	90	5	100	25	27.5	6.54	0.166
11/20/91	90	7	100	25	27.5	8.81	0.144
1/3/92	90	5	120	15	29.67	3.20	0.383
1/3/92	90	7	120	15	29.67	4.64	0.282

the material on to the belt press with Moyno pump will reduce the air gaps in the filter cake, effectively enhancing EAD performance.

Decatur Versus Dimmitt Corn Product. A comparison of these two products shows that the Dimmitt product is harder to dewater. For example, the product of centrifugation at Decatur consisted of 21 to 27 percent solids, while screw pressing, which is far more effective than centrifugation, produced about 39 percent solids (Table 4, Test No. 10 on 01/07/92). On the other hand, screw pressing of Dimmitt material only produced about 26 to 30 percent solids. Apparently, the Dimmitt Plant grinds the corn fiber finer than in other plants, making dewatering harder. For this reason, the Dimmitt material is probably a better test of the potential of EAD.

A comparison of the Decatur and Dimmitt materials with respect to EAD performance is shown in Figure 6. As seen here, the delta EAD is lower for the Dimmitt material. It is believed that this difference is only partly because the Dimmitt material is harder to dewater, having already been taken to limit of mechanical dewatering. An additional reason for lower delta EAD for Dimmitt material is believed to be the longer aging period. The screw pressed Dimmitt material is apparently allowed to sit in a pile before sampling which the Mercone centrifuge product from Decatur is sampled soon after centrifugation. It is, therefore, believed that the Dimmitt material will dewater far better than discovered in the laboratory.

Recommended Range of Field Test Conditions. Based upon the analysis of data, the range of independent variable values for field tests can be determined with some confidence. Applied voltage should be high (100-120 V). Residence time values are determined based on the economic trade off between processing rate and amount of dewatering desired. Assuming that there is no scale-up effect, and the ultrasonic coupling efficiency in the prototype is comparable to that in the bench scale unit, then the ultrasonic wattage for the field tests should be at the maximum possible wattage (0.5 W/cm^2) since that would correspond to 22.5 watts on the laboratory apparatus in which the peak effect of ultrasonics occurred around 30 watts. Actually, since the ultrasonic coupling in field unit cannot be as good as in the laboratory unit, any improvement in EAD prototype (field unit) design to achieve a higher input level of ultrasonics will be beneficial unless there is a favorable scale-up effect similar to that observed for sewage sludge EAD. Finally, any design improvements to increase the pressure capability of the current prototype from a maximum of 4 psi will be most beneficial; a target of 7 to 10 psi is suggested. We expect the EAD performance to be better than the 5 to 8 percent

Table 6. Experimental Data on Dewatering of Corn Gluten (from Decatur, Alabama)

TEST #	TEST DATE	SAMPLE WEIGHT GRAMS	APPLIED VOLTAG VOLTS	AVERAGE CURRENT AMPS	U/S POWER WATTS	ELEC. TIME MIN	APPLIED PRES. PSI	INITAL SOLIDS %	FINAL SOLIDS %	DELTA SOLIDS %	MAX SAMPLE TEMP., F	LIQUID REMOVED GRAMS	ENERGY KW.HR/ LB.FILT.
2	01-07-92	89.89	40	1.975	0	3.0	5	24.34	39.69	15.35	136	34.76	0.052
3	01-07-92	89.69	40	1.235	15	3.0	5	24.34	40.03	15.69	93	35.15	0.034
4	01-07-92	90.04	40	1.872	30	3.0	5	24.34	40.47	16.13	142	35.89	0.051
5	01-07-92	89.94	40	2.064	45	3.0	5	24.34	40.65	16.31	125	36.09	0.058
1	01-08-92	90.09	40	1.852	0	3.0	5	28.61	38.84	10.23	112	23.73	0.071
2	01-08-92	90.12	40	1.866	10	3.0	5	28.61	38.11	9.50	124	22.46	0.077
3	01-08-92	90.15	40	1.868	25	3.0	5	28.61	38.66	10.05	126	23.44	0.077
4	01-08-92	89.97	60	2.572	25	2.0	5	28.61	39.10	10.49	123	24.14	0.098
5	01-08-92	60.69	40	1.858	15	3.0	5	28.61	43.80	15.19	120	21.05	0.081
6	01-08-92	60.45	40	1.814	0	3.0	5	28.61	42.19	13.58	127	19.46	0.085
7	01-08-92	59.85	40	1.869	8	3.0	5	28.61	42.11	13.50	120	19.19	0.089
8	01-08-92	60.10	50	1.934	8	3.0	5	28.61	42.14	13.53	129	19.30	0.114
9*	01-08-92	90.35	40	1.458	0	3.0	5	28.61	41.21	12.60	112	27.62	0.048
10*	01-08-92	90.25	40	1.473	25	3.0	5	28.61	40.30	11.69	105	26.18	0.055a
11*	01-08-92	89.90	40	1.435	10	3.0	5	28.61	40.22	11.61	108	25.95	0.052
1	01-10-92	44.95	0	0.000	0	0.0	5	28.61	31.42	2.81	74	4.02	0.000
2	01-10-92	44.99	30	1.552	15	3.0	5	28.61	35.73	7.12	112	8.97	0.125
3	01-10-92	45.35	40	2.440	15	2.0	5	28.61	37.33	8.72	131	10.59	0.144
4	01-10-92	45.27	40	2.287	15	2.0	5	28.61	37.54	8.93	133	10.77	0.133
5	01-10-92	45.58	40	1.559	15	3.5	5	28.61	38.00	9.39	137	11.26	0.154
6	01-10-92	45.18	50	2.562	15	2.0	5	28.61	37.37	8.76	158	10.59	0.187

* TETKO Filter belt, the rest are Copper-poly belt.

a material leaked though belt

delta solids obtained in the bench-scale tests in the laboratory. The freshness of the screw press product, removal of air gaps due to pumping the material and shearing action of the belt press should enhance the EAD performance making the 8 to 11 percent increase in solids content projected in Phase II a reasonable target for field testing.

3.2.2 Corn Gluten Testing

In Phase II, the corn gluten tests were not successful since the feed was very dilute and the particle size was small compared to the openings in the belt used in the belt press. However, with the Phase III design, which uses predewatered material with the consistency of a filter cake, produced after centrifugation, it may be possible to handle this material without requiring any special belts. Therefore, a series of tests were conducted on one batch of corn gluten material. The sample initially had a solids content of 11 percent. This sample was centrifuged further in the laboratory to 24.3 percent solids level in one case and to 28.6 percent in another case before being subject to EAD. These data, summarized in Table 6 showed the following:

(1) The copper-poly belt was adequate for handling the corn gluten feed stock. However, with the polymeric Tetko belt, some material extruded through the belt at high ultrasonic (25-watt) intensity.

(2) The ultrasonic effect was much smaller than the electric field effect, unlike for corn fiber.

(3) The delta solids for corn gluten was up to about 16 percent which was roughly twice that for Dimmitt corn fiber, while employing only one-third the voltage level (i.e., 40 volts versus 120 volts). In the absence of EAD, i.e., with pressure only, the delta solids were only 2.8 percent.

(4) The energy consumption was low--in the range of 0.05 to 0.075 kwh filtrate--disregarding the data obtained on the last day of testing (01/10/92), which showed an aging effect. This energy consumption level was about half of that observed in Phase II simulation tests with a special belt. The average observed value (0.06 kwh) corresponds to an energy level less than one-third of the thermal energy required for drying. At this EAD energy consumption level and assuming a 13 percent delta solids, i.e., increase in solids content for 30 to 43 percent, the estimated energy savings due to the requirement

of a smaller thermal dryer are 25 percent. This translates to an estimated $2.2x10^{12}$ Btu/yr energy savings by 1995.

Based on the above results, the application of EAD to corn gluten dewatering/drying is worth considering in the future.

3.3 Equipment Modifications and Readiness Testing

Based on the analysis of corn fiber dewatering requirements, a checklist of items was prepared for the first shakedown testing. This checklist along with pass/fail criteria and the observations during the first shakedown testing is given in Table 7. The details of this shakedown testing and additional efforts by Ashbrook-Simon-Hartley in modifying and testing the EAD belt press are provided below.

3.3.1 First Readiness (Shakedown) Testing

A Battelle staff member visited Ashbrook-Simon-Hartley to assist in the installation and checkout of the EAD prototype belt press. An installation checkout list had been provided to Ashbrook by Battelle and this was followed item-by-item throughout the installation and checkout procedure. Table 7 shows the list of items checked as part of the shakedown testing of the EAD prototype belt press.

The control room and belt press was installed on site and all electrical wiring and plumbing was completed and checked out. The belt press was found to be in good mechanical working order. All the electrical motors and water pumps were checked for rotation and pumping capacity and found to operate satisfactorily. The water flow meter to the fluid coupling seal has been removed and needs to be reinstalled so the water flow rate to the seal can be measured.

Eight barrels of 36 percent solids, corn fiber from American Fructose, Dimmitt, Texas, were delivered on site and used to check the feed spreader system and the operation of the belt press. (The anticipated solids content of the feed, based on earlier testing was 24 to 29 percent.) Due to the high solids content of the feed, the corn fiber was loaded directly into the feed spreader hopper, so the Moyno feed pump or the belt conveyor feed systems were not used during this checkout. For future testing a belt conveyor was identified. Also, the stainless steel cake exit chute needed to be installed.

Table 7. Results of First Shakedown Testing (July 29-31, 1992) of EAD Prototype Belt Press

STB #	Step	Instructions	Start Time Date	Pass Criteria	Fail Criteria	Observations and Results	Action to be Taken
1	Verify belt press skid on site Verify control room skid on site Verify pump skid on site	All components are installed on site		Installed	Not installed	Installed and in good working order	
2	Verify all electrical wiring is completed and operational	Check motor rotation-lights power supplies-wash pump		All systems powered motor rotation direction OK wash pump pressure 60 PSI	No Power-Wrong motor direction No lights Wash pump pressure less than 40 PSI	All systems powered; Motor rotation OK; Water pump pressure > 60 PSI	
3	Verify all plumbing installed and operational	Check water flows to belt fluid coupling seal Check for leaks Check filtrate drain		Water flow to belt No leaks No overflow from drain	No or low flow Leaks Drain overflow	No flow meter on seal water Flow; need plugs on all water exits except one drain line	Install new water flow meter on seal inlet water line
4	Verify feed material is on site	Check material type Corn fiber Number of barrels		Material type OK Corn fiber Total number of barrels 8	No material Wrong material Not enough barrels, less than 4	8 Barrels Corn fiber; to high solids (36 percent)	
5	Verify material handling equipment on site and operational	Barrel handling equipment operational Cake collection hoppers available Hand equipment		Barrel handling equipment on site Hoppers available Hand equipment available	No barrel handling equipment No hoppers No hand equipment	Barrel handling equipment on site-hoppers available	Install cake exit chute
6	Verify filter belt installation and type	Install proper belt-copper or poly Check belt tracking Check belt tension		Install desired belt Tracks within guides Belt tension (90 - 125 PLI)	No belt or wrong type Trips machine stops Less than 90 PLI	Tetko inner belt is satisfactory, Copper Poly belt stretches Nonuniformly	Order new Copper-Poly belt without water seal edges
7	Check Moyno feed pump	Check screw rotation Check for output material Check material bridging		Counterclockwise Pump is discharging material Pump empties hopper	Clockwise rotation No output material Material remains in hopper	Not used in this test, using belt conveyor	Ashbrook will set up and check out
8	Check feed spreader system	Check screw rotation Check for uniform output cake thickness Check motor speed of output screw		Clockwise Uniform 1/2 inch thickness, + -10 percent Between 2 -10 rpm	Counterclockwise + or - 10 percent of 1/2 inch Lower than 2 rpm	Rotation OK, spreads evenly Minimum inlet thickness 1.25 inch (< 0.75 inch outlet). Stalls when over half full	Install larger motor and gear box
9	Check belt speed control	Check low belt speed Check high belt speed		Belt speed of 0.68 m/min Belt speed of 3.8 m/min	Belt speed higher than 0.68 m/min Belt speed lower than 3.8 m/min	Low speed 0.28 m/min, High speed 3.65 m/min	High speed satisfactory

Table 7. Results of First Shakedown Testing (July 29-31, 1992) of EAD Prototype Belt Press (Continued)

STE #	Step	Instructions	Start Time Date	Pass Criteria	Fail Criteria	Observations and Results	Action to be Taken
10	Check D.C. power supply	Check cooling fans Check voltage output-open terminals Check current draw with load		Clockwise rotation and air output 100 D.C. volts output 700 amps with 1/2 inch corn fiber cake	Counterclockwise rotation or no air output Less than 80 volts D.C. output Less than 500 amps output	Rotation and air output OK; 100 volts output; 700 amps with 3/4 inch (outlet thickness) corn fiber	Replace red flashing safety beacons
11	Check ultrasonic power supply and transducers Check tunning procedure	Check cooling fans Check ultrasonic power output See tuning procedure below		Cooling air 1600 watts ultrasonic power each Full 1600 watts output	No cooling air Less than 1400 watts ultrasonic Does not tune to procedure	Cooling air OK; 1400 watts output each; Tuned to full 170 watts each	
12	Check fluid coupling seals	Check water level Check for water leakage		Water level with ultrasonic plate Less than 8 gpm of cooling water added	Water below plate More than 8 gpm water flow rate to seals	Water overflows at 1 gpm; Water leakage < 1 gpm	Fabricate drip pans to collect drain water
13	Verify laboratory batch test equipment installation and operation	Equipment installed on site System operation is satisfactory		Water Electric Air Sample pressure to 10 psi max System does operate satisfactory	No water - Air - Electric Sample pressure less than 3 psi System does not operate satisfactory	Equipment on site; Need pressure readout; System operates satisfactory	Order new pressure readout
14	Verify laboratory batch test supplies are available	Drying plans - Gram scale - Oven - Spatulas Ph probe if needed		Pans-Gram scale Drying oven Spatulas-Paper towels-Ph probe	No pans-No scale-No drying oven No spatulas-No paper towels-No ph probe	Not used in checkout	

Tuning procedure for ultrasonic generator
(1) Set external frequency control fully clockwise
(2) Set ultrasonic generator to full power
(3) Adjust feedback pot to obtain 2.5 volts
(4) Adjust internal frequency pot to minimize feedback voltage
(5) Readjust feedback voltage to 2.5 volts
(6) Adjust power to maximum valve
(7) Feedback voltage reading is valid only at full power.

The new Tetko 7041 inner belt and a copper-poly outer belt were installed and checked for belt tracking and tension. Both belts had a 4-in.-wide water seal strip on both sides to eliminate water leaking through the side edge of the belt when passing through the fluid coupling seals. The belts were cycled for approximately 10 hours at 1 m/min belt speed and a belt tension of 90 pounds per linear inch (pli). The Tetko inner belt appeared to stretch uniformly and track well and would be satisfactory for use with corn fiber. The copper-poly outer belt stretched nonuniformly across the stitched seam, the outer sealed edges did not stretch while the copper-poly material in the center section of the belt was approximately 12 inches off initial seam-line positions. This belt would not be satisfactory for use in the configuration. A new copper-poly belt without the water-sealed edge strips was, therefore, ordered from IFC. Ashbrook had tested a smaller unsealed copper-poly belt on their small belt tester without a stretching problem.

Corn fiber was loaded directly into the feed spreader hopper to check for uniformity of thickness and even distribution or corn fiber across the belt width. The corn fiber spread very evenly across the width of the belt, down to a minimum thickness of 1.25 inches with this dry corn fiber feed material. The feed screw stalls when the hopper is loaded over half full. Ashbrook was advised to install a larger motor and gear to eliminate this problem. The minimum feed of 1.25 inches results in a cake output of approximately 3/4-inch thickness and this may be reduced even further when feeding corn fiber material with 28-30 percent solids content. The belt speed control system was checked out and found to be in good working order. Minimum belt speed was 0.28 m/min and the maximum belt speed was 3.65 m/min; this wide range of belt speed should be satisfactory for corn fiber testing.

The direct-current power supply checked out satisfactory. Open voltage output was 100 volts. With a 3/4-inch cake output, the voltage was 70 volts with a current of 700 amps. The red flashing safety beacons needed to be replaced.

The ultrasonic generators were checked and found to be all operative and in good working order. Power output of all 6 generators was low with a maximum output of 1400 watts each. All 6 generators were returned under load, 3/4-inch-thick corn fiber, using the standard tuning procedure. All tuned to a minimum of 1700 watts ultrasonic power output which should be acceptable for use with corn fiber.

New soft rubber lining was applied over the hard outside liner of the fluid coupling water seals. The water leakage from the seals was estimated to be less than one gallon per minute. Some leaking occurred when the belt flaps went through the seals. It was not possible to measure the water flow to the fluid coupling seals because the flow meter has been removed. Ashbrook planned to install a new flow meter. It was suggested that a stainless steel drip pan be fabricated to catch this fluid coupling seal leakage and overflow water for disposal to the drain system.

In summary, the following seven action items were discussed with Ashbrook for taking action on, prior to retesting:

(1) Install new water flow meter in the fluid coupling water line.

(2) Checkout belt feed loading conveyor.

(3) Install stainless steel cake exit chute.

(4) Order a copper-poly belt without side water seals.

(5) Replace feed spreader screw motor and gearbox.

(6) Fabricate stainless steel drip pans for fluid coupling seals.

(7) Replace red flashing safety beacons.

3.3.2 Second Readiness Testing

Two Battelle staff visited Ashbrook to assist in the checkout of the EAD prototype belt press before shipment to the Dimmitt, Texas, test site. The objective was to ensure proper operation of all the belt press mechanical systems and to see if the new copper-poly outer belt would be satisfactory for use with the Dimmitt corn fiber material. The seven action items identified during the first readiness (shakedown) testing, done in July 1992, were followed up during the second readiness testing during September 16-17, 1992. The results of the follow-up were as follows:

1. Install new water flow meter. (Installed and operational.)
2. Install and checkout belt loading conveyor. (Installed and operational.)
3. Install cake exit chute. (Installed and operational.)
4. Order and install a new copper-poly belt. (Operation not satisfactory--details below.)
5. Replace feed spreader screw motor and gearbox. (Operation not satisfactory--details below.)
6. Fabricate stainless steel drip pans. (Installed and operational.)
7. Replace red flashing safety beacons. (Replaced and operational.)

Six barrels of 36 percent solids, corn fiber from Dimmitt were delivered on site to be used for checking the feed system and operation of the new copper-poly belt, which eliminates one of the three belts on the system. The corn fiber was loaded into the feed conveyor for transport to the feed spreader hopper located on top of the belt press. After relocation of the conveyor and adjustments to the feed spreader screw system, it appeared that we could achieve a reasonably uniform feed thickness with a ± 15 percent thickness variation. With this high solids material, it appeared that 1.25 inches was the minimum uncompressed thickness that could be obtained with the present feed spreader system. This thickness was substantially reduced (approximately 0.5 inch) when compressed between the two belts. Ashbrook had not replaced the feed spreader screw motor and gearbox system, which appeared to be marginally operating. Ashbrook agreed to modify the feeder system to avoid motor stalling under load.

A more serious problem was the failure of the stitching or the retaining metal clips of the copper-poly belt under load. The new copper-poly outer belt was installed and checked for belt tension and tracking. The belt was cycled for about 7 hours at 1 m/min belt speed and a belt tension of 45 pli (pounds per linear inch). The belt tracked well and no stretching at the seams was visible. The belt tension was increased to 65 pli and corn fiber material was loaded on the belt. After a very short operating time the metal clips used to stitch the seam began to pull out and the belt test had to be terminated. This 65 pli was well below our minimum required 90 pli, which corresponds to 3.5 psi pressure on the filter cake. All laboratory tests for corn fiber dewatering were performed with cake pressure of at least 5 psi. It was agreed that Ashbrook should consult with the belt manufacturer in New York to see if this problem can be resolved. Although a moving belt press allows some shearing motion to the cake, a belt tension of 90 pli is believed to be the minimum necessary to dewater corn fiber with solids greater than 28 percent. Since Ashbrook and Battelle did not want to return to the three-belt system, the prototype shakedown was put on hold until this belt problem was corrected.

3.3.3 Additional Belt Press Modifications

The main equipment problem remaining after the second readiness testing was the failure of the stitches on the new, improved cathode belt. While the old, three-belt system worked well mechanically, the new two-belt system is more desirable for improving the EAD process economics. On further discussion with IFC, the supplier of the copper-poly belt, it was decided to vulcanize a 3-inch-wide strip across each end of the belt, then metal stitch the seam together. A 15-inch-wide piece of such an endless belt was fabricated by IFC. This belt was tested at over 100 pli and elevated temperatures without any problems. Then, IFC prepared a vulcanized-seam endless belt for the prototype for on-site testing at a sludge treatment plant in March 1993. Unfortunately, the seams came apart on testing under EAD conditions. IFC believes that the failure was caused by inadequate, on-site curing of the epoxy used for sealing.

After the above testing, it was necessary either to launch an additional developmental effort to make the more economical two-belt system work or to revert back to the proven, but expensive, three-belt system. At this point, Ashbrook, which was also acquired by another firm about the same time, was not able to commit the manpower and other resources to modify the copper-poly belt, which they felt was critical for the economic viability of the process. Therefore, the plans for further development and field testing had to be abandoned.

4.0 CONCLUSIONS

The following conclusions can be drawn from this study:

(1) Both corn fiber and corn gluten can be effectively dewatered in a bench-scale (laboratory) EAD unit even after mechanical predewatering. The EAD behavior of this predewatered material, with a solids content as high as 30 percent, is comparable to the EAD behavior of dilute (17 percent solids) feedstocks observed in previous research.

(2) For corn fiber dewatering, the electric as well as the ultrasonic effects are important. But, for corn gluten, the ultrasonic effect is considerably smaller than the electric field effect.

(3) The bench-scale EAD data show that corn gluten is also, along with corn fiber, a worthy candidate for future field testing.

(4) The single-roll, postdewatering EAD belt press prototype can accept material predewatered by a screw press, centrifuge, or any other mechanical dewatering device.

(5) The laboratory tests show that the two-belt system, utilizing a copper-polymer cathode belt, performs as well as the three-belt system used in Phase II; however, its mechanical performance in full-scale tests remains to be seen.

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FOUNDRIES, METAL CASTING R&D, GLASS, AND REFRACTORIES

Integrated manufacturing information system: implement mill model.	January 1994

Create a mill software model which represents mill production positions at any point in time; this model will indicate unit production availability.

Integrated manufacturing information system: develop data bases.	February 1994

Create mainframe and Reduced Instruction Set Computing (RISC) data bases to support the total program.

Integrated manufacturing information system: develop short term process code logic.	April 1994

Process codes are descriptions of production rates that material must follow. Completion of the short term code will enable early delivery of schedule systems. Completion of the long term code will follow in early FY 1995.

Integrated manufacturing information system: material tracking.	July 1994

Complete material tracking points, formats, and lead times; incorporate capacities, capabilities, and configurations of handling devices.

Integrated manufacturing information system: design/develop scheduling system.	August 1994

Design and develop initial three phases of "intelligent push-through scheduling." Other subsequent schedules will be based on this concept.

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