NOTICE

**CERTAIN DATA
CONTAINED IN THIS
DOCUMENT MAY BE
DIFFICULT TO READ
IN MICROFICHE
PRODUCTS.**

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615)576-8401, FTS 626-8401.

Available to the public from the National Technical Information Service, U. S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

PITT MILL DEMONSTRATION

FINAL REPORT

May, 1990

Prepared by

EXPORTech Company, Inc.
P. O. Box 588
New Kensington, PA 15068-0588

Principal Investigator
R. R. Oder

Investigator
L. A. Borzone

Subcontractor
John T. Hagy
Fort Pitt Machine Company
809 Alden Drive
Pittsburgh, PA 15220

Prepared for
U.S. Department of Energy
Pittsburgh Energy Technology Center
Contract DE-AC22-88PC88884

ACKNOWLEDGEMENTS

The authors wish to acknowledge the cooperation of Richard P. Killmeyer of the Pittsburgh Energy Technology Center during the course of this work. The authors also wish to thank Ralph J. Gray of Ralph Gray Services and Kenneth Brame of Kennedy Van Saun Corporation for their assistance, and Netzsch, Inc., for carrying out the comparison grinding. They thank Dr. S-M. Bobby Chi for providing engineering assistance during Phase I of the program, Mark Johnsen and Joseph R. Scobel, Jr., for their assistance in carrying out the grinding runs and Russell Jamison and Michael Fetchko for making the analytical measurements.

The authors also wish to thank the Consolidation Coal Company and the Pen Coal Corporation (formerly P&C Coal Company) for donating coal to this program.

SUMMARY

Results of a technical and economic evaluation of application of the Pitt Mill to fine coal grinding are presented. The Pitt Mill (U.S. Patent No. 4,850,541, July 25, 1989) is a vertically oriented, batch operated, intermediate energy density (0.025 kW/lb media), stirred ball mill. The mill grinds coal from coarse sizes (typically 3/16 inch or 4 mesh topsize) to the 10 micron to 20 micron mean particle diameter size range in a single step using a shallow grinding bed containing inexpensive, readily available, coarse grinding media. Size reduction is efficient because of rapid product circulation through the grinding bed caused by action of a novel circulation screw mounted on the agitator shaft. When a dispersant is employed, the grinding can be carried out at 50% to 60% solids concentration. Use of coarse grinding media offers the possibility of enhanced mineral liberation because size reduction is achieved more by impact shattering than by attrition. The batch method offers the possibility of very close control over product particle size distribution without overproduction of fines.

A two-phase program was carried out. In the first phase, Grinding Studies, tests were run to determine a suitable configuration of the Pitt Mill. Machine design parameters which were studied included screw configuration, media type, agitator RPM, time, media size, and slurry chamber aspect ratio.

During the last part of this phase of the program, tests were carried out to compare the results of grinding Pocahontas seam, Pittsburgh #8, and East Kentucky Mingo County coals by the Pitt Mill and by a two-stage grinding process employing a Netzsch John mill to feed a high energy density (0.05 kW/Lb media) disc mill. In the comparison study the Pitt Mill ground the coals to the product target size in a single step operation employing 5/16 inch grinding media. The first stage John Mill employed nominally 10 mm grinding media. It prepared minus-200-mesh coal which was fed to the disc mill. The disc mill employed 3 mm grinding media. A comparison of the results with regard to energy consumption is given in Table I.

Table I
Comparison of Energies to Grind Test Coals
to 10 Micron Mean Particle Size
Using Pitt Mill Prototype and Netzsch Mills

	Mingo County	Pittsburgh #8	Pocahontas
<u>Prototype Mill</u>			
Energy (kW-h/Ton coal)	69	122	75
Throughput (lb.coal/min)	1.8	1.0	1.2
<u>Netzsch Mill</u>			
Energy (kW-h/Ton coal)	120	129	96
Throughput (lb.coal/min)	3.4	3.0	3.8

During the second phase of the program, Engineering Evaluation, an engineering scaleup was made of the Pitt Mill for the purpose of estimating the cost of fabrication of a 1-ton-per-hour unit. Estimated capital costs of the unit using 3/16 inch grinding media are compared at the 1-ton-per-hour level in Table II with costs for a batch operated attritor and for a two-stage fine grinding circuit located at EPRI's Coal Quality Development Center at Homer City, PA, and jointly supported by the U.S. Department of Energy and the Electric Power Research Institute. The numbers in the table have been rounded upward to three figures.

Table II
Estimated Capital Cost of Three Methods of Coal Grinding
1 Ton Per Hour

	Pitt Mill	Union Process Model 200 SL Batch Attritor	2 Stage Ball Mill /Netzsch LME 200
Mill Purchase Price	\$ 62,600	\$ 74,400	\$178,000
Cost of Grinding Media	\$ 14,500	\$ 10,700	\$ 23,000
Cost of Control Instrumentation	\$ 64,500	\$ 64,500	\$ 64,500
Cost of Mill Installation	\$ 5,000	\$ 5,000	\$ 10,000
	-----	-----	-----
Cost of Installed Mills	\$147,000	\$155,000	\$276,000

The purchase price of the Union Process Model 200 SL has been quoted. The price of the 2 Stage units, including an MPSI ball mill and a Netzsch LME 200 fine grinding mill, were supplied by the Department of Energy. The installation cost of the 2 Stage units is more expensive because of the ball mill requirements.

In order to estimate operating costs, grinding energies and media loss rates were developed for the Pitt Mill and estimated for

the 2 Stage grinding circuit. These are given in Table III for grinding 17% ash Pittsburgh #8 coal to 10 micron mean particle diameter.

Table III
Comparison of Energies and Media Loss Rates to Grind 3/16" X 0
Pittsburgh #8 Coal to 10 Micron Mean Particle Size
for the Pitt Mill Prototype and the Two-Stage Netzsch Mills

<u>Prototype Mill (3/16" Media)</u>		
Energy (kW-h/T)*		65.7
Media Loss (lb/T)*		1.57
<u>Netzsch VM 30 (10 mm Media)</u>		
Energy (kW-h/T)†		45
Media Loss (lb/T)‡		0.63
<u>Netzsch LME 20 (3 mm Media)</u>		
Energy (kW-h/T)†		84
Media Loss (lb/T)‡		2.37
* 17.05% ash coal		
† 12.24% ash coal		
‡ Estimated from measurements made grinding 17.05% ash coal in the Pitt Mill		

This information was used to estimate the cost of coal grinding using the Pitt Mill and the 2 Stage circuit. Media wear rates have been measured for the Pitt Mill and have been estimated for the fine grinding mill based on data developed in the Pitt Mill. A comparison of the costs are given in Table IV where the numbers have been rounded to two figures.

Table IV
Estimates of Costs in Dollars per Ton
to Operate Two Alternative Grinding Circuits to Prepare
10 Micron Pittsburgh No. 8 Coal of 17.05% Ash and 49-64 HGI

	2 Stage Ball Mill/ <u>Pitt Mill Netzsch LME 200</u>	
Media Consumption	\$ 7.6	\$19.2
Machine	\$ 4.9	\$ 9.3
Energy	\$ 3.9	\$ 7.8
Labor	\$ 5.4	\$ 5.4
Dispersant	\$ 5.3	\$ 5.3
Maintenance	\$ 2.3	\$ 4.4
	-----	-----
	\$29	\$51

Systematic measurements were made of the effects of product particle size on the cost to grind in the Pitt Mill. The grinding cost of \$29 per ton at the 10 micron particle size drops to \$17 per ton at the 15 micron particle size, and drops further to \$10 per ton at the 20 micron size range. If the 20 micron particle size could be prepared without use of dispersant, then the cost of preparing 20 micron particles in the Pitt Mill could drop to less than \$5 per ton.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS.....	i
SUMMARY.....	iii
TABLE OF CONTENTS.....	vii
LIST OF FIGURES.....	ix
LIST OF TABLES.....	xi
 I. INTRODUCTION	 I-1
Significance of the Work.....	I-1
Pitt Mill Grinding Technology.....	I-1
 II. GOALS AND OBJECTIVES.....	 II-1
Phase I: Grinding Studies.....	II-1
Phase II: Engineering Evaluation.....	II-1
 III. TEST PROGRAM.....	 III-1
Pitt Mill Prototype	III-1
Test Coals	III-2
Methodology.....	III-4
Grinding Curves and Sampling Procedure.....	III-4
Dispersion.....	III-5
Media Wear.....	III-6
Test Results.....	III-6
Grinding Study.....	III-6
Effect of Slurry Concentration	III-8
Effect of Grinding Media.....	III-9
Effects of Shaft Speed.....	III-10
Screw Configuration.....	III-11
Pitt Mill Modification.....	III-14
Media Wear Rates --- Pittsburgh Seam Coal....	III-14
Media Wear Rates --- Effect of Grinding Media Size.....	III-16
Media Wear Rates --- Coal Effects.....	III-16
Grinding Energy and Grinding Time.....	III-18
Summary of Test Program Findings.....	III-22
Rheology.....	III-22
Grinding Media.....	III-22
Screw.....	III-22
Agitator Shaft RPM.....	III-23
Grinding Chamber Volume.....	III-23
Grinding Comparison Study.....	III-23
Pitt Mill Prototype Grinding.....	III-23
Commercial Grinding	III-25
Effects of Grinding Energy and Media Loss on Grinding Costs.....	III-28

IV.	ENGINEERING EVALUATION.....	IV-1
	Evaluation of 1 TPH Pitt Mill.....	IV-2
	KVS Design.....	IV-2
	KVS Cost Estimate.....	IV-5
	ETCi Cost Estimate.....	IV-7
	Estimated Costs for 1 Ton Per Hour	
	Production Model Pitt Mill.....	IV-7
	Comparison With Costs of Other Mills.....	IV-8
	Union Process Attritor.....	IV-9
	Two Stage Grinding Mills.....	IV-10
	Estimated Installation Costs for Three Mills.....	IV-12
	Annual Charges.....	IV-13
	Media Consumption.....	IV-14
	Capital Equipment.....	IV-14
	Energy.....	IV-15
	Labor.....	IV-15
	Dispersant.....	IV-15
	Maintenance.....	IV-15
	Systematics of Pitt Mill Grinding.....	IV-16
	Effects of Mill Parameters on Grinding Energy	
	and Grinding Time.....	IV-16
	Effect of Grinding Parameters on Mill	
	Capacity.....	IV-18
	Effect of Grinding Parameters on Operating Costs	
	and Mill Capacity.....	IV-19
APPENDIX A	SOUND MEASUREMENTS	
APPENDIX B	EXPERIMENTAL AND PROJECTED VALUES OF GRINDING	
	ENERGY, GRINDING TIME, AND MEDIA LOSSES	
APPENDIX C	NETZSCH MILLS USED IN THE COMPARISON GRINDING	
	STUDY	
APPENDIX D	KENNEDY VAN SAUN REQUEST FOR QUOTATIONS	
APPENDIX E	UNION PROCESS, INC.	
APPENDIX F	K-TRON CORPORATION	
APPENDIX G	PITT MILL PUBLICATIONS	

LIST OF FIGURES

Figure I-1.	Diagram of the Pitt Mill.....	I-2
Figure II-1.	Work Breakdown Structure.....	II-2
Figure II-2.	Organization Chart.....	II-4
Figure III-1.	Dimensions of the Pitt Mill Prototype. (Dimensions in millimeters).....	III-1
Figure III-2.	Power Curve for the Prototype Mill.....	III-2
Figure III-3.	Spatial Profile of Sizes Inside the Mill ...	III-5
Figure III-4.	Prototype Mill Grinding Curves.....	III-8
Figure III-5.	Effect of Slurry Concentration.....	III-9
Figure III-6.	Effect of Grinding Media Size.....	III-10
Figure III-7.	Effect of Shaft Speed on Grinding Time and Energy.....	III-11
Figure III-8.	Screw Parameters.....	III-12
Figure III-9.	Effect of Screw on the Grinding Energy of a 50% Slurry of Pittsburgh #8 Coal Using 3/16 inch 52100 Media at Different Shaft Speeds.....	III-13
Figure III-10.	Comparison of Grinding Curves of Original and Modified Prototypes.....	III-14
Figure III-11.	Effect of Grinding Media Size on Wear Loss in the Pitt Mill Prototype.....	III-16
Figure III-12.	Specific Media Loss Versus Ash for Four Coals.....	III-18
Figure III-13.	Grinding Times to Produce 10, 15 and 20 Microns Mean Particle Size Coal in the Pitt Mill...	III-20
Figure III-14.	Grinding Energies to Produce 10, 15 and 20 Microns Mean Particle Size Coal in the the Pitt Mill.....	III-21
Figure III-15.	Pittsburgh #8 Batch Test Series Using the Pitt Mill.....	III-25
Figure III-16.	Netzsch Grinding Set-up.....	III-26

Figure IV-1.	Engineering Scale-up.....IV-1
Figure IV-2.	Grinding of 50 HGI Montana Rosebud Coal at 30% Solids in No. 6 Fuel Oil in Attritor.....IV-10
Figure IV-3.	Comparison of Grinding Costs for Two Alternative Grinding Methods.....IV-16

LIST OF TABLES

Table III-I.	Characterization of the Test Coals Used in the Grinding Comparison Study (% in volume).....	III-3
Table III-II.	Effects of Four Dispersants on Viscosity of 35% Solids 10 Micron Mean Diameter Pittsburgh #8 Coal Slurry.....	III-5
Table III-III.	Grinding Variables.....	III-7
Table III-IV.	Grinding Times and Throughputs for the Pitt Mill to Prepare a Ten (10) Micron Product at Different Solids Concentrations.....	III-9
Table III-V.	Experimental Results on Media Loss.....	III-15
Table III-VI.	Effects of Coal Characteristics on Grinding Energy and Grinding Media Weight Loss.....	III-17
Table III-VII.	Standard Conditions for the Prototype Mill Grinding.....	III-24
Table III-VIII.	Standard Conditions for the Netzsch Mills..	III-26
Table III-IX.	Comparison of Energies to Grind Test Coals to 10 Micron Mean Particle Size Using Pitt Mill Prototype and Netzsch Mills.....	III-27
Table III-X.	Grinding Energies and Media Consumption Rates for Pitt Mill and Netzsch VM30 and LME 20 Grinding Mills.....	III-28
Table III-XI.	Grinding Media Costs.....	III-29
Table III-XII.	Estimated Cost of Grinding Media and Energy for the Pitt Mill Prototype and for the Netzsch VM30 and LME 20 Grinding Mills Producing 10 Micron Pittsburgh #8 Coal.....	III-30
Table IV-I.	Mill Assembly Costs.....	IV-5
Table IV-II.	Cost of Final Design and Fabrication Drawings for 1 TPH Pitt Mill.....	IV-6
Table IV-III.	Grinding Media Costs, AISI 52100 Chrome Alloy Steel Balls.....	IV-7

Table IV-IV.	Selling Price of a 1 TPH Production Model Pitt Mill With Control Unit.....IV-7
Table IV-V.	Comparison of Costs of Fine Grinding Mills...IV-9
Table IV-VI.	Comparison of Grinding Results for Two Stage Grinding Circuit at Homer City Coal Quality Development Center.....IV-11
Table IV-VII.	Capital Cost of Three Methods of Coal Grinding.....IV-12
Table IV-VIII.	Estimates of Annual Costs to Operate Two Alternative Grinding Circuits to Prepare 10 Micron Pittsburgh #8 Coal of 17.05% Ash.....IV-13
Table IV-IX.	Comparison of Energies and Media Loss Rates to Grind 17.05% Ash Pittsburgh #8 Coal to 10 Micron Mean Particle Size for the Pitt Mill Prototype and the Two Stage Netzsch Mills.....IV-14
Table IV-X.	Estimates of Costs in Dollars per Ton to Operate Two Alternative Grinding Circuits to Prepare 10 Micron Pittsburgh No. 8 Coal of 17.05% Ash and 49-64 HGI.....IV-15
Table IV-XI.	The Effects of Product Particle Size, Grinding Media Diameter, and Shaft RPM on Grinding Energy, Grinding Time, and Grinding Media Wear Loss for the Pitt Mill.....IV-17
Table IV-XII.	Duty Cycle and Annual Production of Pitt Mill versus Product Particle Size, Grinding Media Size, and Shaft RPM.....IV-18
Table IV-XIII.	Effects of Particle Size, Grinding Media Size, and Shaft RPM on Operating Cost and Average Throughput (TPH) of Pitt Mill.....IV-20

I. INTRODUCTION

Significance of the Work

The high cost of grinding has been recognized as a limiting factor in the commercialization of fine coal cleaning technology. Coal particle sizes in the range of 10 to 20 microns must be achieved in order to obtain the necessary liberation for the purposes of advanced coal cleaning technology. This size range is also convenient for advanced fine coal combustion applications, where coal can be burned efficiently in diesel engines and other combustors which do not normally use coal.

The primary factors responsible for the high cost of fine grinding are: 1) the high cost of fine-sized grinding media used in advanced mills, 2) the high cost of energy, 3) the high consumption rates of the grinding media, and 4) the high capital cost of the mills resulting from a complex mechanical design.

Pitt Mill Grinding Technology

Our strategy to reduce the capital and operating costs of fine grinding has resulted in the development of the Pitt Mill (Figure I-1). The Pitt Mill is a batch-operated, intermediate energy density mill. All product circulation is achieved internally, simplifying the mechanical design of the mill. The mill is divided into two regions. The size reduction occurs in the bottom chamber, by action of the grinding media. On top, a slurry chamber gives capacity to the mill. Good circulation patterns in both chambers are vital to assure good product quality. A first circulation pattern is generated in the grinding chamber, the consequence of having the top surface of the grinding media unrestricted. Under this condition, the radial motion of the media will gain an upward axial component near the walls of the mill, generating a vortex. Vorticity acts as a pumping mechanism for incorporation of the slurry into the grinding chamber. The unrestricted bed can also expand, allowing coarse-sized material to be incorporated. A second circulation pattern is generated in the top chamber by the pumping action of the screw, which directs the flow into the grinding media vortex. As a result, the slurry is recycled many times during the grinding cycle, generating a very uniform product.

The implementation of this technology requires both a detailed knowledge of the effect of the different parameters that control the performance of the mill, and of how those parameters can be scaled-up. The development of cost information is also essential for the evaluation of this technology in a commercial application. In this work, both technical and economic information has been developed and used as a basis for an engineering evaluation of a 1 TPH mill.

Figure I-1. Diagram of the Pitt Mill.

Development of the Pitt Mill was begun by John Hagy of the Fort Pitt Machine Company who had been involved with grinding mills for several years. During the initial phases of the development work analytical services were provided by EXPORTEch Company, Inc. This relationship evolved into a more formal arrangement in which a joint effort was made to develop the mill. A U.S. patent was issued to Mr. Hagy in July, 1989 (4,850,541) to which he and EXPORTEch Company share rights and ownership.

II. GOALS AND OBJECTIVES

The overall goals of the program were to determine the most suitable configuration of the 5 HP Pitt Mill, to demonstrate its grinding capability and simplicity of design, and to prepare an evaluation of a scaled up 1 TPH unit. A two-phase program was undertaken to achieve these goals.

Phase I: Grinding Studies

Phase I consisted of grinding studies which were directed at demonstrating and quantifying efficient coal grinding with the 5 horsepower Pitt Mill prototype and at exhibiting its operational simplicity in grinding coal to the 10 to 20 micron mean particle size range. The criteria for efficient grinding were the following:

- Low energy consumption
- Coarse media size
- Low media consumption
- Ability to grind coarse coal (no pregrinding)
- High solids slurries
- Generation of a uniform product
- Simple mechanical design and operation

A secondary goal was to demonstrate the feasibility of using the Pitt Mill in coal applications by comparing the results of grinding coal by the new method with those achieved by more conventional technology now widely used in coal research.

Phase II: Engineering Evaluation

The technical and cost information gathered in the experimental program was used in the conceptual design and evaluation of a 1 TPH unit which could then be used as a basis for economic comparison with commercial units.

In order to meet the goals of the two phase program, a contract work plan was laid out which included the specific tasks listed below. The organization of the work is given in Figure II-1.

Task 1.	Project Planning
Task 2.	Installation and Instrumentation of Pitt Mill
Task 3.	Grinding Studies
Task 3.1	Procure, Prepare and Characterize Three Coals
Task 3.2	Dispersant Demonstration
Task 3.3.1	Screw Configuration
Task 3.3.2	Media Type, and Quantity
Task 3.3.3	Agitator RPM
Task 3.3.4	Media Loss
Task 3.3.5	Time Studies

Task 3.3.6	Sized Feed
Task 3.3.7	Grinding Chamber Aspect Ratio
Task 3.4	Grinding Comparison Study
Task 3.4.1	Prototype Mill Grinding
Task 3.4.2	Commercial Grinding
Task 3.4.3	Analysis of Comparison Grinding Study Results
Task 4	Engineering Evaluation and Project Review
Task 4.1	Design and Cost of Mark II Pitt Mill
Task 4.2	Project Review

Figure II-1. Work Breakdown Structure.

In Task 1, Project Planning, details of the work plan were finalized with the DOE.

In Task 2, Pitt Mill Installation and Instrumentation, a 5 HP prototype Pitt Mill, which had been donated to the program by Fort Pitt Machine Company, was moved from the Fort Pitt facilities in Carnegie, PA, and installed and instrumented at the EXPORTEch laboratories in New Kensington, PA.

Four major activities were carried out in Task 3, Grinding Studies. In Task 3.1, Coal Procurement and Preparation, four procurements of coal were made to obtain coal for use in all phases of the test program. Characterization of the coal was done in this task. Over ten tons of coal were ground using the 5 HP prototype mill during the course of the work of Task 3. The effects of the use of dispersants on grinding efficiency were demonstrated in Task 3.2, Dispersant Demonstration. A specific dispersant and concentration was chosen in this task for use in the remainder of the program.

The major operational and design features of the Pitt Mill were tested in Task 3.3, Pitt Mill Configuration Studies. This work was carried out for the purposes of demonstrating the Pitt Mill, of choosing a mill configuration for use in Task 3.4, Grinding Comparison Study, and for the purpose of developing information to be used in the scaleup design and cost estimation work of Task 4, Engineering Evaluation and Project Review.

In Task 3.4, Grinding Comparison Study, splits from three coals were ground in the Pitt Mill and in a two stage high energy density mill at the laboratories of Netzsch Incorporated in Exton, PA.

In Task 4, Engineering Evaluation and Project Review, the Kennedy van Saun Corporation of Danville, PA, was engaged to prepare a conceptual level scale-up of the 5 HP prototype mill to the 1 ton coal per hour size and to estimate the shop floor cost to build the larger mill. EXPORTEch then estimated the cost to operate the 1 ton per hour Pitt Mill and compared the operating costs to estimates for a two stage mill employing a ball mill feeding a high energy density disc mill of the type tested in Task 3.4, Grinding Comparison Study.

Results of the project were reviewed with the DOE after the engineering evaluation had been completed.

The organizational structure of the program is shown in Figure II-2.

ORGANIZATION CHART

Figure II-2. Organization Chart

III. TEST PROGRAM

The first phase of the Pitt Mill Demonstration project was a test program in which all relevant technical and cost parameters of the mill were systematically studied. Technical parameters included screw geometry, grinding media selection, shaft speed, feed size and slurry chamber geometry. Cost parameters included energy consumption, mill throughput and grinding media consumption. In the final task of this program, the mill was configured in order to compare it to other advanced mills available in the market. The configuration study also provided information for scale-up of the Pitt Mill; this task carried out as part of the Engineering Evaluation, in which a 1 TPH device was designed.

Pitt Mill Prototype

A 5 horsepower batch-operated Pitt Mill prototype was transferred from the Fort Pitt Machine Company facilities in Carnegie, PA, to the EXPORTEch laboratories in New Kensington, PA. The mill was completely instrumented for the configuration study. The dimensions of the 5 HP prototype are shown in Figure III-1. The mill consists of two cylindrical steel chambers, 10 inches ID and 14 inches high. A curved steel plate is bolted in place forming the bottom of the mill. This plate has a drain hole in the center, used to remove the grinding media after the experimental runs. The grinding media is agitated by a set of pins mounted directly in the shaft. The shaft also drives a screw, which generates a circulation pattern of the slurry in the top chamber. The shaft is driven by a 5 HP motor, via a speed reducer. Sheave sizes can be changed to modify the shaft speed. The screw is also interchangeable, allowing control of the slurry circulation.

Figure III-1. Dimensions of the Pitt Mill Prototype.
(Dimensions in millimeters)

The mill was instrumented with a 3-phase Ohio Semitronics Model PC5-15B power transducer for continuous power measurements up to a maximum of 8 kW. Temperature of the grinding chamber was monitored continuously using a Type J Thermocouple. Both temperature and power were displayed and recorded continuously in a three channel vertical-face modular strip-chart recorder.

Sixty pounds of slurry was used for all tests. The solids content was set by adjusting the weight of dry coal. A dispersant was added, at the rate of 0.75 Wt.% based on dry coal. The feed materials are charged without premixing through the open top of the mill. After start up, time, power and temperature are recorded. An example of a power curve for a 50% solids slurry is shown in Figure III-2. The comminution is evaluated by grabbing samples for particle size measurements at different time intervals, ranging from 6 to 30 minutes. Samples are taken by dipping down into the slurry while the mill is running. After the test is completed, the product slurry is discharged using a vacuum pump down to the grinding media level. The remaining slurry, mixed with the grinding media, is removed through the bottom of the mill. Both the mill and the grinding media are thoroughly washed with water, and the media is dried and stored in a rust inhibitor for the next test.

Figure III-2. Power Curve for the Prototype Mill.

Test Coals

A total of eight and a half (8.5) tons of Pittsburgh #8 coal, one and a half (1.5) tons of Pocahontas coal and one (1) ton of

Mingo County coal were procured during the project. The procurements were made in batches, according to the requirements of the task being performed. Pittsburgh #8 was procured in four batches. The first two batches (4 tons and 1/2 ton, respectively) were used in the configuration study. A third batch of one ton was procured for the comparison grinding study. Three tons of this coal were procured at a later stage for the media loss determinations. While all the batches came from the same mine, there were variations in the chemical and physical properties of the coal in each batch, which translated into different performance in the mill. For this reason, any comparative work was carried out using coal from the same batch. This was particularly important in the case of comparison grinding studies and media wear loss determinations.

The procured coal was sized reduced to 4 mesh top size, split in 36 pound bags and stored in 55 gallon steel drums under argon atmosphere. Periodic checks of the argon pressure were carried out to ensure proper storage conditions throughout the project. Three hundred pounds of Pittsburgh #8 coal were further size reduced for the study of the effect of feed size on grinding performance. These fractions were also split and stored under argon. Samples of each batch were characterized chemically and petrographically. Table III-I summarizes some of the properties of the coals used during the grinding comparison study.

Table III-I
Characterization of the Test Coals Used in the
Grinding Comparison Study (% in volume)

	Mingo County	Pittsburgh #8	Pocahontas
Coal	84.0	93.6	97.8
Durain	36.4	-	-
Exinite	15.0	3.1	0.3
Mineral Matter	9.2	5.2	2.0
Oxidized Coal	6.0	0.8	0.0
Brecciated Coal	0.8	0.4	0.2
Ash (Wt. %)	23.06	12.24	5.47
Sulfur (Wt. %)	0.74	4.74	0.71
Pyritic (Wt. %)	0.24	1.11	0.10
Sulfate (Wt. %)	0.01	0.35	0.01
Organic (Wt. %)	0.49	3.28	0.60
HGI	38	49	81

Pittsburgh #8 seam coal is a high volatile A rank bituminous coal. Its maceral composition is consistent with an intermediate value for Hardgrove Grindability (HGI). The characterization presented in Table III-I corresponds to the batch of coal used in the comparison grinding study. For the other batches, ash values varied from 11.7 to 17.1 % and HGI's from 49 to 56.

Pocahontas #3 coal is a high grindability metallurgical grade, low-volatile bituminous coal. Reactive macerals of this coal consist mostly of vitrinite, with only traces of exinite and resinite, resulting in a high HGI value.

Mingo County coal is a relatively dull banded high volatile A rank bituminous coal. A high content of exinite and micrinite, along with a relative abundance of vitrinite types number 7 and 8, results in a low HGI (38). Being a strip-mined coal, six percent is oxidized, with 3.2% in an advanced state of oxidation. The extent of oxidation of the Mingo County coal makes it distinctively different from the two other coals used in the program.

Methodology

Grinding Curves and Sampling Procedure

The grinding efficiency of the mill was evaluated by relating the product mean particle size to grinding time and energy consumption. Grinding energies are calculated by integration of the power curves of the mill (Figure III-2). These relationships provide a comprehensive view of how the machine is operating. Since the Pitt mill is batch operated, with complex circulation patterns, a sampling procedure was developed to assure consistent and accurate measurement of the product mean particle size. Figure III-3 shows the mean particle size as a function of time for samples taken at different height elevations in the mill. Data correspond to a 60% slurry, using 150 pounds of 5/16 inch media. The top sample was taken directly from the top of the mill, in the slurry vortex. The middle sample was taken right above the grinding media, using a vacuum pump. The bottom sample was taken when the grinding media was recovered. The slight differences between particle size in the media and on the slurry chamber converge after five minutes grinding, becoming uniform. This fact indicates that a high circulation rate has been achieved inside the mill. As size reduction levels off, the asymmetries in size inside the mill become negligible. This assures that after ten minutes, sampling at the top of the mill is representative of the entire batch.

Figure III-3. Spatial Profile of Sizes Inside the Mill

Particle size measurements were carried out using a Leeds & Northrup Microtrac II Particle Size Analyzer. The instrument has a nominal working range from 0.9 to 700 microns. The accuracy of the instrument was tested by using diagnostic standards provided by the manufacturer, and by independent measurements (Sedigraph) carried out by Micromeritics Corporation.

Dispersion

Wet grinding is facilitated by using surface active agents that keep coal particles dispersed, reduce viscosity, and allow the use of higher solids concentrations. Four surfactants were tested during the dispersant demonstration: Henkel A-23M and Pfizer FLOSP 370X, FLOSP 390X, and Floc 4800. Their effect on slurry viscosity can be seen in Table III-II. Henkel A-23M was chosen over FLOSP 370X because of its lower cost. The low shear measurements were made using a Brookfield Model LVF Synchro-Lectric viscometer.

Table III-II
Effects of Four Dispersants on Viscosity of 35% Solids
10 Micron Mean Diameter Pittsburgh #8 Coal Slurry

		Viscosity (Centipoise)			
Dispersant Concentration					
Wt. %	A23	Floc 4800	FLOSP 370X	FLOSP 390X	
0.00	974	923	939	943	
0.29	20	820	16	816	
0.57	5	615	3	354	
0.86		492		123	
1.14		483		22	
1.43		521			

The effect of dispersant concentration on grinding energy was demonstrated using a 1 HP stirred ball mill. The results of that study were presented in the Quarterly Technical Progress Report for the period September 28 - December 31, 1988.¹ In that work it was shown that addition of A-23M dispersant at concentrations of 0.75 Wt.% based on dry coal permitted efficient grinding to small particles (10 microns) at high solids concentrations (60% solids). This concentration level was used for the remainder of the test program.

Media Wear

Grinding media wear loss is also a significant component of the operating cost in any stirred ball mill. In order to obtain accurate values for media degradation, a method for handling and washing the media was developed which allows the determination of small weight losses in a 150 pound load of media. The method addresses the variations in moisture and hydrocarbon content in the surface of the media, and is described in detail in the Quarterly Technical Progress Report for the period July 1 - September 30, 1989.²

Test Results

The results of the experimental program provide a technical basis for understanding the operation of the Pitt Mill and are instrumental for the selection of the mill configuration for the work carried out during the comparison study. The grinding curves and media loss data gathered in the test program were used in the economic evaluation carried out in Phase II of this program. The final portion of the experimental program was a comparison grinding study, in which the Pitt Mill prototype was compared to Netzsch grinding technology under controlled conditions.

Grinding Study

During the grinding study a set of grinding curves was generated showing the effect of solids concentration, grinding media, shaft speed, screw geometry and slurry chamber geometry. These curves provided quantitative information regarding the operation of the mill under different conditions. The range of variation of the parameters considered in the study are shown in Table III-III.

¹EXPORTEch Company, Inc., "Pitt Mill Demonstration", U. S. Dept. of Energy Contract DE-AC22-88PC88884, Quarterly Technical Progress Report, September 28 - December 31, 1988.

²EXPORTEch Company, Inc., "Pitt Mill Demonstration," U. S. Dept. of Energy Contract DE-AC22-88PC88884, Quarterly Technical Progress Report, July 1 - September 30, 1989.

Table III-III
Grinding Variables

Variable	Range
Solids Concentration	40% to 60% by weight
Grinding Media	Zirconium oxide; stainless steel punchings; 3/16 inch to 3/8 inch vacuum degassed ball bearing quality chrome steel
Shaft Speed	250 to 585 RPM
Feed Top Size	4 mesh to 60 mesh
Screw Geometry	Pitch 4 and 4-1/2 inch/rev. Width from 0 to 1-1/4 inch
Slurry Chamber	6 and 10 gallons

A typical set of grinding curves for the Pitt Mill prototype is shown in Figure III-4. These curves represent a Pittsburgh #8 seam coal with 11.7% ash and a Hardgrove Grindability Index of 52. The mill was filled with 150 pounds of 5/16 inch 52100 chrome-steel media. The shaft speed was set at an intermediate value, 485 RPM. The feed slurry consisted of 36 pounds of 4x0 mesh coal and 24 pounds of water, (60% slurry, 0.75% dispersant). The curves show that the target range of 10 to 20 microns can be easily achieved using this coarse-sized media. The upper region of the target, a 20 micron mean particle size product, was reached after 10 minutes, with an energy consumption of about 40 kw-h/ton coal. Below fifteen (15) microns, the grinding rate slows down and the energy efficiency decreases. Still, the lower end target of ten (10) microns was reached after 24 minutes with an energy consumption of approximately 100 kw-h/ton coal. For this media size, ten microns is a reasonable lower limit. Two important points to remember are that these values correspond to grinding a batch starting with a 3/16 inch top size coal and using a 5/16 inch (about 8 mm) grinding media.

Figure III-4. Prototype Mill Grinding Curves

Effect of Slurry Concentration

An important variable determining energy efficiency in the mill is slurry concentration. In a batch operation it is desirable to operate at the highest slurry concentration possible in order to reduce the total volume of the mill to process a given batch size. Experimental results, presented in Figure III-5, show that the

prototype not only can grind well at high slurry concentrations, but it does so more efficiently. The grinding energy curves for 50 and 60% slurries are very close, while grinding at 40% solids results in poorer performance. The throughput for the 50-60% slurries is higher than for the 40% slurry (see Table III-IV). For a ten micron mean particle size, throughputs at 50% and 60% solids are 1.1 pounds per minute, while in the case of the 40% slurry the throughput is only 0.8 pound per minute. This indicates that the grinding efficiency at slurry concentrations of 50% and 60% is constant, decreasing as the solids concentration is reduced below 50%. There is a clear advantage in working at high solids concentrations. The effect that the solids content has on the wear rates was not measured in this program.

Table III-IV
Grinding Times and Throughputs for the Pitt Mill
to Prepare a Ten (10) Micron Product at
Different Solids Concentrations

Solids Content (Wt.%)	Weight of Coal Ground (lb)	Grinding Time (min)	Throughput (lb/min)
40	24	30.0	0.8
50	30	26.1	1.1
60	36	32.4	1.1

Figure III-5. Effect of Slurry Concentration

Effect of Grinding Media

Grinding media is the single most important factor determining technical and economic performance of the mill. The selection of the grinding media must be based on cost and wear characteristics

(breakage, erosion, corrosion). From several candidates considered initially in this project, including zirconium oxide cylindrical punchings, 409 stainless steel punchings, 440C stainless steel balls and 52100 degassed chrome steel balls, only the last two were suitable as grinding media for the Pitt Mill. Zirconium oxide and 409 stainless steel punchings broke up frequently, resulting in excessive media consumption. While the performance of the 440C steel media was similar to the 52100 media,³ media cost made the 52100 chrome steel media the preferred one; this was used for the remainder of the program.

The grinding media size has an significant influence on the energy efficiency, especially when approaching very small product sizes. This effect is illustrated in Figure III-6, which shows the grinding time and energy as a function of media size.

Figure III-6. Effect of Grinding Media Size

The general tendency is that the small media sizes tend to grind faster and more efficiently. This behavior holds at all shaft speeds tested, although it should be noted that at the lowest speed (345 RPM) the small media tend to leave oversized material in the product. This problem is reduced significantly at higher speeds (485, 585 RPM).

³EXPORTech Company, Inc., "Pitt Mill Demonstration", U. S. Dept. of Energy Contract DE-AC22-88PC88884, Quarterly Technical Progress Report, January-March, 1989.

Effects of Shaft Speed

The shaft speed controls the number of impact events per unit time on the grinding chamber and bed pumping and expansion. For a given product particle size, the grinding time is reduced as the shaft speed increases, resulting in a higher throughput. The net effect on grinding energy depends on the balance between savings in energy due to the reduction of the grinding time, and the increase in power due to the more intensive interaction. That balance can go both ways, as is shown in Figure III-7, where Pittsburgh #8 seam coal is ground to ten microns at different shaft speeds using 3/16 and 5/16 inch 52100 chrome steel media. The grinding times (based on 25 pounds of dry coal) present a consistent trend, while the grinding energy tends to increase for the 5/16 inch media and to decrease in the case of the 3/16 inch media. Generally, the mill performed better using the 3/16 inch media, grinding faster and more efficiently.

Figure III-7. Effect of Shaft Speed on Grinding Time and Energy

Screw Configuration

The screw performs two important tasks in the slurry chamber of the Pitt Mill. First, it promotes mixing of coal and water which are charged separately at the beginning of the run. Secondly, during the operation of the mill, the screw promotes the product circulation and incorporation into the grinding media vortex. This circulation is essential to guarantee uniformity of the mill product. The actual role of the screw during these two operations was investigated by varying the screw parameters. Design parameters of the screw are pitch (P), blade width (W) and screw terminus (T), defined in Figure III-8. The first two

parameters determine the mass flow and circulation rate of the slurry. The screw terminus position determines how far into the grinding media vortex the slurry is pumped.

Figure III-8. Screw Parameters

The importance of the screw as a premixing device is illustrated in Figure III-9, where a 50% Wt. Pittsburgh #8 coal slurry was ground using a 4-inch pitch, 1-inch wide screw and compared to the case in which no screw was used. At the lowest shaft speed (345 RPM) the mill performance without a screw is very poor, mainly because the coal is not properly wetted during the initial stage of the run. The presence of a 1-inch wide screw makes a significant improvement on the grinding characteristics of the machine. As the shaft speed increases, the effect of the screw becomes less pronounced. In this case (485 RPM), premixing is achieved by the circulation generated inside the upper chamber by the rotating grinding bed, which is manifested as a vortex. However, as the grinding proceeds towards its final stage, where the viscosity of the slurry is high, the circulation of the bed is not enough to promote effective grinding, and a screw becomes helpful, as can be seen in the plot at the highest shaft speed (585 RPM).

The effect of screw terminus and pitch on the grinding curves was found to be very small, as is discussed on Reference 1. The same is the case of screw width. The exception was the use of the 1-1/4 inch width screw, which showed a poorer performance than the 1 inch width screw. Excessive pumping by the screw can be detrimental for the grinding operation, lifting the grinding media and reducing the grinding action. These results indicate that the main role of the screw is as a premixer of coal and water, while playing a secondary role during the final stages of grinding, when high viscosities demand forced circulation.

Figure III-9. Effect of Screw on the Grinding Energy of a 50% Slurry of Pittsburgh #8 Coal Using 3/16 inch 52100 Media at Different Shaft Speeds

Pitt Mill Modification

The capacity of the slurry chamber of the prototype mill was increased by replacing the top chamber by a 15 inch diameter cylinder, coupled to the grinding chamber by a three inch high transition piece. With this configuration, the capacity of the mill was increased from 60 to 100 pounds of 60% slurry. The performances of the original and modified mills, using a 5/16 inch grinding media, are compared in Figure III-10. The throughput of the mill remained the same, since the weight of grinding media is the same in both configurations. The energy efficiency was also the same, which is an indication that the slurry circulation is still efficient. While grinding times per pound and grinding energies remained the same, the modified mill has the advantage of reducing the relative proportions of discharge and loading times, thereby increasing the overall throughput of the unit.

The modified Pitt Mill was not used further in the test program, however, because of problems associated with settling of coarse particles at the interface between the grinding and product chambers. This could be avoided with use of a conical upper section.

Figure III-10. Comparison of Grinding Curves of Original and Modified Prototypes.

Media Wear Rates -- Pittsburgh Seam Coal

Measurements of media weight loss were made for 3/16, 5/16 and 3/8 inch diameter 52100 chrome steel media at shaft speeds ranging from 250 to 585 RPM. Data was developed relating the average product particle size, average grinding energy, average grinding

time per batch, and overall media loss for sequences of eleven (11) batch runs, each carried out under the same conditions.⁴ For a description of the procedure used in making the sequence of runs, see the section, Pitt Mill Prototype Grinding, page III-23 and Figure III-14. A Pittsburgh #8 seam coal of 17.1 % ash and 56 HGI was used for the measurements. The results of the measurements of media loss are summarized in Table III-V.

Table III-V
Experimental Results on Media Loss

Media Size (in)	Shaft Speed (RPM)	Mean Particle Size (micron)	Grinding Energy (kW-h/ton)	Grinding Time (min/25 lb.)	Specific Loss (lb/kW-h)	Media Loss (lb/Ton)
3/16	345	7.6	114.3	31.3	0.0243	2.78
	485	10.9	65.4	13.4	0.0240	1.57
	585	8.2	92.8	15.3	0.0246	2.29
<hr/>						
5/16	250	11.9	76.2	26.5	0.0234	1.79
	345	10.9	90.5	23.6	0.0197	1.79
	485	10.7	117.9	21.2	0.0194	2.29
	585	10.0	165.0	23.6	0.0186	3.07
<hr/>						
3/8	250	12.5	75.4	26.5	0.0189	1.43
	345	12.4	93.5	23.6	0.0139	1.43
	485	11.3	134.5	23.4	0.0149	2.00
	585	13.0	169.0	23.6	0.0140	2.36

The analysis of the data indicates the presence of three components in the wear loss: one dependent on media size, one dependent on grinding energy and a third one dependent on time. Physically, the time component can be interpreted as a corrosion term. The practical consequence of this component is that media consumption cannot be avoided by just reducing the agitator speed. Based on this analysis, the data shown in Table III-V can be correlated by the following expression:

$$\text{Media Loss (lb/ton coal)} = 1.31 - 3.84 D + 0.0127 E + 0.0248 t$$

$$\text{Corr. coef.} = 0.8677 \quad (1)$$

where D is the media size in inches, E is the grinding energy in kW-h/Ton coal and t is the grinding time for a 25 pound batch of coal in minutes. This type of correlation is useful in the

⁴EXPORTech Company, Inc., "Pitt Mill Demonstration", U. S. Dept. of Energy Contract DE-AC22-88PC88884, Quarterly Technical Progress Report, October 1 - December 31, 1989.

prediction of media consumption under operating conditions which are different from those in the Pitt Mill.

Media Wear Rates --- Effect of Grinding Media Size

A simplified version of the correlation shown in Eq. (1) is relevant for the case of high shaft speeds which result in relatively short grinding times. Under these conditions the media loss per unit energy (specific media loss) is nearly independent of grinding energy (Table III-V, 345, 485 and 585 RPM). The specific media loss is related to grinding media diameter. This relationship for the 17.1 % ash Pittsburgh #8 coal is illustrated in Figure III-11.

$$\text{Specific Media Loss (lb/kW-h)} = 0.03436 - 0.05170 * D, \quad r^2 = 0.9577 \quad (2)$$

This correlation is used in the **Commercial Grinding Cost Comparison** (Table III-X) and in Part IV, **Engineering Evaluation**, to estimate wear losses of the Netzsch mills .

Figure III-11. Effect of Grinding Media Size on Wear Loss in the Pitt Mill Prototype.

Media Wear Rates --- Coal Effects

In the July 1- September 30, 1989, Quarterly Technical Progress Report (Reference 2) we reported measurements of grinding energy and weight loss when grinding three coals: 5.47% ash Pocahontas coal, 12.24% ash Pittsburgh #8 coal, and 23.06 % ash

Mingo coal, using 5/16 inch grinding media. The grinding energies and weight losses for those coals and for a Pittsburgh #8 coal from the same source but with 17.05% ash are summarized in Table III-VI.

Table III-VI
Effects of Coal Characteristics on Grinding Energy
and Grinding Media Weight Loss.
5/16 inch Media, 485 RPM, 10-Micron Mean Particle Size Product

Coal	Ash	HGI	Grinding Energy (kW-h/T)	<....Media Loss....>	
				(lb/kW-H)	(lb/Ton)
Pocahontas	5.47	81	75	0.0074	0.55
Pittsburgh #8	12.24	49	122	0.0128	1.56
Pittsburgh #8	17.05	56	121	0.0188	2.28
Mingo	23.06	38	69	0.0246	1.70

Our data indicates that the grinding energy determined in the Pitt Mill does not correlate with the Hardgrove Grindability Index (HGI) measured for the four coals tested. As reported in the Quarterly Progress Report, we believe that this discrepancy is due to the fact that the Mingo coal exhibited signs of weathering. The other three coals did not appear oxidized. The Mingo coal was the only one of the four that was surface-mined. The HGI may not be a good index of grinding energy requirements for oxidized coals.

We have also observed that the grinding media loss, measured in pounds of grinding media lost per ton of coal ground, can be affected by the coal's history, such as weathering. This can be understood when it is realized that the media loss can be expressed as the product of the grinding energy and the specific media loss, measured in pounds of media per kW-hr of energy input to the grinding bed, as given in Eq. (3).

$$\text{Loss (lb/Ton)} =$$

$$\text{Grinding Energy (kW-h/T)} * \text{Specific Loss (lb/kW-h)} \quad (3)$$

The grinding energy is affected by the coal's history whereas the specific media loss is not. The specific media loss is affected by the amount of abrasive material in the coal. The major source of abrasiveness is associated with mineral components in the coal such as quartz and iron pyrite.

Specific media weight losses, measured in pounds media lost per kilowatt hour of grinding energy input, for these coals and for the 17.05% ash Pittsburgh coal are shown in Figure III-12 where it is apparent that ash level is an important factor in determining media loss in fine grinding of coal.

The relationship between specific media loss and coal quality characteristics such as shown in Figure III-12 is more directly related to coal and mineral matter characteristics than is loss per ton of coal. This is to be expected because the grinding energy for coal can be strongly affected by weathering while the abrasiveness of the minerals in the coal is not.

Figure III-12. Specific Media Loss Versus Ash for Four Coals.

Grinding Energy and Grinding Time

The effects of grinding media particle size and of Pitt Mill prototype shaft RPM on the grinding energy and the grinding time have been determined from the grinding curves of the mill. This information provides quantitative information about the performance of the mill when grinding at different levels of comminution. A detailed tabulation of values is presented in Appendix B of this report and in the October 1-December 31, 1989, Quarterly Technical Progress Report (Reference 4). The experimental conditions used for the determination of these values are those used in the work discussed above (Media Wear Rates --- Coal Effects).

The effects of grinding media size and mill shaft RPM on grinding time to produce 10 micron, 15 micron, and 20 micron products are illustrated in Figure III-13. The points marked by an asterisk (*) are the result of significant extrapolations. The 3/8 inch media is not suitable for preparing the 10 micron product and the data for the 3/16 inch media were not suitable for projecting reliable results for grinding to the 20 micron size range. The

figures indicate that the 3/16 inch media grinds fastest and that grinding time generally decreases as the mill RPM increases.

The effects of grinding media size and mill shaft RPM on grinding energy to produce 10 micron, 15 micron, and 20 micron products are given in Figure III-14. The 3/8 inch media is not appropriate for preparing the 10 micron product and the data for the 3/16 inch media were not suitable for projecting accurate values of grinding time for preparing the 20 micron product. The figures indicate that 3/16 inch media consume less energy to grind for all product sizes.

Figure III-13. Grinding Times to Produce 10, 15 and 20 Microns Mean Particle Size Coal in the Pitt Mill.

Figure III-14. Grinding Energies to Produce 10, 15 and 20 Microns Mean Particle Size Coal in the Pitt Mill.

Summary of Test Program Findings

The results of the test program demonstrate that the Pitt Mill can grind 3/16 inch topsize coal to 10 microns mean particle size in a single step without requiring premixing. The mill can grind feedstocks of high solids content to these sizes if dispersants are employed. Relatively coarse sized and inexpensive grinding media can be used.

Rheology

The combination of grinding media size and quantity, shaft RPM, and screw-blade pitch and width are chosen to achieve the best overall effect of low grinding energy and high throughput in relation to the rheology of the product and the natural tendency of the grinding bed to incorporate coarse coal for grinding.

Grinding Media

A variety of grinding media were tested in the program. Ceramic media were abandoned because the oblate cylindrical shape used fractured in the Pitt Mill. Chrome steel and stainless steel spherical media ranging from 3/16 inch up to 3/8 inch diameter were tested. The finest media grind quickest and produce the finest product but can have problems in leaving oversized materials when the coal contains significant amounts of hard components. The 3/8 inch media were not suited to preparation of 10 micron products. The 5/16 inch 52100 chrome steel media was chosen for the comparison grinding test work because of its overall performance and low cost. Mixtures of grinding media sizes were tested. Small amounts of 5/16 inch media mixed into the 3/16 can help to avoid problems associated with oversize while maintaining the fast grind associated with the fine media.

Screw

The screw acts as a mixer at the beginning of the grinding run which allows the mill to grind high solids feedstocks. With the screw present, the coal and water can be simply dumped into the grinding chamber and grinding commences immediately when the mill is energized. There is no grinding when employing solids above about 45% to 50% without premixing when the screw is absent.

Near the end of the run, the screw keeps the viscous slurry in the product chamber moving into the media vortex. Grinding to 10 microns would take much longer without the screw. The screw width and pitch have been chosen to match the pumping rate of the bed at 485 RPM shaft speed.

Agitator Shaft RPM

When the pump rates of the agitator shaft screw and the grinding bed are matched, the grinding energy is insensitive to shaft RPM and the grinding time decreases with RPM within the limits of the parameters tested in the program. Because of this, the agitator shaft RPM of 485 was chosen as a good compromise. It can be decreased for grinding soft coals and increased for grinding hard coals.

Grinding Chamber Volume

Increasing the volume of the grinding chamber by increasing its diameter relative to that of the grinding bed can increase the capacity of the mill and improve its practicality if the product and media vortices are maintained. The straight-walled original mill design was employed in the grinding comparison test work, however, to avoid sedimentation problems encountered with the large capacity design tested in the experimental program.

Once the laboratory portion of the program had been completed, a comparison of the Pitt Mill and a commercial mill was undertaken. This is discussed in the following section.

Grinding Comparison Study

The main purpose of this portion of the work was to compare the performance of the Pitt Mill and a commercial mill operating under the same grinding conditions. Three test coals were used for the grinding comparison study. Properties of these coals are shown in Table III-I, Characterization of Test Coals. The coals selected provide a wide range of grindabilities and mineral composition. The inventory of each coal assured enough material to carry out the prototype grinding and commercial grinding studies using splits from the same batches of coal.

Pitt Mill Prototype Grinding

Two-hundred-eighty pounds of each of the three test coals was ground in the prototype mill. Each test consisted of eleven batches. A standard set of conditions was selected, shown in Table III-VII.

The mill was operated with 30 pounds of coal and 30 pounds of water in the first batch. After comminution goals were achieved, the slurry from the slurry chamber was removed by vacuum pumping and replaced by a new charge of coal and water (50 lb. of 50% slurry). Power consumption and temperature of the grinding chamber were recorded for each run. Particle sizes were measured at regular intervals to check grinding goals. An additional sample of

the composite was taken to represent the whole test. This procedure continued for a total of eleven batches.

Table III-VII
Standard Conditions for the Prototype Mill Grinding

<u>Coal Slurry</u>	
Slurry Concentration (%)	50
Dispersant	A23M
Dispersant Concentration (%)	0.77 (dry coal)
<u>Grinding Media</u>	
Type	52100 Vacuum degassed Chrome Steel
Size (inch)	5/16
Amount (lb)	150
<u>Screw Configuration</u>	
Shaft Speed (RPM)	485*
Width (inch)	1
Pitch (inch/revolution)	4

*345 RPM was used for the Pocahontas coal due to the high HGI number of this coal.

The particle size and energy consumption during comminution of Pittsburgh #8 coal in an eleven batch series are shown in Figure III-15. The time-trend in their values indicates that the mill achieves a steady operation, which can be seen more clearly from the energy consumption curve. Particle size data show more variability due to the nature of the measurement method. The range of temperatures also becomes uniform in the steady state, with an increase of about 12°C in each run.

Figure III-15. Pittsburgh #8 Batch Test Series
Using the Pitt Mill.

Energy consumption and throughput for the different grinding series are presented in Table III-IX, along with the results of the commercial grinding. These values correspond to interpolations to a ten microns product, to provide a common basis for comparison with the commercial mill.

Commercial Grinding

This task was carried out at the commercial grinding laboratory of Netzsch Incorporated in Exton, PA. The tests were carried out by Netzsch personnel, in the presence of Fort Pitt and EXPORTEch representatives.

In order to reach the goal of a 10 micron mean particle diameter, the experimental set-up consisted of two stages: a VM30 Vertical Mill pregrinding unit, coupled to a 2NL15A Nemo progressive cavity pump which pumped the slurry to a LME20 horizontal mill. The VM30 unit was fed via an Accurate model 602 dry solids feeder. Water and dispersant were added using a gear pump. Both solids and liquid flows were calibrated before the tests. The instrumentation of the mills consisted of electric current, temperature and shaft rpm indicators. A set of standard conditions, shown in Table III-VIII, was chosen for all the tests by Netzsch personnel. Residence times and amount of grinding media for both mills were adjusted to assure a continuous operation.

A diagram of the Netzsch grinding circuit is shown in Figure III-16.

Figure III-16. Netzsch Grinding Set-Up.

Table III-VIII
Standard Conditions for the Netzsch Mills

	VM30	LME20
<u>Coal Slurry</u>		
Slurry Concentration (%)	50	50
Dispersant	A23M	A23M
Dispersant Concentration (%)	0.8	0.8
<u>Grinding Media</u>		
Type	Chrome Steel	Chrome Steel
Size (mm)	8-12	3
Amount (lb)	300	430
<u>Agitator</u>		
Shaft speed (RPM)	255	1000
Tip speed (m/s)	3.1	9.4
<u>Cooling System</u>		
Water flow rate (l/min)	12.0	8.0
Inlet temperature (°C)	11.0	4.5

A total of nine tests were completed which consisted of three flow conditions for each coal. The results of these tests, projected to a ten (10) micron product size, are presented in Table

III-IX, where they are compared to the results of the Pitt Mill Prototype grinding.

In all cases, the Pitt Mill Prototype consumed less energy in preparing the 10 micron particle size. The Prototype Mill requires significantly less energy to grind the Mingo and Pocahontas coals. For the Pittsburgh #8 coal, the grinding energies for the two technologies are similar.

Table III-IX
Comparison of Energies to Grind Test Coals
to 10 Micron Mean Particle Size
Using Pitt Mill Prototype and Netzsch Mills

	<u>Mingo</u> <u>County</u>	<u>Pittsburgh</u> <u>#8</u>	<u>Pocahontas</u>
<u>Prototype Mill</u>			
Energy (kW-h/Ton coal)	69	122	75
Throughput (lb.coal/min)	1.8	1.0	1.2
<u>Netzsch Mills</u>			
Energy (kW-h/Ton coal)	120	129	96
Throughput (lb.coal/min)	3.4	3.0	3.8

Differences in throughput between the prototype mill and the Netzsch system are in part the result of differences in working volumes. The volume of the prototype mill is 7.9 liters. This is to be compared with 22.9 liters for the Netzsch configuration. This is a ratio of 1 to 2.9. Nominal energy densities were 1.2 HP/liter for the VM30 mill, 2.1 HP/liter for the LME20 mill and 0.6 for the Pitt Mill.

It is interesting to note that both methods use less energy to grind the Mingo coal (HGI=38) than the Pittsburgh #8 (HGI = 49). In the case of the Prototype mill, this energy is also lower than that required to grind Pocahontas coal (HGI=81), even considering that the shaft speed used in grinding the Pocahontas coal was less than that used for the Mingo coal. For the 5/16 inch media, a lower shaft speed results in lower energy consumption at the expense of grinding time and decreased throughput. These results indicate that the Hardgrove Grindability Index cannot be used as a rule of thumb to predict grinding energy. There may be a relationship between HGI and media wear losses, however, since hardness and abrasiveness are related at least for the mineral components in the coal.

Effects of Grinding Energy and Media Loss on Grinding Costs

The effects of grinding energy and of media consumption on the cost of preparing 10 micron mean particle size coal can now be illustrated for three different approaches. The first, Case 1, employs 5/16 inch media in the Pitt Mill. The second, Case 2, employs 3/16 inch media in the Pitt Mill. The third, Case 3, is that of a two stage grinding circuit employing a Netzsch VM 30 employing nominal 10 mm media to feed a Netzsch LME 20 mill employing 3 mm grinding media.

We measured the rate of media loss in the Pitt Mill to grind a 17.05% ash Pittsburgh #8 coal which was procured from the same mine as the 12.24% ash coal which was used in making the grinding energy measurements in the Grinding Comparison Study. Since we have not observed any significant effect of moderate changes in ash level on grinding energy for coals from a common source using the Pitt Mill, we estimate the costs of energy from measurements made on the 12.24% ash coal and of media consumption from measurements made on the 17.05% ash coal.

We do not know the rate of media consumption in the Netzsch mills. In an effort to estimate these quantities, we have employed the correlation of Eq (2). Our estimates are in the nature of a "best" guess since measurements of media loss made in the Pitt Mill may not be valid in the second stage high energy density Molinex disc mill employed in the Netzsch circuit.

Measurements of grinding energies and estimates of media consumption rates are given in Table III-X below.

Table III-X
Grinding Energies and Media Consumption Rates
for Pitt Mill and Netzsch VM30 and LME 20 Grinding Mills

Case	Media Diameter (inches)	Mill	Grinding Energy (kW-h/T)	Media Consumption (lb/T)
1	5/16 in.	(485 RPM) Pitt Mill	122*	2.28†
2	3/16 in.	(485 RPM) Pitt Mill	65.7†	1.57†
3	10 mm	(255 RPM) Netzsch VM30	45*	0.63‡
	3 mm	(1000 RPM) Netzsch LME 20	84*	2.37‡

- * Measured using a 12.24% ash Pittsburgh #8 coal.
- † Measured using a 17.05% ash Pittsburgh #8 coal.
- ‡ Estimated from measurements made in the Pitt Mill.

We assume the cost of electric power to be \$0.06 per kW-h. Recent quotes for the cost of grinding media are given in Table III-XI.

Table III-XI
Grinding Media Costs*
AISI 52100 Chrome Alloy Steel Balls

<u>Size</u>	<u>Price Per Pound</u>
1.5 mm	\$16.26
2 mm	9.12
3 mm	7.13
3/16 inch	4.38
5/16 - 3/8 inch	0.99
Over 1 inch	0.84

*As quoted by Royal Steel Ball Products, Inc., January, 1990, for lots of 2000 to 5000 pounds, F.O.B. Sterling, Illinois

The effects of grinding media size, media costs and losses and of grinding energy on grinding costs for the 5 HP prototype Pitt Mill⁵ and the two stage Netzsch mills are compared in Table III-XII.

⁵See Reference 4, Quarterly Technical Progress Report, October 1- December 31, 1989.

Table III-XII
Estimated Cost of Grinding Media and Energy for the Pitt Mill
Prototype and for the Netzsch VM30 and LME 20 Grinding Mills
Producing 10 Micron Pittsburgh #8 Coal

Media Diameter (inches) Mill		Cost of Grinding Energy (\$/T Coal)	Cost of Media Loss (\$/T Coal)	Combined Cost of Energy and Media Loss (\$/T Coal)
<u>Case 1</u>				
5/16	(485 RPM) Pitt Mill	7.3*	2.3†	9.6
<u>Case 2</u>				
3/16	(485 RPM) Pitt Mill	3.9†	6.9†	10.8
<u>Case 3</u>				
10mm	(255 RPM) Netzsch VM 30	2.7*	0.6‡	3.3
3mm	(1000 RPM) Netzsch LME 20	5.0*	16.9‡	21.9
		-----	-----	-----
		7.7	17.5	25.2

* Measured using a 12.24% ash Pittsburgh #8 coal.

† Measured using a 17.05% ash Pittsburgh #8 coal.

‡ Estimated from measurements made in the Pitt Mill.

The comparison grinding work shows the importance of using inexpensive grinding media where possible. It does not, however, establish the cost of the grinding mills or of the effects of grinding time on the mill throughputs. These costs will be covered in the following section, Engineering Evaluation.

IV. ENGINEERING EVALUATION

Cost estimates for a scaleup of the Pitt Mill are given in this section. The results of this scaleup and of the comparison with alternative technologies contain considerable uncertainty for several reasons. First, the largest Pitt Mill built and operated to date is the 5 horsepower prototype unit. Therefore, estimates for commercial scale equipment based on operating data obtained with the small mill are restricted to the conceptual level, whereas equipment costs for the comparison technologies are quotes on actual sales prices. Secondly, important information about the comparison technologies, such as consumption of grinding media, is not available. Because of this, it has been necessary to approximate some of this information based on measurements made in the Pitt Mill. In making these approximations, we assume that information developed in the Pitt Mill can be extrapolated to other mills without serious error. This approach may be acceptable for batch attritors where the mill operation is similar to that of the Pitt Mill but can be questioned when applied to high energy density fine grinding mills where the media dispersion differs from that employed in vertical mills.

In order to address the cost of building a 1 TPH Pitt Mill, the Kennedy Van Saun Corporation of Danville, PA, was engaged to prepare a conceptual level evaluation of the Pitt Mill based on the results obtained in laboratory testing of the 5 horse power prototype mill. The purpose of the evaluation was to have an independent engineering assessment made of the feasibility of scaling up the Pitt Mill.

The KVS evaluation includes a conceptual design and cost estimate of a one (1) ton per hour (TPH) batch operated Pitt Mill and a comparison quote from the Union Process Corporation for a 1 TPH batch attritor. While the conceptual design addresses the obvious issues of manufacture of the Pitt Mill, it does not address issues of mill design optimization. Because of the nature of the work, design issues associated with mill feed and discharge, optimization of mill grinding chamber access, mill maintenance, instrumentation and controls for batch operation, cooling, noise, etc., have not been considered. Additional work with intermediate size mills will be required to finalize aspects of the design not tested in this work before drawings suitable for fabrication of a 1 TPH process demonstration unit could be prepared.

Using the information supplied by Kennedy Van Saun, ETCi has estimated the cost to operate a 1 TPH Pitt Mill. ETCi has also estimated the cost to operate a two stage circuit employing a ball mill and a commercial scaleup of the Netzsch disc mill used in the comparison grinding work.

The results of the engineering evaluation and the cost comparisons are reported in this section.

Evaluation of 1 TPH Pitt Mill

KVS Design

Figure IV-1 illustrates the KVS conceptual design of a Pitt Mill scaled to prepare 1 TPH throughput of nominal 10 micron Pittsburgh #8 seam coal. Mill characteristics such as connected horse power, quantity of grinding media, and grinding chamber dimensions are linear scale ups of the 5 horsepower prototype mill. Mill features such as grinding chamber support and shaft removal employed in the KVS design are similar to those of a batch operated attritor supplied by the Union Process Corporation and do not reflect the views of ETCi or the Fort Pitt Machine Company. Cooling is limited to heat removal by product withdrawal as in the 5 HP prototype mill and to heat exchange to ambient air over the mill's surface.

The mill is slightly over eleven feet, four inches tall. It extends approximately 5 feet, eight inches from front to back, allowing for the slurry discharge valve (item #7 of Figure IV-1). The overall width requirement is approximately six feet, ten inches. The minimum floor space requirement is 39 square feet. With space allowance for passage, the floor space requirement is estimated at 13 feet on a side.

The material of construction of both the shell and frame is carbon steel, A-36. The entire mill, including drive motor and gear reduction mechanism, is estimated to weigh 6429 pounds. The static floor loading is 165 pounds per square foot. It is assumed that surge storage for minus 4 mesh feed coal and for product slurry are provided. The installed mill consists of the grinding unit, mounting pad, and a process control box with access to electrical power.

Feed coal input is assumed to be provided by chutes or conveyors and water and dispersant input is provided by pipes (not shown). Product exit in the KVS design is via a slurry discharge valve located just above the top of the quiescent grinding bed (item #7 of Figure IV-1). The exit valve, shown in concept only, is assumed to be solenoid actuated. Slurry removal is by gravity flow. The grinding time is estimated at seventeen (17) minutes to prepare 10 micron mean particle diameter Pittsburgh No. 8 coal of 12.2% to 17% ash and 49 to 60 HGI (see Figure III-13). The operations of discharge of 50% to 60% solids product slurry and feed coal refill are estimated to require three (3) minutes. The process duty cycle, given as the ratio of grinding time to total cycle time, including feed and discharge, is 85%.

The mill is powered by a 100 horse power motor chosen to deliver a power density of 0.025 kW per pound of grinding media. The motor is a TEFC, NEMA design "B," Class "B" insulation, 1.0 service factor, short shaft, 405 TS frame, squirrel cage induction motor operating on 460 volts, 3-phase, 60 Hz. A water cooled Cone drive gear reducer is employed to provide an agitator shaft rotation of 131 RPM which corresponds to an agitator pin tip speed of 5 meters per second. The overall energy efficiency of the reducer and drive is assumed to be 90%.

3000 pounds of 3/16 inch diameter 52100 chrome ball bearing quality steel balls are employed as grinding media. The grinding chamber is scaled to accommodate 160 gallons of slurry. 134 gallons reside in the free space above the grinding bed. Approximately 26 gallons of slurry reside in the void volume of the bed.

In the KVS design means have been provided to access the grinding chamber for cleaning or maintenance by uncoupling the shaft and tilting the chamber via a trunion arrangement, items 5 and 6 of Figure IV-1. This approach is identical to that employed by the Union Process batch operated mill mentioned above.

The shaft and pin sizes were determined from calculations assuming 100 connected horse power and shaft speed of 131 RPM. The pins have been faced with tungsten carbide to provide improved wear characteristics. Where possible, dimensions such as pin diameter and clearances between moving and stationary parts in the grinding chamber have been taken from rules of thumb supplied by Fort Pitt Machine Company.

KVS Cost Estimate

Table IV-I presents the KVS estimates of costs to fabricate a 1 TPH commercial version of a production Pitt Mill.

Table IV-I
Mill Assembly Costs

Item No.	Description	Quantity	<.....Costs (\$).....>			
			Quantity Pounds	Material	Labor	Total
2	Frame Weldment	1 Ea.	1700	\$850	\$3500	\$4350
3	Shell Assembly	1 Ea.	1450	\$2950	\$3960	\$6910
4	Shaft Detail	1 Ea.	530	\$640	\$1376	\$2016
5	Hub Assemblies	2 Ea.	281	\$1060	\$408	\$1468
6	Tilt Arm Weldment	1 Ea.	40	\$50	\$460	\$510
7	Discharge Valve Assy	1 Ea.	75	\$300	\$1355	\$1655
8	Ball Valve Assy	1 Ea.	5	\$250		\$250
9	Motor (100 H.P.)	1 Ea.	1020	\$2945		\$2945
10	Motor Base	1 Ea.	61	\$293		\$293
11	Reducer Cone Drive	1 Ea.	1150	\$5790		\$5790
12	Coupling	1 Ea.	60	\$231		\$231
13	Air Clutch	1 Ea.	131	\$2160		\$2160
14	Sheave	1 Ea.	50	\$360		\$360
15	Belts	1 Set	7	\$175		\$175
16	Motor Starter	1 Ea.		\$2500		\$2500
17	Pins	1 Set		\$2100		\$2100
18	Miscellaneous	1 Lot		\$250		\$250
19	Assembly	1 Lot			\$4200	\$4200
Totals			6560	\$22904	\$15259	\$38163

The following sources were used in developing cost estimates:

Ball Valve	Apollo Price Book
Motor and Base	Reliance Price Book*
Reducer	Falk Price Book**
Coupling	Falk Price Book
Air Clutch	Horton Price Book***
Sheaves and Belt	McMaster Carr
Pins	Fort Pitt Machine Company

* Squirrel Cage induction motor, totally enclosed fan cooled, NEMA Design "B," Class "B" insulation, 1.0 service factor, short shaft, 405 TS frame, horizontally

mounted ball bearings, for operation on 460 volts, 3 phase 60 Hz.

** Reducer Cone drive model WHV 100-7B, Standard Single Reduction, 10" C.D., 10:1 ratio, single extended input and output shaft. Floor mounted, through fin water cooling.

***Air Clutch, Horton DPC-11T, completed with 5" 5V GROVE 10.3" O.D. Sheave, QD Bushing with 2-1/8" bore, soft start air circuit.

Labor costs reflect cost of skilled (\$35 per hour) and unskilled labor (\$32 per hour) for assembly. Three months has been estimated for the time required to assemble the machine.

The cost of the bare 1 TPH Pitt Mill at the manufacturing plant is estimated at \$38,200.

The KVS estimate of engineering hours to develop final production machine design and drawings for manufacture are given in Table IV-II. The cost associated with the engineering given in the table has been developed using \$45 per hour for engineering and \$25 per hour for drafting.

Table IV-II
Cost of Final Design and Fabrication Drawings
for 1 TPH Pitt Mill

	Engineering Hours	Drafting Hours	Cost
General Arrangement	20	40	\$1900
Electrical Schematic and Hardware	10	20	\$950
Shell Detail	20	40	\$1900
Chain Shaft Assy & Details	30	60	\$2850
Tilting Mechanism Details	20	40	\$1900
Discharge Valve Assy & Details	30	60	\$2850
Frame Details	30	60	\$2850
Engineering Layout & Design	80		\$3600
Coordination, Meetings, Etc.	40		\$1800
Drive Re-evaluation	40		\$1800
Others, Guards, Specifications, Etc.	20	40	\$1900
	---	---	-----
Totals	340	360	\$24300

ETCi Cost Estimate

Estimated Costs for 1 Ton Per Hour Production Model Pitt Mill

The commercial price for the 1 TPH Pitt Mill is not known because no units have been sold. It can only be estimated at this time because the mill is still at an early stage of development. The basis for ETCi's estimate of the selling price of a 1 Ton Per Hour (TPH) Pitt Mill is given in this section. The price of the mill includes the KVS estimate of the cost to build the 1 TPH model as shown in Table IV-I above. The estimated selling price includes an allocation of 2% of development costs which have been estimated at \$500,000 and an 8% cost of sales and a 30% profit. The media charge is 3000 pounds of 3/16" diameter 52100 ball bearing quality chrome steel balls. The price is F.O.B. New Kensington, Pennsylvania. Recent quotes for grinding media are given in Table IV-III.

Table IV-III
Grinding Media Costs*
AISI 52100 Chrome Alloy Steel Balls

<u>Size</u>	<u>Price Per Pound</u>
1.5 mm	\$16.26
2 mm	9.12
3 mm	7.13
3/16 inch	4.38
5/16 - 3/8 inch	0.99
Over 1 inch	0.84

*As quoted by Royal Steel Ball Products, Inc., January, 1990, for lots of 2000 to 5000 pounds, F.O.B. Sterling, Illinois.

The estimated selling price of a 1 TPH Pitt Mill is given in Table IV-IV.

Table IV-IV
Selling Price of a 1 TPH Production Model Pitt Mill
With Control Unit

Fabrication Cost	\$38,200
Allocated Cost of Engineering and Development	\$10,000
Profit	\$14,400

Machine Cost	\$62,600
Media Charge*	\$14,500

Cost for 1 TPH Pitt Mill and 3/16 inch Media Charge*	\$77,100
*F.O.B. New Kensington, PA	

The price of the 3/16 inch grinding media has been increased by 10% over the values shown in Table IV-III to account for delivery to New Kensington, PA.

It is to be stressed that the selling price of a Pitt Mill is not known with certainty at this time. The price shown in Table IV-IV is only approximate and has been developed from the KVS estimate of the cost to build a 1 TPH Pitt Mill.

Comparison With Costs of Other Mills

KVS requested quotations from equipment manufacturers for batch attritors for use in preparation of 1 ton per hour of ground coal. The specifications in the request for quotations are given in Appendix D. A response was received from the Union Process Corporation. That response, dated October, 1989, is given in Appendix E.

Cost information is supplied for a second fine grinding circuit which is being tested as part of a fine coal cleaning technology demonstration program jointly funded by the U.S. Department of Energy and the Electric Power Research Institute at the Electric Power Research Institute's Coal Quality Development Center at Homer City, PA. That circuit is listed as "2 Stage Ball Mill/Disc Mill." The second stage disc mill is a Netzsch Model LME 200. Information on the costs of the two stage circuit have been obtained from the Department of Energy and was current in June, 1987.⁶ The cost of pumps required to feed the ball mill product to the fine grinding mill have not been included. The Netzsch mill operated at Homer City employs 2 mm stainless steel shot. The Netzsch Model LME 20 disc mill employed in the comparison grinding work used 3 mm chrome steel grinding media. Since our information on grinding energies has been developed for the 3 mm media, use of this media has been assumed in pricing the cost of media for the 2 Stage circuit. The price of grinding media for the Pitt Mill and for the 2 Stage circuit have been increased by 10% over the prices of Table IV-III to include cost of transportation to the point of mill origin.

⁶Provided by Mr. Thomas J. Feeley III, U.S. Department of Energy, November 8, 1989.

Table IV-V
Comparison of Costs of Fine Grinding Mills

	Pitt Mill	Union Process Batch Attritor Model 200-SL	2 Stage Ball Mill/Disc Mill
Ball Mill			\$89,000
Media Charge			\$7,400**
Fine Grinding Mill	\$62,600	\$74,400	\$89,000
Media Charge	\$14,500*	\$10,700†	\$15,700‡
	-----	-----	-----
	\$77,100	\$85,100	\$201,000

All media F.O.B. point of mill origin.

- * 3000 pounds of 3/16 inch chrome steel balls @ \$4.82/lb.
- † 6000 pounds of 5/16 inch carbon steel balls @ \$1.78/lb.
- ‡ 2000 pounds of 3 mm chrome steel balls @ \$7.84/lb.
- ** 4000 pounds of 1-1/2" and 4000 pounds of 2" steel balls @ \$0.92/lb.

The Pitt Mill employs less media than does the Union Process batch attritor. Even though no grinding test work was done with an attritor, this shallow bed advantage of the Pitt Mill is believed to be due to its unique internal recirculation method.

The second stage Netzsch mill employs less media than does the Pitt Mill. This is because of the use of finer sized grinding media and higher shaft RPM in the Netzsch mill which also grinds finer topsize coal.

Union Process Attritor

The Union Process mill is a single stage vertically oriented batch attritor. The agitator stirs a bed of grinding media which supports its own weight. The tip speed used in the attritor, however, is less than that of the Pitt Mill.

The attritor consists of a stainless steel grinding tank and carbon steel jacket and a stainless steel agitator shaft with L-shaped tool steel agitator arms. It has a stainless steel discharge valve located on the bottom of the tank. The unit includes a tilting assembly for removal of the agitator shaft for maintenance or cleaning of the tank. The attritor is described in the Union Process literature in Appendix E. A charge of 6000 pounds of 5/16 inch carbon steel grinding media is included. It is assumed that the mill can be fed by minus 4 mesh coal and that it operates with an 85% duty cycle. The mill has a two piece aluminum cover.

The drive specified is a 75 HP, two-speed, T.E.F.C. motor, 460 volts/3 phase/60 cycles with specially engineered 450% starting torque. NEMA 1 wired starters are included. The motor is connected to a 10" Cone drive gear reducer via sheaves and belts.

The pumping system employs an air-operated diaphragm pump, with cast iron housing and Neoprene diaphragms and balls. All necessary plumbing is included.

Coal with an HGI of 50 was ground at the University of Utah using an Attritor. The results of that work, taken from Union Process Literature are shown in Figure IV-2. The data indicate that wet grinding of coal-oil mixtures is more efficient in an Attritor than in a conventional tumbling ball mill. Approximately 200 kW-h/T was required to reduce 50 HGI Montana Rosebud coal to 10 microns mean particle diameter when grinding at 30% solids in No. 6 fuel oil.

Figure IV-2. Grinding of 50 HGI Montana Rosebud Coal at 30% Solids in No. 6 Fuel Oil in Attritor.

Two Stage Grinding Mills

The 2 Stage mill circuit, designed for 1 ton per hour throughput, employs a ball mill feeding a high intensity fine grinding mill. The first stage is an MPSI 4 foot diameter by 7 foot ball mill grinding nominally 1 ton coal per hour from minus 1/4 inch to 70% below 100 mesh. The mill is driven by a 40 HP motor, rotates at 32 RPM, and employs approximately 4000 pounds of 1-1/2 inch and 4000 pounds of 2 inch steel grinding media. Including media charge, the mill weighs 34,500 pounds and is mounted on a 14-1/2 foot by 8-1/2 foot pad designed for high

⁷Attritor Processing of Coal Dispersions, Union Process, Inc., 1925 Akron-Peninsula Road, Akron, OH 44313.

dynamic load. It stands approximately 7 feet tall. A window screen is placed around the output trommel to assure that the feed to fine grinding mill contains no 2 mm oversize material.

The second stage is a 230 liter Netzsch LME-200 disc mill employing approximately 2000 pounds of 3 mm grinding media. While the mill operating at Homer City employs 2 mm steel shot, the mill used in the comparison grinding test work at Netzsch for this study used 3 mm chrome steel grinding media. The use of 3 mm media is assumed in the cost analysis because grinding energies were measured for the 3 mm media in the grinding comparison work, using a small version of the Netzsch LME 200. The fine grinding mill is energized by a 125 HP motor and is designed for 1 TPH in continuous operation. The design used in the Netzsch mill employs means to separate media and product at the exit end of the mill. The double-walled mill is water cooled. The mill is approximately 105 inches long, 69 inches wide and 69 inches tall. The mill and media is estimated to weigh 7900 pounds. The mill employs a 2 to 3 HP slurry drive pump. Feed to the mill is nominal minus 200 mesh coal.

Table IV-VI compares results of grinding three coals with the ball mill-Netzsch fine grinding mill combination. The range of HGI values shown in the table represent measurements on as-received coal and plant feed size reduced to pass 1/4 inch.

Table IV-VI
Comparison of Grinding Results for Two Stage Grinding Circuit at
Homer City Coal Quality Development Center

	Ohio Pittsburgh #8	Upper Freeport	Illinois #6
Feed Coal HGI	57-61	83	51-57
Product M_v (Microns)	12.8	4.5	14.7

The particle size prepared for the Pittsburgh #8 coal is similar to the results of the comparison grinding work of this study employing a VM 30 mill feeding the LME 20 carried out at the Netzsch laboratories.

The Pitt Mill and the Union Process Attritor are both vertically oriented batch mills whereas the fine grinding mill of the 2 Stage process is a horizontally oriented, high energy density (0.05 kW per pound of grinding media) continuously operating mill.

⁸Private conversations with Mr. Horst Huettenhain and Mr. Michael J. Schaal, Bechtel, Inc.

⁹Bechtel National, Inc., "Advanced Physical Coal Cleaning: Microbubble Flotation," Final Report, U.S. Dept. of Energy Contract No. DE-AC22-85PC81205, Volumes 1 and 2 (September, 1988).

The batch mills are simple in design, have no complex mechanical seals, employ low (.01 kW/lb media, attritor) and intermediate (0.025 kW/lb media, Pitt Mill) energy density, and employ coarse grinding media. The Pitt Mill is even less complex than the Union Process Attritor, however, because of the use of patented internal recirculation means.

It is apparent that the cost of a single stage system is less than that of two stage grinding at this level of comparison. The cost of grinding media is the next largest factor differentiating the mills. Lastly, simple mills such as the Pitt Mill and the Union Process Attritor which have no complex mechanical seals are the least expensive to build at the 1 TPH level for the coal application.

Estimated Installation Costs for Three Mills

As described above, it is assumed that the mills are installed in an operating plant so that feed and product are provided. The installed capital costs are associated with mill purchase, cost of process control instrumentation, and the cost of installing the mill. Capital costs for the three alternative approaches to preparing 10 micron Pittsburgh #8 coal at the rate of 1 TPH are compared in Table IV-VII below.

Table IV-VII
Capital Cost of Three Methods of Coal Grinding

	Pitt Mill	Union/Process Model 200 SL Batch Attritor	2 Stage Ball Mill/ Netzsch LME 200
Mill Purchase Price	\$ 62,600	\$ 74,400	\$178,000
Cost of Grinding Media	\$ 14,500	\$ 10,700	\$ 23,000
Cost of Control Instrumentation	\$ 64,500	\$ 64,500	\$ 64,500
Cost of Mill Installation	\$ 5,000	\$ 5,000	\$ 10,000
	-----	-----	-----
Cost of Installed Mills	\$147,000	\$155,000	\$276,000

Process control is required by and is assumed to be the same for all three mills. Instrumentation has been incorporated which includes automatic sequencing for process feed and product flow control. The method chosen can be used to control multiple batch units or a single continuous mill. The same process control method has been employed for all three mills. A process control unit provided by the K-TRON Corporation of Glassboro, New Jersey, has been used for costing purposes. Details are shown in Appendix F. With this unit, pulverized coal is fed by a K-TRON LWB4-500 Single

Screw Loss-In-Weight Batcher with a 40 cu.ft. conical hopper. Water is fed by a K-TRON Model LLWB4-200 Liquid Loss-In-Weight Batcher with a 200 gallon series 300 stainless steel tank. A wall mounting control panel is provided. The cost of the process controls shown in Table IV-VII is F.O.B. Glassboro, NJ. Literature on the K-TRON unit is attached in Appendix F.

The installation cost includes construction of the mill support pad, electrical wiring, and plumbing. The installation cost for the two stage circuit has been doubled because of the foundation requirement for the MPSI ball mill (34,500 pounds).

Annual Charges

The evaluation of the Pitt Mill is based on laboratory results obtained in grinding 10 tons of three widely differing coals using a 5 HP prototype mill. The evaluation of the Union Process Attritor is based on information supplied by Union Process. Since this does not include energy and media consumption for the Pittsburgh seam test coal, it was decided not to evaluate operating costs for the attritor because of the large uncertainties that would result. The two stage circuit at Homer City is continuous in operation and produced approximately 60 tons of coal during the summer and winter of 1987. Grinding energies and media consumption rates used in the cost comparison for these mills are approximated from results developed in the Pitt Mill test program and in the grinding comparison work. Since the mode of operation of the fine grinding mill in the second stage is fundamentally different from the Pitt Mill, considerable uncertainty can be expected in estimating media losses from Pitt Mill data.

Estimates of annual costs for the Pitt Mill and the 2 Stage Ball Mill have been made using information developed during Pitt Mill grinding of Pittsburgh #8 coal having an HGI ranging from 49 to 64 and an ash level of 17.05%. These estimates are given in Table IV-VIII.

Table IV-VIII

Estimates of Annual Costs to Operate Two Alternative Grinding Circuits to Prepare 10 Micron Pittsburgh #8 Coal of 17.05% Ash

	Pitt Mill	2 Stage Ball Mill/ Netzsch LME 200
Media Consumption	\$ 43,800	\$110,000
Capital Equipment	\$ 28,500	\$ 53,600
Energy	\$ 22,700	\$ 44,900
Labor	\$ 31,300	\$ 31,300
Dispersant	\$ 30,200	\$ 30,200
Maintenance	\$ 13,200	\$ 25,300
	-----	-----
Total Annual Cost	\$170,000	\$295,000

The mills are assumed to operate 24 hours per day for 5 days per week, 48 weeks per year. The on-line factor for the 2 stage continuous mills is 100% and for the Pitt Mill is assumed to be 85%. The annual production of the 2 Stage mill and the Pitt Mill is 5760 short tons, assuming the 2 Stage circuit operates at 1 ton per hour.

Media Consumption

The grinding energies and media wear rates for grinding 17% ash Pittsburgh No. 8 coal to 10 microns mean particle diameter for the Pitt Mill and for a two stage mill are given in Table IV-IX.

Table IV-IX
Comparison of Cost Effects of Energies and Media Loss Rates to Grind Pittsburgh #8 Coal to 10 Micron Mean Particle Size for the Pitt Mill Prototype and the Two Stage Netzsch Mills

		<u>\$/lbs</u>	<u>\$/T</u>
<u>Prototype Mill (3/16" Media)</u>			
Energy (kW-h/T)*	65.7		3.9
Media Loss (lb/T)*	1.57	4.82	7.6
<u>Netzsch VM 30 (10 mm Media)</u>			
Energy (kW-h/T)†	45		2.7
Media Loss (lb/T)‡	0.63	1.09	0.7
<u>Netzsch LME 20 (3 mm Media)</u>			
Energy (kW-h/T)†	84		5.0
Media Loss (lb/T)‡	2.37	7.84	18.6

* 17.05% ash coal

† 12.24% ash coal

‡ Estimated from measurements made using the Pitt Mill

Capital Equipment

It is assumed that the cost of capital equipment for each of the mill arrangements is financed at 11% per year for a period of 8 years. The capital equipment charge shown in Table IV-VIII is the annual payment.

All mills are assumed to use 52100 ball bearing quality chrome steel grinding media. The Pitt Mill uses 3/16 inch balls, the ball mill of the 2 stage circuit employs approximately 4000 pounds of 1-1/2 inch and 4000 pounds of 2 inch balls. The fine grinding mill of the 2 Stage process employs 3 mm diameter media.

Energy

The cost of energy has been calculated at \$0.06 per kW-h.

Labor

A rate of \$15/hour has been used for labor. It is assumed that 20% of labor time is charged to the Pitt Mill. A rate of \$25/hour is used for supervision. 10% of labor time is charged as supervision. A labor fringe benefit rate of 35% and an overhead rate of 15% has been used in calculating the labor charge rate.

Dispersant

The dispersant is consumed at 0.75 Wt.% based on dry coal. It is assumed to cost \$0.35 per pound.

Maintenance

Maintenance has been charged at a rate of 10% of the capital cost of the installed machine, not including the charge of grinding media. For the Pitt Mill this allows for 3 pin set replacements per year (\$5,000), 1 grinding chamber replacement per year (\$5,000), and approximately \$3,000 of added labor.

The annual costs are expressed as dollars per ton of coal ground in Table IV-X.

Table IV-X
Estimates of Costs in Dollars per Ton
to Operate Two Alternative Grinding Circuits to Prepare
10 Micron Pittsburgh No. 8 Coal of 17.05% Ash and 49-64 HGI

	2 Stage Ball Mill/ <u>Pitt Mill Netzsch LME 200</u>	
Media Consumption	\$ 7.6	\$19.2
Machine	\$ 4.9	\$ 9.3
Energy	\$ 3.9	\$ 7.8
Labor	\$ 5.4	\$ 5.4
Dispersant	\$ 5.3	\$ 5.3
Maintenance	\$ 2.3	\$ 4.4
	-----	-----
	\$29	\$51

The cost of grinding with the 1 TPH Pitt Mill by this estimate is approximately \$29 per ton of coal. That cost is strongly affected by the ash level of the coal and by the operating conditions of the Pitt Mill.

The costs of Table IV-X are illustrated in Figure IV-3.

Figure IV-3. Comparison of Grinding Costs for Two Alternative Grinding Methods

It is apparent that consumption of grinding media is a major factor in the cost of fine grinding of coal. The media consumption rate has been estimated for the 2 Stage circuit. Measurements of the actual mill and media consumption rates could have large effects on the cost estimates for these circuits.

Capital equipment is also a major factor in the cost of grinding coal. Clearly, single stage, less energy intensive arrangements are less expensive.

Systematics of Pitt Mill Grinding

The cost comparison with conventional technology developed above assumes that the Pitt Mill is operated at 485 RPM with 3/16 inch chrome steel grinding media. Those conditions do not necessarily result in the lowest operating cost because the comparison does not show the effect of media size and shaft RPM on grinding costs.

Effects of Mill Parameters on Grinding Energy and Grinding Time

In order to illustrate the effects which mill operating conditions can have on grinding costs, calculations of the effects of mill operating conditions and of product particle size are presented in this section. To make these calculations, we have used the results of measurements of the effects of grinding media size,

shaft RPM, and product particle size¹⁰ on the grinding energy, the grinding time, and consumption of grinding media.

Results of these measurements are given in Table IV-XI. The values of media loss, lb/T, have been calculated from measurements of specific loss rates, lb/kW-h, and grinding energies. The particle size dependence of the grinding energy has been determined from measured grinding curves.

Table IV-XI
The Effects of Product Particle Size, Grinding Media Diameter,
and Shaft RPM on Grinding Energy, Grinding Time, and Grinding
Media Wear Loss for the Pitt Mill

		Product Part Size (Microns)								
Media (inches)		<-----3/16----->			<----- 5/16----->			<----- 3/8----->		
RPM		345	485	585	345	485	585	345	485	585
E(kW-h/T)	10	74.9	65.7	62.0	121.1	117.5	136.3	116.4*	179.4	181.3
	15	47.1	36.1	28.5	48.8	63.4	69.5	66.2	71.4	94.7
	20	27.4	19.9	10.2*	29.3	33.9	22.1	44.7	44.2	57.5
Time(Min)	10	19.2	16.9	10.4	28.4	22.2	19.5	35.8*	31.7	25.4
	15	11.2	8.3	4.1	12.2	11.5	9.6	19.8	12.0	12.8
	20	5.6	3.5	0.7*	6.8	5.6	2.6	12.9	7.0	7.5
Loss(lb/T)	10	1.82	1.57	1.52	2.39	2.28	2.54	1.62*	2.67	2.53
	15	1.14	0.87	0.70	0.96	1.23	1.29	0.92	1.06	1.33
	20	0.66	0.48	0.25*	0.58	0.66	0.41	0.62	0.66	0.81

*Impractical

Grinding times less than 3 minutes are probably unrealistic for a mill operating with a 3 minute load and unload time. Because of this, the results of the calculations corresponding to production of a 20 micron product with use of 3/16 inch media and a shaft RPM of 585 are probably unreliable. Similarly, production of 10 micron particles using 3/8 inch media and 345 RPM is probably not practical. Because of this, the data corresponding to these criteria are also not reliable. (See Reference 4.) The operating conditions which are deemed impractical are marked by * in this and the following tables.

As is expected, grinding energy, grinding time, and media loss generally increase as the product particle size is decreased.

¹⁰See Reference 4, Quarterly Technical Progress Report, October 1 - December 31, 1989.

Additionally, grinding energy generally increases with shaft RPM for the coarser product particle sizes for the 5/16 inch and the 3/8 inch grinding media sizes but increases with decreasing shaft RPM when preparing the 10 micron product with the 3/16 and the 5/16 inch media. This latter may be caused by different flow characteristics in the grinding bed for the smaller media.

All of the above factors have an effect on the systematics of grinding with the Pitt Mill.

Effect of Grinding Parameters on Mill Capacity

The process parameters of Table IV-XI have been factored into an estimation of operating costs which includes the effects of grinding time. The grinding time affects the throughput which is proportional to the duty cycle divided by the grinding time. Assuming that the time to load and to unload the mill is constant, the duty cycle, which is the percentage of each cycle in which product is being produced, is related to the grinding time through Eq. (4).

$$\text{Duty cycle \%} = (\text{Grinding time}) / (\text{Grinding time} + \text{dead time}) * 100 \quad (4)$$

The effects of product particle size and of mill operating parameters on duty cycle and annual production, assuming that the mill produces 1 TPH at the 10 micron particle size when employing 3/16 inch media and operating at 485 RPM, are given in Table IV-XII.

Table IV-XII
Duty Cycle and Annual Production of Pitt Mill versus Product Particle Size, Grinding Media Size, and Shaft RPM

Product Part Size (Microns)		<-----3/16----->			<-----5/16----->			<-----3/8----->		
Media (inches)	RPM	345	485	585	345	485	585	345	485	585
Duty (%) Cycle	10	86.5	84.9	77.6	90.4	88.1	86.7	92.3*	91.4	89.4
	15	78.9	73.5	57.7	80.3	79.3	76.2	86.8	80.0	81.0
	20	65.1	53.8	18.9*	69.4	65.1	46.4	81.1	70.0	71.4
Tons/Yr	10	5163	5760	8554	3650	4549	5094	2954*	3303	4036
	15	8072	10144	16144	7541	7905	9097	5027	7642	7255
	20	13328	17634	30979*	11696	13328	20469	7209	11462	10917

*Impractical

To within practical limits, the grinding energy, the grinding time, and the media loss can be decreased by operating at the smallest media size and highest shaft RPM feasible. The

smallest media size practical is determined by topsize of mill feed and final product slurry rheology. The grinding media must be large enough to nip the feed coal. Further, the grinding media has a tendency to be floated out of the grinding bed as the slurry viscosity increases because of particle fineness and concentration, or because of buoyancy forces associated with particle density. If the media is lifted out of the grinding bed, the mill as presently configured is no longer effective. This sets a lower limit on the grinding media employed and hence a practical lower limit on product particle size that can be prepared with the Pitt Mill.

Effect of Grinding Parameters on Operating Costs and Mill Capacity

The effects of product particle size, grinding media size, and of shaft RPM (tip speed) on the cost of coal grinding in the Pitt Mill are given in Table IV-XIII. The effect these parameters on mill throughput is also shown at the bottom of the table.

Within the range of variables studied, the cost of grinding increases as the product particle size is decreased. The lowest cost at any of the three particle sizes is achieved with the use of the 3/16 inch media at the highest shaft RPM, assuming that the product specification can be made.

Table IV-XIII
Effects of Particle Size, Grinding Media Size, and Shaft RPM
on Operating Cost and Average Throughput (TPH) of Pitt Mill

Product Part Size (Microns)		Grinding Cost (\$/Ton)								
		<-----3/16----->			<-----5/16----->			<-----3/8----->		
Media (inches)	RPM	345	485	585	345	485	585	345	485	585
Media	10	8.9	7.6	6.7	2.8	2.6	2.8	1.9*	3.1	2.9
	15	5.1	3.6	2.3	1.0	1.3	1.3	1.0	1.1	1.4
	20	2.4	1.5	0.3*	0.5	0.6	0.2	0.6	0.6	0.7
Capital	10	5.6	4.9	3.0	7.7	6.0	5.3	9.7*	8.6	6.9
	15	3.3	2.4	1.2	3.3	3.1	2.6	5.4	3.2	3.5
	20	1.6	1.0	0.2*	1.8	1.5	0.7	3.5	1.9	2.0
Energy	10	4.6	3.9	3.4	7.7	7.3	8.3	7.6*	11.6	11.5
	15	2.6	1.9	1.2	2.8	3.6	3.7	4.1	4.0	5.4
	20	1.3	0.8	0.1*	1.4	1.6	0.7	2.6	2.2	2.9
Labor	10	6.2	5.4	3.3	9.1	7.1	6.3	11.5*	10.2	8.2
	15	3.6	2.7	1.3	3.9	3.7	3.1	6.4	3.9	4.1
	20	1.8	1.1	0.2*	2.2	1.8	0.8	4.1	2.3	2.4
Disp	10	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
	15	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
	20	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
Maint	10	2.6	2.3	1.4	3.9	3.0	2.6	4.9*	4.3	3.4
	15	1.5	1.1	0.6	1.7	1.6	1.3	2.7	1.6	1.7
	20	0.8	0.5	0.1*	0.9	0.8	0.4	1.8	1.0	1.0
Total	10	33.2	29.5	23.1	36.4	31.3	30.6	40.8*	43.0	38.1
	15	21.4	17.0	11.8	17.9	18.4	17.2	24.7	19.1	21.4
	20	13.1	10.1	6.2*	12.1	11.4	8.1	17.8	13.1	14.4
Throughput (TPH)										
	10	0.9	1.0	1.5	0.6	0.8	0.9	0.5*	0.6	0.7
	15	1.4	1.8	2.8	1.3	1.4	1.6	0.9	1.3	1.3
	20	2.3	3.1	5.4*	2.0	2.3	3.6	1.3	2.0	1.9
RPM		345	485	585	345	485	585	345	485	585
Media (inches)		<-----3/16----->			<-----5/16----->			<-----3/8----->		

It is interesting to speculate that the 20 micron mean particle size product might be made without the use of a dispersant. If that should prove to be true, then the cost to grind the Pittsburgh coal to this size in the Pitt Mill would decrease to less than \$5 per ton.

APPENDIX A

SOUND MEASUREMENTS

OSHA sound measurements were conducted using a Simpson Model 884 Sound Level Meter Type 2. The measurements were made at various distances from the mill. The variation of sound with the distance is illustrated in Table A-I.

Table A-I

Variation in Sound Level with Distance for
a Mixed Size Grinding Media (75% 3/16 inch,
25% 5/16 inch) at a Shaft Speed of 485 RPM

<u>Distance (ft.)</u>	<u>Sound level (dB)</u>
1	96
5	90
10	85

The maximum sound level was found to be at 1 foot from the machine, directly above the slurry chamber. Sound measurements at this point as a function of shaft speed and media size are presented in Table A-II. The slurry concentration during these runs varied from 50% to 60% solids. The main factor determining sound level was media size, with a smaller but noticeable effect of shaft speed.

Table A-II

Effect of Grinding Media Size and Agitator Speed
on the Sound Level

<u>Shaft Speed (rpm)</u>	<u>Media Size (inch)</u>	<u>OSHA Level (dB)</u>	
		<u>1 ft.</u>	<u>5 ft.</u>
345	3/16	103	92
	5/16	108	93
	3/8	112	
485	3/16	104	
	5/16	111	100
	3/8	113	
585	3/16	105	
	5/16	113	

APPENDIX B

EXPERIMENTAL AND PROJECTED VALUES OF GRINDING ENERGY, GRINDING TIME AND MEDIA LOSSES

Experimental and calculated values for grinding energy, grinding time and media loss at different shaft speeds are presented in Tables B-I through B-IV. Lines ended with a ! mark correspond to experimental values. Projections are based on the correlations shown at the bottom of each table, where t is the grinding time required to reduce 25 pounds of dry coal to the mean particle size MV, in microns, and E is the energy in units of kW-h/ton of dry coal required to reach such size. The grinding curves at 250 RPM have not been presented in the quarterly reports but are included here in Tables B-V and B-VI.

Table B-I
Grinding Energy, Grinding Time and Media
Consumption at 250 RPM

Media Size (in)	Mean Particle Size (micron)	Grinding Energy (kW-H/Ton)	Grinding Time (min/25 lb)	Media loss lb/Kw-h	lb/Ton
5/16	11.9	76.2	26.5	0.0234	1.79 !
	11.9	70.7	24.6		1.65
	10.0*	96.7	34.1		2.26
	15.0	47.9	16.5		1.12
	20.0	26.9	8.9		0.63
3/8	12.5	75.4	26.5	0.0189	1.43 !
	12.5	68.3	23.9		1.29
	10.0*	82.2	28.9		1.55
	15.0	56.9	19.8		1.08
	20.0	38.9	13.3		0.74

* Values may have significant error due to extrapolation.
! Experimental values.

GRINDING CURVES.

$$\begin{aligned}
 MV(5/16) &= 8.0 + 22.55 \exp(-0.05924 (30/25) t) & R^2 &= 0.976189 \\
 MV(5/16) &= 8.0 + 23.76 \exp(-0.02566 E) & R^2 &= 0.975980 \\
 MV(3/8) &= 0.0 + 36.08 \exp(-0.03693 (30/25) t) & R^2 &= 0.949620 \\
 MV(3/8) &= 0.0 + 23.76 \exp(-0.01599 E) & R^2 &= 0.951175
 \end{aligned}$$

Table B-II
Grinding Energy, Grinding Time and Media
Consumption at 345 RPM

Media Size (in)	Mean Particle Size (micron)	Grinding Energy (kW-H/Ton)	Grinding Time (min/25 lb)	Media loss	
				lb/Kw-h	lb/Ton
3/16	7.6	114.3	31.3	0.0243	2.78 !
	7.6	93.7	24.6		2.28
	10.0	74.9	19.2		1.82
	15.0	47.1	11.2		1.14
	20.0 *	27.4	5.6		0.66
5/16	10.9	90.5	23.6	0.0197	1.79 !
	10.9	90.0	22.6		1.77
	10.0	121.1	28.4		2.39
	15.0	48.8	12.2		0.96
	20.0	29.3	6.8		0.58
3/8	12.4	93.5	23.6	0.0139	1.43 !
	12.4	84.8	21.4		1.17
	10.0 *	116.4	35.8		1.62
	15.0	66.2	19.8		0.92
	20.0	44.7	12.9		0.62

* Values may have significant error due to extrapolation.
! Experimental values.

GRINDING CURVES.

$$\begin{aligned}
 MV(3/16) &= 0.0 + 26.59 \exp(-0.04248 (30/25) t) & R^2 &= 0.979600 \\
 MV(3/16) &= 0.0 + 29.85 \exp(-0.01460 E) & R^2 &= 0.976251 \\
 \\
 MV(5/16) &= 9.0 + 23.41 \exp(-0.09266 (30/25) t) & R^2 &= 0.997414 \\
 MV(5/16) &= 9.5 + 27.76 \exp(-0.03317 E) & R^2 &= 0.996995 \\
 \\
 MV(3/8) &= 8.0 + 33.09 \exp(-0.07842 (30/25) t) & R^2 &= 0.967743 \\
 MV(3/8) &= 8.0 + 36.63 \exp(-0.02498 E) & R^2 &= 0.970249
 \end{aligned}$$

Table B-III
Grinding Energy, Grinding Time and Media
Consumption at 485 RPM

Media Size (in)	Mean Particle Size (micron)	Grinding Energy (kW-H/Ton)	Grinding Time (min/25 lb)	Media loss	
				lb/Kw-h	lb/Ton
3/16	10.9	65.4	13.4	0.0240	1.57 !
	10.9	58.3	12.2		1.40
	10.0	65.7	16.9		1.57
	15.0	36.1	8.3		0.87
	20.0 *	19.9	3.5		0.48
5/16	10.7	117.9	21.2	0.0194	2.29 !
	10.7	106.8	20.1		2.07
	10.0	117.5	22.2		2.28
	15.0	63.4	11.5		1.23
	20.0	33.9	5.6		0.66
3/8	11.3	134.5	23.4	0.0149	2.00 !
	11.3	119.4	20.7		1.78
	10.0 *	179.4	31.7		2.67
	15.0	71.4	12.0		1.06
	20.0	44.2	7.0		0.66

* Values may have significant error due to extrapolation.
! Experimental values.

GRINDING CURVES.

$$\begin{aligned}
 MV(3/16) &= 6.0 + 19.50 \exp(-0.09364 (30/25) t) & R^2 &= 0.986545 \\
 MV(3/16) &= 6.0 + 24.16 \exp(-0.02737 E) & R^2 &= 0.987068 \\
 \\
 MV(5/16) &= 6.0 + 21.43 \exp(-0.06295 (30/25) t) & R^2 &= 0.850825 \\
 MV(5/16) &= 6.0 + 23.27 \exp(-0.01498 E) & R^2 &= 0.851515 \\
 \\
 MV(3/8) &= 9.6 + 26.26 \exp(-0.11010 (30/25) t) & R^2 &= 0.987790 \\
 MV(3/8) &= 9.6 + 30.13 \exp(-0.02408 E) & R^2 &= 0.988900
 \end{aligned}$$

Table B-IV
Grinding Energy, Grinding Time and Media
Consumption at 585 RPM

Media Size (in)	Mean Particle Size (micron)	Grinding Energy (kW-H/Ton)	Grinding Time (min/25 lb)	Media loss	
				lb/Kw-h	lb/Ton
3/16	8.2	92.8	15.3	0.0246	2.29 !
	8.2	86.7	15.0		2.13
	10.0	62.0	10.4		1.52
	15.0	28.5	4.1		0.70
	20.0 *	10.2	0.7		0.25
5/16	10.0	165.0	23.6	0.0186	3.07 !
	10.0	136.3	19.5		2.54
	15.0	69.5	9.6		1.29
	20.0	22.1	2.6		0.41
3/8	13.0	169.0	23.6	0.0140	2.36 !
	13.0	118.0	16.2		1.65
	10.0 *	181.3	25.4		2.53
	15.0	94.7	12.8		1.33
	20.0	57.5	7.5		0.81

* Values may have significant error due to extrapolation.

! Experimental values.

GRINDING CURVES.

$$\begin{aligned}
 MV(3/16) &= 6.0 + 15.37 \exp(-0.10785 (30/25) t) & R^2 &= 0.987630 \\
 MV(3/16) &= 6.0 + 17.94 \exp(-0.02421 E) & R^2 &= 0.987697 \\
 MV(5/16) &= 0.0 + 22.28 \exp(-0.03431 (30/25) t) & R^2 &= 0.910921 \\
 MV(5/16) &= 0.0 + 22.87 \exp(-0.00606 E) & R^2 &= 0.913980 \\
 MV(3/8) &= 8.0 + 25.31 \exp(-0.08337 (30/25) t) & R^2 &= 0.888417 \\
 MV(3/8) &= 8.0 + 27.59 \exp(-0.01447 E) & R^2 &= 0.888790
 \end{aligned}$$

Table B-V
Grinding curves for Pittsburgh #8 Coal,
at 50% Wt. Solids, 250 RPM, Using 5/16 Inch Media

<u>Grinding Time (min)</u>	<u>Grinding Energy (kW-h/Ton coal)</u>	<u>Mean Particle Size (micron)</u>
9	23.0	20.6
12	30.0	20.1
15	37.0	16.6
18	43.9	16.3
21	50.8	14.3
24	57.8	13.5
27	64.5	12.5

Table B-VI
Grinding Curves for Pittsburgh #8 Coal,
at 50% Wt. Solids, 250 RPM, Using 3/8 Inch Media

<u>Grinding Time (min)</u>	<u>Grinding Energy (kW-h/Ton coal)</u>	<u>Mean Particle Size (micron)</u>
9	22.6	25.8
12	29.8	24.0
15	36.7	20.5
18	43.7	18.6
21	50.6	16.4
24	57.5	13.5
27	64.2	14.5

APPENDIX C

NETZSCH MILLS USED IN THE COMPARISON GRINDING STUDY

Molinox Small Media Mill LME Series Closed Design—Horizontal

LME production size mills are pressurized grinding systems with either a non-clogging Johnson screen, or a rotating ring gap product/media separator. Designed to produce fines from solid particles in any type of solvent or aqueous system, the mills produce high quality dispersions on a continuous basis, with any particle size distribution required.

LME mills utilize the Molinox principle of media agitation with discs that push the grinding media against the product flow, eliminating dead spots in the grinding chamber. The double-walled, water-cooled chamber can be removed without stripping the agitator shaft seal. Dual-action mechanical seal with pressurized and cooled sealing fluid

has a low-pressure and low liquid level switch.

LME mills are capable of processing low to medium viscosities (200 to 60,000 cps), high solids (up to 75%) in some aqueous slurries. They are convertible to the John milling system, up to the 20 liter size.

Molinox Small Media Mill LME Series

Materials of Construction

Chambers—high-chrome, wear-resistant steel

Agitators—high-chrome, wear-resistant steel

Gasketing—PTFE, Viton

Separators—tungsten carbide

Optional Materials

Casted ceramics

Flame-coated ceramics

Flame-coated tungsten carbide

Molded urethanes

Stainless steel

Mechanical Seal

Tungsten carbide

Silicone carbide

Carbon

Chrome steel

Mechanical seals are cartridge type, double-acting pressurized, cooled units with a fail safe internal pump.

Grinding Media

Glass, steel or ceramic between 0.50 and 3.0 mm in diameter

Separators

Johnson Screen with .2, .4, or .8 mm openings

Rotating Ring Gap with .2 to .5 mm fixed slot widths depending on media size

LME 2, 4, 12, 20, 50

LME 100, 200

Mill Type

	LME 2	LME 4	LME 12	LME 20	LME 50	LME 100	LME 200
¹ Grinding Chamber Capacity Gal. (Ltrs.)	0.55 (2.10)	1.10 (4.15)	3.42 (13.0)	6.00 (22.7)	15.6 (59.0)	33.30 (126.0)	61.6 (233.0)
Agitator Drive HP	5	5	20	25	50	75	100
Pump Drive HP	0.75	0.75	1.00	1.50	2.00	2.00	3.00
Agitator Circumferential Speed (Avg.)							
Fixed Ft./Min. (M./Sec.)	—	—	—	1720 (8.72)*	1667 (8.50)*	1782 (9.05)*	1640 (8.32)*
Variable Ft./Min. (M./Sec.)	985-2069 (5.00-10.50)	985-2069 (5.00-10.50)	823-1880 (4.20-9.54)	1004-2294 (5.10-11.63)	—	—	—

¹Less Grinding Media, with Agitator Shaft Installed

*Other fixed speeds are possible with different pulley belt combinations

Dimensional Data In. (Cm.) Approx.

	LME 2	LME 4	LME 12	LME 20	LME 50	LME 100	LME 200
A	40½ (103)	40½ (103)	45½ (116)	49½ (26)	59 (150)	59 (150)	59 (150)
B	67 (170)	67 (170)	71 (180)	63 (60)	79¾ (203)	67 (170)	69 (175)
C	33¾ (86)	37½ (95)	43¾ (111)	59 (50)	75 (191)	90½ (230)	105 (267)
D	16¼ (41)	16¼ (41)	21¾ (55)	23¾ (60)	31½ (80)	67 (170)	69 (175)
Approx. Weight Lbs. (Kg.)	617 (280)	617 (280)	1350 (612)	1433 (650)	3307 (1500)	4409 (2000)	6173 (2800)

Netzsch Incorporated
119 Pickering Way
Exton, PA 19341-1393
215-363-8010, TWX: 510-663-9340

APPENDIX D

KENNEDY VAN SAUN REQUEST FOR QUOTATIONS

TELECOPY MESSAGE

Page 1 of 5
Date Oct. 16, 1989

To: Union Process, Inc. Of: _____

Telefax # 216 / 929 - 3034 Ext. _____

From: KEN BRAME Of: Kennedy Van Saun Corp.

Subject: REQUEST FOR QUOTATION ON A BATCH ATTRITOR, Wet
COAL GRINDING APPLICATION
KVS S.O. # 20007

✓
10-16-89
1140pm

Message:

PLEASE SUPPLY FIRM PRICE ($\pm 10\%$), UNIT WEIGHT,
OUTLINE DIMENSIONS AND HORSEPOWER FOR A BATCH
ATTRITOR TO PRODUCE 1 TPH OF GROUND COAL
SLURRY. THE BATCH ATTRITOR SHOULD BE DESIGNED ON
THE FOLLOWING OPERATING CONDITIONS:

- FEED COAL: PITTSBURGH SEAM, 49-52 HGI
(ATTACHMENT A GIVES THE PROXIMATE
ANALYSIS)
- FEED SIZE: NOMINAL MINUS 4 MESH, APPROXIMATE
60% PASSING 20 MESH
(ATTACHMENT B GIVES A TYPICAL MICRO TRAC
DISTRIBUTION OF THE MINUS 20 MESH
FEED FRACTION)
- FEED SOLIDS: 50% SOLIDS BY WEIGHT
- PRODUCT SIZE: ATTACHMENT C GIVES THE TARGET
PRODUCT SIZE DISTRIBUTION AS MEASURED
BY MICRO TRAC.

Signed Kenneth A. Brame

KENNEDY VAN SAUN CORP.
Danville, Pa. U.S.A. 17821-0500
Telephone # 717/275-3050
Telex # 442-3060
Telecopier # 717/275-6789

Page D-1

TELECOPY MESSAGE

Page 2 of 5
Date Oct. 16, 1989

Message (Cont'd):

IF AT ALL POSSIBLE, PLEASE SUBMIT YOUR QUOTE
ON OR BEFORE OCTOBER 26, 1989.

IF YOU SHOULD HAVE ANY QUESTIONS OR IF YOU
REQUIRE ANY ADDITIONAL INFORMATION, PLEASE DO NOT
HESITATE TO CONTACT ME.

SINCERELY,

Signed

KENNEDY VAN SAUN CORP.
Danville, Pa. U.S.A. 17821-0500
Telephone # 717/275-3050
Telex # 442-3060
Telecopier # 717/275-6789

ATTACHMENT A

Analysis of Pittsburgh Seam Coal

<u>Proximate (Dry)</u>		<u>Mineral Analysis of the Ash</u>	
Ash	15.44	SiO ₂	45.21
Vol		Al ₂ O ₃	23.30
F.C.		TiO ₂	1.11
Sulfur	4.90	Fe ₂ O ₃	20.62
Btu	12565	CaO	3.28
		MgO	0.80
<u>Proximate (As Rec.)</u>		Na ₂ O	0.42
Moisture	3.01	K ₂ O	1.49
Ash	14.98	P ₂ O ₅	0.26
Sulfur	4.75	SO ₃	2.72
Btu	12187	SrO	0.10
		BaO	0.04
HGI	49-52	Mn ₂ O ₄	0.02

ATTACHMENT B

4 Mesh Topsiz

59.24%
+ 20 mesh

The graph displays the particle size distribution of a material. The x-axis represents particle size in microns on a logarithmic scale from 0.1 to 1000. The left y-axis represents the cumulative volume percentage from 0 to 100. The right y-axis represents the differential volume percentage from 0 to 25. The differential volume distribution is shown as vertical bars, and the cumulative volume distribution is shown as a smooth curve.

Particle Size (microns)	Differential Volume (%)	Cumulative Volume (%)
2.0	12	1
3.0	15	3
4.0	5	8
5.0	12	13
6.0	12	18
8.0	20	28
10.0	20	38
15.0	23	53
20.0	30	68
30.0	30	83
50.0	35	93
70.0	45	98
100.0	38	100
150.0	34	
200.0	32	
300.0	18	

ATTACHMENT C

PRODUCT COAL

NORMAL		: ch-top 1 pass 1-ch	: summary data
NORMAL or HIGH resolution		: 704.00 100.0 0.0	: dv: 0.0404
		: 497.80 100.0 0.0	: \$10: 2.36
*****		: 352.00 100.0 0.0	: \$50: 7.67
MICROTRAC DATA: MANUAL MODE		: 248.90 100.0 0.0	: \$90: 22.03
pressure 1/present'nl: 422 -		: 176.00 100.0 0.0	: mv: 10.42
27 0.63-704. GRA res: NORMAL		: 124.45 100.0 0.0	: co: 1.169
select bounds: 0.69- 704.00		: 88.00 100.0 0.0	:
progression: standard 8 chans:20		: 62.23 100.0 1.1	: sd: 1.99
sample date/time: 08/30/89 18:16		: 44.00 98.9 2.6	: wa: 5.13
sample ident: 290612		: 31.11 96.3 6.3	*****
sample ID : 11 run composite		: 22.00 90.0 11.0	: parameters
int code:		: 15.56 78.2 14.1	: name value
count 0: printer: OFF		: 11.00 64.2 13.6	: smpl amt
run time: 30 sec. run 0: 100/ 2		: 7.78 50.6 12.3	: dispersnt
sample-preparation code:		: 5.50 38.3 7.5	: disp amt
fee:		: 3.87 30.8 14.8	: disp med
		: 2.75 16.0 12.3	: dmnd amt
		: 1.94 3.7 2.4	: agitator'n
		: 1.38 1.3 1.2	: agit tie
		: 0.97 0.1 0.1	: circul'n
		:	: circ tin
		:	: para0 01
*****		:	: para0 02
[sc-exit] 12-commands :		:	: para0 03

290612
11 run composite
Record Number: 422

QUOTATION

Union Process

1925 Akron-Peninsula Road, Akron, Ohio 44313-4896
Telephone: (216) 929-3333, Telex: 98-6490

QUOTATION NO
620-89 V
DATE
10/30/89
YOUR INQUIRY NO
S.O. No. 20007

QUOTATION TO:

KENNEDY VAN SAUN CORPORATION
Attn: Kenneth Brame
350 Railroad Street
Danville, PA 17821-0500

cc: UNI-REP OF PA - Representative
(215) 647-1118

QUANTITY	DESCRIPTION	PRICE
1	<p>MODEL 200-SL BATCH ATTRITOR</p> <p>Attritor is complete with stainless steel grinding tank and carbon steel jacket, stainless steel agitator shaft with L-shaped tool steel agitator arms. A stainless steel discharge valve and bar grid are located on the tank bottom. A tank tilting assembly facilitates easy removal of the agitator shaft for maintenance or cleaning of the tank. A two-piece aluminum cover is also included.</p> <p>The drive is based on a 75 hp, two-speed, T.E.F.C. motor, 460 volts/3 phase/60 cycles with 450% specially engineered 450% starting torque. NEMA 1 starters and pushbuttons are included and completely wired. The motor is connected to a 10" Cone Drive gear reducer via sheaves and belts.</p> <p>The pumping system is based on a Sandpiper air-operated diaphragm pump, Model SB1-1/2-A, Type SN-4-CI with cast iron housing and Neoprene diaphragms and balls. Includes all necessary plumbing.</p> <p style="text-align: right;">UNIT COST....</p>	\$74,366.00
6,000 lbs	<p>GRINDING MEDIA</p> <p>5/16" Carbon Steel Balls @ \$1.78/lb.</p>	\$10,680.00

TERMS	CANCELLATION CHARGES	FOB	ESTIMATED SHIPPING DATE
30% Down w/Order 40% On Delivery 30% Net 30 Days	<p>A service charge of 1 1/4% per month (18% ANNUAL RATE) will be added to all invoices which are 30 days beyond invoice date.</p> <p>Cancellation Charges: Up to 1 week - no charge Up to 30 days - 15% Up to 60 days - 30% After 60 days - All costs incurred by vendor</p>	Akron, OH	18-20 weeks after receipt of purchase order.

QUOTATION IS VALID UNTIL 30 Days/Date - Media
60 " " - Attritor

BY Vic Herbert
TITLE Eastern Sales Manager

The batch Attritor consists of a jacketed vessel filled with grinding media. Either hot or cold water or low-pressure steam is run through the specially designed jacket for temperature control. Pressurized jackets can be made for ASCM-coded vessels for use with either high-pressure cooling or steam systems. The vessel material is generally constructed of 304 stainless steel but can also be made from AR (abrasion-resistant) steel, or lined with ceramic,

plastic, polyurethane or rubber.

Production-size Attritors are equipped with a built-in pumping system which maintains circulation during grinding for accelerated attrition and uniformity. The pump can also be used for discharging.

ENGINEERING DATA

ATTRITOR MODEL	10-S	15-S	30-S	50-S	100-S*	200-S	400-S
Slurry Capacity (Gallons)	6-8	10-12	23-25	34-38	70-75	140-150	280-300
HP	5-7½	5-7½	10-20	15-25	20-40	40-75	75-150
Floor Space (W x D)	52"x36"	52"x36"	60"x41"	74"x48"	82"x56"	88"x72"	108"x80"

*These specifications apply to all 100-S machines manufactured since 1987 when the machine was redesigned to have a larger capacity.

**Varies according to motor HP

APPENDIX E

UNION PROCESS, INC.

ATTRITOR PROCESSING OF COAL DISPERSIONS

Interest in fine grinds of coal in various suspending liquids has increased dramatically during the past few years because of the potential for reducing oil consumption by substituting the liquid like coal dispersions for oil in industrial and utility power and heat generating systems. Coal dispersions, which include coal oil mixtures (COM), coal water mixtures (CWM) and micronized coal dispersions (MICO), are pumpable composite fuels suitable for use in oil fired boilers and furnaces, with only modest retrofits. A typical COM is a viscous dispersion of 50% coal and 50% No. 6 fuel oil by weight.

Union Process has been actively engaged in research on Attritor comminution of coal and the development of MICO (micronized coal). DOE contracts were awarded to Union Process for the production by Attritor of test MICO dispersions with mean coal particle size in the 1-3 micron range, approximately an order of magnitude smaller than all previously tested coal based slurry fuels. Coarser COM's and CWM's, in which the coal particle size is in the 200 to 325 mesh range (75 to 45 microns), are readily produced by Attritor processing at lower energy consumption than is required for MICO dispersions.

Attritor processing of coal and other minerals accomplishes grinding, dispersing and fine mixing simultaneously in the most economical and efficient way. A recent independent study* has indicated that the Attritor is capable of producing a product of **smaller particle size with less amount of energy input** than conventional ball mills. (see figures below)

Such capabilities, small particle size and low energy input, are of utmost importance in processing large quantities of coal dispersions.

SCHEUREDA and HERBSLE, "A MORE EFFICIENT TECHNOLOGY for the PRODUCTION of FINE and ULTRA FINE COAL OIL MIXTURE FUEL,"
DEPT. of METALLURGY and METALLURGICAL ENGINEERING, UNIV. OF UTAH, MARCH, 1979

Comparison of the effectiveness of conventional tumbling ball milling and attritor milling for the fine grinding of Montana Rosebud coal (Hardgrove Index = 50) at 30% solids by weight in #6 fuel oil

Comparison of the effectiveness of conventional tumbling ball milling and attritor milling for the fine grinding of Lower Freeport coal (Hardgrove Index = 96) at 30% solids by weight in #6 fuel oil

UNION PROCESS INC.

1925 AKRON PENINSULA ROAD AKRON, OHIO 44313
PHONE (216) 929 3333 TELEEX 98 6490

Machinery use and product protected under one or more U.S. and other foreign patents and patent applications.

ATTRITORS — THE MOST ENERGY EFFICIENT GRINDING MILL

The Attritor mill has proven to be most efficient in grinding several kinds of minerals. As an example, a comparison of the effectiveness of various grinding devices for producing ultra-fine products from a Pima chalcopryrite concentrate, has shown that the Attritor is capable of producing the finest product for a fixed specific energy input of all the different devices tested. (Figure below). It can be observed in the Figure that, for energy inputs exceeding 200 (KWH/T) Attritors continue to grind into the submicron range when size reduction in other devices has almost stopped. In addition, in the micron range, the capacity of the Attritor is high relative to the other devices because of the exceptionally high power input per unit volume of vessel which gives a much higher grinding potential. For example, the power input per unit volume of the S-1 Attritor operated under typical conditions is 0.33 KW/gallon compared to a value of 0.016 KW/gallon obtained from a 10 in. diameter by 11.5 in. long tumbling ball mill. As a consequence, time required for grinding in the Attritor is shorter than that required to grind in the ball mill for a fixed specific energy input or to a certain desired median particle size.

Comparison of the effectiveness of various grinding devices for the ultrafine grinding of Pima chalcopryrite concentrate. Herbst and Sepulveda, "Fundamentals of Fine and Ultrafine Grinding in a Stirred Ball Mill, Proc. Powder & Bulk Solids Conf., Chicago, IL., May 1978.

Union Process®
1925 Akron-Peninsula Road, Akron, Ohio 44313
Telephone: (216) 929-3333, Telex: 98-6490, FAX (216) 929-3034

Machinery use and product protected under one or more U.S. and other foreign patents and patent applications

Union PROCESS

PRODUCTION ATTRITORS

UNION PROCESS ATTRITOR TECHNOLOGY.

Attritor technology began as an idea developed by Dr. Andrew Szegvari. That idea grew to become the basis for Union Process, Inc. — and one of the most efficient grinding and dispersing technologies in the world.

Today, Union Process Attritors are used in virtually every industry including the chemical, agricultural, rubber, ceramic, paper coating, metal powder, paint and varnish, printing ink, pharmaceutical, cosmetic, plastic, electronic and confectionery industries.

Union Process Attritors are fast — up to ten times faster than conventional ball mills. They're safe, easy to use and maintain, require minimal space, are quiet and energy efficient with good temperature control. And Attritors produce fine, homogeneous dispersions with a very narrow particle size distribution.

BATCH ATTRITORS FOR WET GRINDING

- Cover seals can be provided for conditions which require grinding in a closed, inert gas system.
- Safe for hazardous operation. With proper precautions, volatile and inflammable materials can be handled safely.
- Equipped with two-speed electric drive — a lower speed for charging and discharging and a higher speed for actual grinding.
- Electrical system can be either standard TEFC (totally enclosed, fan cooled) or explosion-proof. Special voltage requirements can be met.
- Requires minimum floor space. No special foundation is necessary.

Grinding action of the Attritor is achieved in a stationary tank by random motion of the grinding media which are agitated by an internal shaft with arms.

Material is fed into the jacketed grinding tank of the Attritor and ground until the desired dispersion and particle size are achieved. No premixing is necessary because that is accomplished in the grinding tank.

Production Attritors are equipped with a built-in pumping system that maintains circulation during grinding for accelerated attrition and uniformity.

ADVANTAGES

- Ruggedly constructed to last for years. Simplicity of design and operation mean minimum maintenance and practically no down-time.
- Material processed can be inspected continuously and corrections can be made at any time without stopping the machine.
- Grinding tanks are jacketed for temperature control. Cooling or heating can be employed. ASME coded tank is available for use with high-pressure water, oil or steam systems.

with air diaphragm pump and explosion-proof electricals.

ATTRITOR ACTION

The operation of an Attritor is simple and effective. The material to be ground is placed in a stationary tank with the grinding media. Carbon steel, stainless steel, chrome steel, tungsten carbide and ceramic-type balls (3/32" to 3/8") are commonly used media. The material and media are then agitated by a rotating internal shaft with arms. The final result is a fine, even particle dispersion.

ATTRITOR TYPES

Attritors are produced in three types:

- Batch
- Circulation
- Continuous

shown tipped 90° with ceramic-lined tank, plastic-sleeved shaft and arms, air diaphragm pump, and TEFC electricals

with heat exchanger in circulation line, gear pump, and explosion-proof electricals.

with gear pump and explosion-proof electricals.

APPLICATIONS

Batch type Attritors ("S" machines) are being used in industries worldwide including ceramic, glass frit, metal, ferrite, carbide, paper coating, industrial coating, paint, ink, toner, cosmetic, chemical, pharmaceutical, electronic, plastic, rubber, confectionery and many others.

Ideal for long-term, heavy-duty, semi- and fully automated production operations, Attritors are often used in conjunction with programmable controllers in highly sophisticated production environments.

The batch Attritor consists of a jacketed vessel filled with grinding media. Either hot or cold water or low-pressure steam can run through the specially designed jacket for temperature control. Pressurized jackets can be made for ASME-coded vessels for use with either high-pressure cooling or steam systems. The vessel material is generally constructed of 304 stainless steel but can also be made from AR (abrasion-resistant) steel, or lined with ceramic.

plastic, polyurethane or rubber.

Production-size Attritors are equipped with a built-in pumping system which maintains circulation during grinding for accelerated attrition and uniformity. The pump can also be used for discharging.

ENGINEERING DATA

ATTRITOR MODEL	10-S	15-S	30-S	50-S	100-S*	200-S	400-S
Tank Capacity (Gallons)					180	316	600
Slurry Capacity (Gallons)	6-8	10-12	23-25	34-38	70-75	140-150	280-300
Media Volume (Gallons)					70	150	300
HP	5-7 1/2	5-7 1/2	10-20	15-25	20-40	40-75	75-150
Height							
Floor Space (W x D)	52"x36"	52"x36"	60"x41"	74"x48"	82"x56"	88"x72"	108"x80"
Machine Weight (Pounds)					2,575		6,000

*These specifications apply to all 100-S machines manufactured since 1987 when the machine was redesigned to have a larger capacity.

**Varies according to motor HP.

In the batch Attritor, the material is fed into the jacketed tank and is ground until the dispersion and desired particle size are achieved. No premix is necessary as it is accomplished in the grinding chamber. Ingredients can be added at any time. Inspection and formula corrections can be made during the grinding process without stopping the machine.

Batch Attritors can process hard material such as tungsten carbide, titanium carbide and boron carbide. In addition, very viscous slurries with a 30,000 cps can be processed easily.

BATCH ATTRITORS FOR TUNGSTEN CARBIDE

Specially designed to meet the requirements for processing tungsten carbide, this heavy duty batch Attritor includes features such as a tapered tank to reduce load on the bottom arms for easy starting, a special lifter arm to lift media and product off the bottom of the tank, and arms sleeved with tungsten carbide for less wear and contamination.

The tank has a ball discharge valve and chute at the bottom for easy discharge of media. A water cooled cover with a floating teflon seal minimizes solvent loss. The tungsten carbide Attritor is also available with a torque meter to precisely measure energy input for determining process time.

All production Attritors have a worm gear assembly attached to the tank for tilting so that shaft and arms may be readily removed, inspected and the grinding media easily changed if necessary.

with diaphragm pump and explosion-proof electricals.

with AR (abrasion resistant) steel tank, air diaphragm pump, and explosion-proof electricals

ENGINEERING DATA

ATTRITOR MODEL	10-SC	15-SC	30-SC	50-SC	100-SC	200-SC
Tank Capacity (Gallons)	12	20	43	62	115	245
Slurry Capacity (Gallons)	5-6	8-10	18-20	25-28	45-50	100-110
Media Volume (Gallons)	5	9	18	26	47	94
HP	10	15	20	30	50	125
Height	86"	86"	92"	98"	103"	126"
Floor Space (W x D)	59" x 41"	59" x 41"	65" x 46"	72" x 54"	83" x 56"	94" x 72"
Machine Weight (Pounds)	2400	2700	3700	4600	6500	11,600

Dry grinding is achieved in a stationary tank by means of a rotating shaft and arms that agitate the media into a random state of motion or internal porosity called kinematic porosity. In this expanded condition, the media and particles are free to move, collide and impinge upon each other.

KINEMATIC POROSITY

ATTRITORS FOR DRY GRINDING — FOR BATCH OR CONTINUOUS PROCESSING

MEDIA AT REST

EXPANDED MEDIA

Stationary Shaft

Rotating Shaft

SHAFT AND
ARM ROTATION
AGITATES THE
MEDIA INTO
AN EXPANDED
CONDITION

APPLICATIONS

The dry grinding Attritor is used in processing pigment, glass frit, ceramic, metal powder, metal oxide, ferrite, coal, coke, limestone and many others. It is also used for mechanical alloying.

with explosion-proof electricals

ADVANTAGES

- Grinding times are reduced to 1/10th or less than that of a pebble or ball mill
- When used for continuous dry grinding, the batch Attritor can be set up with a continuous feed, with material fed in at the top, passed through the grinding chamber, and continuously discharged out the bottom valve
- Various tank liners and arm sleeves can be used, such as tungsten carbide and various types of ceramic, when metal contamination must be eliminated
- Cover seals can be provided for those conditions which require grinding under a closed inert gas system or for controlling dust

Dry grinding Attritors have been used in both batch and continuous processes. In the continuous process, the material is fed into the vessel at the top, passes through the agitating media bed, and is discharged through the grids at the bottom.

Dry grinding Attritors are also used to make dispersion-strengthened metal (DSM). In this process (known as **mechanical alloying** or cold welding), the kinematic porosity results in the grinding media breaking the metals into small particles and beating them together to form agglomerates. By repeating the process, the various metals are evenly mixed and dispersed to form a new composition of alloy (DSM).

with explosion proof electricals

with screw feed for continuous processing

ENGINEERING DATA

ATTRITOR MODEL	10-SDG	15-SDG	30-SDG	50-SDG	100-SDG	200-SDG
Tank Capacity (Gallons)	16	24	52	75	156	256
Material Capacity, (Gallons)	7	10	23	34	50	100
Media Volume (Gallons)	9	12	25	37	75	150
HP	10-15	15-25	25-60	30-75	60-125	125-150
Height	80"	86"	96"	112"	126"	126"
Footprint (W x D)	52" x 36"	59" x 41"	63" x 44"	74" x 48"	84" x 58"	94" x 64"
Machine Weight (Pounds)	2000	3000	3500/5500	4500/6000	5600/7900	13,000

VARIOUS TYPES OF CERAMIC LININGS ARE AVAILABLE FOR ALL MODELS

For ceramic media, less horsepower is required

The circulation Attritor's high pumping rate results in a faster grind and a narrower particle size distribution. This phenomenon is explained by the principle of preferential grinding. The fast pumping stream through the agitated media bed makes the machine's grinding chamber act as a dynamic sieve or filter, allowing the fines to pass and move quickly through, while the coarser particles follow a more tortuous path through the media bed. The entire contents of the holding tank should pass through the Attritor at least once every 7½ minutes, eight times per hour.

CIRCULATION ATTRITORS

APPLICATIONS

- Coatings, paints, inks
- Ceramic dispersions
- Sulphur dispersions
- Agricultural flowables
- Chemical dispersions
- Paper coatings
- Cocoa liquors
- Dark or milk chocolate
- Confectionery compound coating
- Ferrites
- Metal oxides
- Coal dispersions

The circulation grinding Attritor ("Q" machine) is a combination of an Attritor and a large holding tank which is ten times the size of the Attritor. The Attritor is filled with media and contains grids which restrain the media while the slurry is allowed to pass through.

ADVANTAGES

- Features high pumping rates that result in faster grinds and narrower particle size distribution
- Low power consumption.
- Processes large quantities of material and uses less grinding media
- Allows continuous monitoring of slurry and addition of ingredients to the premix tank at any time during the grinding
- Has a jacketed grinding tank specially designed for temperature control. The holding tank may also be jacketed and act as a heat sump

with explosion-proof electricals.

With a circulation Attritor system, large quantities of material can be handled with a smaller investment of Attritor equipment and grinding media. The slurry can be continuously monitored, additional ingredients can be added to the premix tank at any time during the grinding, and the processing can be controlled precisely.

complete system with stainless steel gear pump, and TEFC electricals.

ENGINEERING DATA

ATTRITOR MODEL	Q-6	Q-25	Q-50	Q-100
Grinding Tank Capacity (Gallons)	8.2	27.5	56	111
Media Volume (Gallons)	7.5	25	50	100
Recommended Holding Tank Capacity (Gallons)	75	250	500	1,000
HP*	7 ¹	25	50	100
Pumping Rate** (Gal./min)	11	35	70	130
Height (A)	71"	96"	116"	124"
Base to Discharge Spout — B	31"	44"	53"	63"
Floor Space (W x D)	24"x36"	32"x44"	41"x58"	54"x81"
Machine Weight (Pounds)	1700	4600	6000	9500

CERAMIC, RUBBER OR POLYURETHANE LININGS ARE AVAILABLE FOR ALL MODELS

*With high density media larger than 3/16", higher horsepower is required

** Pumping rate and RPM are somewhat lower when ceramic grinding media are used

The continuous Attritor system has a tall, narrow, jacketed tank into which a well premixed slurry is pumped through the bottom and discharged at the top. Grids located at both the top and bottom of the machine retain the media.

One prerequisite of the continuous Attritor is that it needs a well mixed, uniform, homogeneous feed. Also a good metering pump is required, such as a gear or Moyno pump.

CONTINUOUS ATTRITORS

Fineness of material processed in a continuous Attritor (C machine) depends on residence or "dwell time," i.e., the length of time the material stays in the grinding chamber.

Dwell time is controlled by the pumping rate. The slower the pumping rate, the longer the dwell time and the finer the grind.

Dwell time is calculated by dividing the void volume by the pumping rate. (Void volume is the entire volume of the tank minus the media and the agitator shaft and arms.)

with torque meter and
explosion proof variable speed drive motor

ADVANTAGES

- For continuous large production
- Fastest grinding and processing
- Excellent temperature control
- Simple and safe to operate
- Low maintenance
- Low power consumption
- Minimum floor space requirements

Capable of processing thousands of gallons of material per hour, continuous Attritors can also be set up in series. By using larger media in the first unit, equipped with grids having larger openings, the system can accept a coarse feed size. Subsequent units then utilize smaller media, resulting in a finer grind.

The continuous Attritor is designed to deliver hours of low cost, maintenance-free operation. The basic model features an open system that does not require an expensive shaft seal. In addition, grids separate the media from the discharge area and the discharge area is covered in order to minimize excessive solvent loss.

Shaft seals can be added to the machine to convert it to a pressurized (closed) system. The shaft seal does not come in contact with the grinding media and as a result lasts longer.

APPLICATIONS

Best suited for the continuous production of large quantities of material, continuous Attritors are currently being used for grinding calcium carbonate and clay slurries in the paper industry. They are also at work producing large quantities of various chemical materials, coal slurries and compound coatings in the confectionery industry.

with TEFC
electricals.

ENGINEERING DATA

ATTRITOR MODEL	C-5	C-10	C-20	C-40	C-100
Grinding Tank (Gallons)	5.9	14	28	51	130
Media Volume (Gallons)	11	23	47	94	112
HP	5	10	25/30	50	125-150
Total Height (A)	11"	12"	14"	18"	160"
Intake Height (B)	11"	12"	17"	17"	18"
Discharge Height (C)	6"	7"	8"	9"	98"
Floor Space (W x D)	20"x40"	50"x40"	52"x52"	58"x60"	67"x60"
Machine Weight (Pounds)	1500	2000	4000	6000	10,000

TECHNICAL SUPPORT

Union Process will survey all your needs, beginning with the initial feed size and final particle size you desire. Chemical and physical properties are also analyzed, and contamination concerns are addressed.

TEST ANALYSIS

You are welcome to attend a laboratory test run, if you wish, to observe or assist.

The results are measured utilizing state-of-the-art instruments and procedures.

You will then receive a lab report that includes all test data, processing recommendations and estimated production rates to meet your needs.

You may then decide to proceed on to a pilot plant evaluation at Union Process where you can manufacture large quantities for test marketing or conduct scale-up tests for production.

GRINDING MEDIA

Union Process carries a full line of all types and sizes of the highest quality grinding media available to meet your particular needs.

The examples shown at right are:

1. 1/8" stainless steel	7. 1/4" high alumina 86% or 95%
2. 3/16" chrome steel	8. 3/16" zirconium oxide
3. 1/4" case-hardened carbon steel	9. 3/16" tungsten carbide
4. 3/16" stainless steel diagonals	10. 3/16" silicon nitride
5. 1/8" mullite	11. 1/8" glass
6. 1/4" ceramic	12. Flintstones

For additional information regarding media types, composition and sizing recommendations, contact Union Process.

NOTE: In addition to media illustrated above, other media are also available including: silicon carbide and high purity zirconium oxide.

CUSTOM DESIGN

All Attritors can be equipped with various accessories and custom designed to your specific needs.

The special 450% starting torque motor can be provided with different voltages such as 380 or 550, and with 50 cycles. Special "quiet" motors with 82 dba rating are also available.

In addition to the standard Viking gear and Sandpiper air diaphragm pumps, we can provide Moyno progressive cavity, lobe or peristaltic pumps to meet specific requirements.

All machines can be equipped with a torque meter to precisely measure the energy expended during grinding. This can be used to monitor conditions in the grinding tank and to establish grinding time.

Various tank linings such as ceramic, food-grade rubber, polyurethane or tefzel are available. Shaft arm sleeves can be of 440C stainless steel, hardened tool steel, Polathane, tungsten carbide, nickel hard-faced, plastic, zirconium oxide, silicon nitride or silicon carbide.

Completely automated systems with actuators on all valves can also be engineered.

1925 Akron-Peninsula Road, Akron, Ohio 44313
Phone: (216) 929-3333 Telex: 98-6490
Fax: (216) 929-3034

APPENDIX F

K-TRON CORPORATION

REPRESENTED BY: D.D. Foster Co., 335 First St., Pittsburgh, PA 15215
(412) 781-2221 FAX: 412-781-8103

October 3, 1989

Fort Pitt Machine Company
809 Alden Drive
Pittsburgh, PA 15220

Attention: John Hagy

Subject: K-TRON Proposal #Q23-9020

Gentlemen:

In accordance with your request, we are pleased to offer our proposal for your review and acceptance.

We have quoted a Model LWB4-500 Single Screw Loss-In-Weight Batcher with a 40 cu.ft. conical hopper for feeding the pulverized coal. On page two of our proposal we've included pricing for the recommended options for this unit.

For feeding the water for the batches we've quoted a Model LLWB4-200 Liquid Loss-In-Weight Batcher with a 200 gal. series 300 stainless steel tank. Our pricing does not include a pump. We have included the gear reducer, speed pick-up, base plate, mounting, guards, hardware and totally enclosed 1-1/2 HP DC motor and drive. The pump is normally supplied by the customer. If you would like, we could furnish the pump with the liquid system, but the cost would have to be added to the price quoted.

We've furnished pricing for a wall mounted control panel if required and page five includes our estimated shipment along with our standard terms and conditions.

The operating temperature limit for the equipment quoted is 32°F-113°F. The equipment should be sheltered from the weather if operated outside and protected from temperatures beyond the limits stated.

We trust our proposal will meet with your approval and that we have correctly interpreted your requirements. If you should have any further questions, please don't hesitate to contact me at your convenience.

Very truly yours,

K-TRON CORPORATION
D. D. Foster Co., Representatives

Bob Polard

Bob Polard

BP/vjf

Enclosures:	275	470
	234	530
	260	600
		601

PAGE 1 OF 5QUOTE NO. Q23-9020**QUOTATION****BATCH DRY FEEDING EQUIPMENT**Item No. 1 Model No. LWB4-500

Description Single Screw Loss-In-Weight Batcher
Refer to specification sheets or material test reports for details of accuracy.

Controller: K-10S
Material: Pulverized Coal
Bulk Density: 93.6 PCF

Material Temperature: 32°F-113°F
Particle Size: Unknown
If Required
Hopper Size: 40 Cu.Ft. Conical
Refill Device: By Customer

Batch Size: 2,000 lbs.
Batch Time: 20 min.; 10 min.
Batch Frequency: 3/hr; 5/hr.

Electrical Class: General Purpose
Electrical Req: 115VAC, 60 Hz, 1 Ø
Shipping Weight (approx.): 1,600 lbs.

QTY: 1 UNIT PRICE: \$ 37,770.00 TOTAL PRICE: \$ 37,770.00

Item No. _____ Model No. _____

Description _____
Refer to specification sheets or material test reports for details of accuracy.

Controller:
Material:
Bulk Density:

Material Temperature:
Particle Size:
If Required
Hopper Size:
Refill Device:

Batch Size:
Batch Time:
Batch Frequency:

Electrical Class:
Electrical Req: VAC, HZ, Ø
Shipping Weight (approx.):

QTY: _____ UNIT PRICE: \$ _____ TOTAL PRICE: \$ _____

K-TRON CORPORATION

PAGE 2 OF 5

QUOTATION

QUOTE NO. Q23-9020

RECOMMENDED OPTIONS FOR DRY

LOSS-IN-WEIGHT EQUIPMENT

ITEM
NUMBER

FLEXIBLE CONNECTIONS - required to isolate the equipment from vibration.
Helps to ensure accurate performance.

INLET FLEX

QUANTITY: 1 UNIT PRICE: \$ 100.00 TOTAL PRICE: \$ 100.00

DISCHARGE FLEX & VENT FLEX

QUANTITY: 1 ea. UNIT PRICE: \$ 70.00 TOTAL PRICE: \$ 140.00

PRESSURE BALANCE DOWNSPOUT - required to isolate discharge tube from pressure differentials at the discharge.

QUANTITY: UNIT PRICE: \$ TOTAL PRICE: \$

ACCESS PORT - required to access inside of feeder/~~hopper~~ for cleanout. Five inch diameter hole with six inch diameter cover plate gasketed and bolted.

QUANTITY: 1 UNIT PRICE: \$ std. TOTAL PRICE \$

PAGE 3 OF 5QUOTE NO. Q23-9020**QUOTATION****BATCH LIQUID FEEDING EQUIPMENT**Item No. 2 Model No. LLWB4-200**Description Liquid Loss-In-Weight Batcher**

Refer to specification sheets or material test reports for details of accuracy.

Controller: **K-10S**
Material: **Water**
Specific Gravity: **1.0**
Viscosity: **Water**Material Temperature: **32°F-113°F**
Discharge Pressure: **Atmos.**
If Required
Tank Size: **200 Gal.**
Refill Device: **By Customer**Batch Size: **240 gal.**
Batch Time: **20 min.; 10 min.**
Batch Frequency: **3/hr.; 6/hr.**Electrical Class: **General Purpose**
Electrical Req: **115VAC, 60 Hz, 1 ϕ**
Shipping Weight (approx.): **Unknown**

Price does not include pump.

QTY: 1UNIT PRICE: \$ 24,400.00TOTAL PRICE: \$ 24,400.00

Item No. _____

Model No. _____

Description _____

Refer to specification sheets or material test reports for details of accuracy.

Controller:
Material:
Specific Gravity:
Viscosity:Material Temperature:
Discharge Pressure:
If Required
Tank Size:
Refill Device:Batch Size:
Batch Time:
Batch Frequency:Electrical Class:
Electrical Req: **VAC, Hz, ϕ**
Shipping Weight (approx.):

QTY: _____

UNIT PRICE: \$ _____

TOTAL PRICE: \$ _____

K-TRON CORPORATION

QUOTATION**CONTROL PANEL****ITEM
NUMBER**

The K-TRON All-Digital Controller can be mounted in a control panel suitable for installation in a control room or remote area.

The control panel would be totally interwired to common terminal blocks for power and cable connections between the feeder and the remotely located panel.

Panel-type recommended: Wall Mount
~~Free Standing~~

For mounting two (2) K-10S Controllers and circuit breakers with the necessary 24 volt transformers.

QUANTITY: 1 UNIT PRICE: \$ 2,340.00 TOTAL PRICE: \$ 2,340.00
F.O.B. PITMAN, N.J.

QUOTATION

Page 5 of 5

Date: October 3, 1989

Customer: Fort Pitt Machine

Quote No: Q23-9020

Estimated Shipment (see Item 12):

14-16 weeks

STANDARD TERMS AND CONDITIONS OF SALE

1. **CONDITIONS OF SALE:** All orders for K-Tron Corporation (hereinafter referred to as "K-Tron") products and services shall be subject to these terms and conditions of sale. No modification of these terms and conditions or any other conditions will be recognized by K-Tron unless specifically agreed to in writing by an authorized representative of K-Tron. The failure of K-Tron to object to provisions contained in any order or other communication from the purchaser shall not be construed as a waiver of these terms and conditions or an acceptance of such provisions.

2. **PURCHASE ORDERS:** Purchase orders must be issued to K-Tron Corporation.

3. **PRICES:** Prices are subject to CHANGE WITHOUT NOTICE. Verbal quotations expire, unless accepted in writing by the purchaser, the same day they are made. Written quotations automatically expire thirty (30) calendar days from the date issued and may be terminated by K-Tron by written notice within that period. Unless indicated in the quotation, prices do not include service or travel expenses of a factory trained serviceman. A purchase order is required for any field start-up or service.

4. **ESCALATION:** a) **EQUIPMENT PRICES - F.O.B. factory price** for equipment is fixed as quoted if shipment is made within three (3) months or within the quoted delivery schedule, whichever is longer, from the date of purchase order. If shipment is not made prior to the aforementioned periods due to delays caused by the purchaser, prices in effect at time of shipment will apply or, if higher, an escalation charge of 1.5% per month, computed from the respective aforementioned periods to the date of delivery, shall be added to the purchase price. b) **CUSTOMER INSPECTION OR ACCEPTANCE TESTING - A per diem charge** of .05% of the purchase order value of the involved equipment or a per diem charge of \$50.00, whichever is greater, will be charged for delays created by the purchaser to scheduled customer inspection or acceptance testing. The charge will be computed commencing two (2) weeks after the purchaser has been notified of a specific date for the inspection or test. Also, if final inspection of equipment is required that includes testing of the equipment with material, a \$250 per diem charge will apply.

5. **TERMS OF PAYMENT:** For purchasers whose credit is acceptable to K-Tron, in K-Tron's absolute discretion, the standard terms of payment are NET WITHIN 30 DAYS from the date of invoice. Progress payments may be required, based on the complexity and/or delivery requirements of the project. Pro rata payments shall become due as shipments are made. If shipment is delayed by the purchaser, payments shall be made based on the price and percentage of completion. If the purchaser defaults in any payment when due, then the full contract price shall immediately become due and payable on demand or K-Tron, at its option, without prejudice to its other lawful remedies, may defer delivery or cancel any order. Products held for the purchaser shall be at the risk and expense of the purchaser and payment shall become due from the date on which K-Tron is prepared to make shipment.

6. **ERRORS:** All clerical errors are subject to correction.

7. **ACCEPTANCE:** No order shall be valid until accepted in writing by K-Tron.

8. **TAXES:** Any manufacturer's tax, use tax, sales tax, or tax or duty of any nature whatsoever, which may be assessed against this order, shall be added to the price quoted or invoiced and shall be paid by the purchaser. In the event K-Tron is required to pay any such tax or duty, the purchaser shall reimburse K-Tron therefor, or in lieu of such payment, shall provide K-Tron at the time the order is submitted, with exemption certificates or other documents acceptable to taxing or customs authorities.

9. **CHANGE ORDERS:** Changes from the original specifications on which an accepted order or proposal is based will not be accepted unless requested in writing and subject to the following conditions: in the event such change increases the cost of any product, including actual component cost and expenses incurred in modifying a partially or completely manufactured product, then such additional expenses shall be added to the original accepted price. This policy will also apply to changes submitted by means of approval drawings.

10. **PENALTIES AND DELAYS:** No penalty clause of any kind, in any specification or order, shall be effective unless specifically approved in writing by K-Tron. K-Tron shall not be liable for any damage caused by delays beyond K-Tron's reasonable control, including, but without limitation to fire, strike, act of the purchaser, restrictions by civil or military authority, acts of God, transportation failures, or inability to obtain labor, materials or manufacturing facilities. In the event of any such delay, the date of delivery shall be extended for a period equal to the time lost by reason of delay.

11. **CANCELLATION:** Any order or contract may be cancelled by the purchaser only upon payment of the reasonable charges based upon expenses already incurred and commitments made by K-Tron. The minimum cancellation charge in any event will be ten percent (10%) of the net sales price.

12. **SHIPMENT:** a) K-Tron products are normally quoted F.O.B. Glassboro. When purchaser requests other than F.O.B. Glassboro, the additional costs will be billed to the purchaser. b) The estimated time to ship is based from the date of receipt of a purchase order or return of approval drawings (if required), and clarification of all technical details, whichever is later.

13. **DAMAGE OR LOSS IN SHIPMENT:** Great care is taken in the packaging of K-Tron products. K-Tron is not responsible for damage or loss in transit and all such claims must be made by the purchaser direct to the carrier. K-Tron will assist insofar as practical in securing satisfactory adjustment of reasonable claims. Claims for shortages or incorrect equipment must be made in writing within thirty (30) days after receipt of the shipment by the purchaser and failure to give K-Tron such written notice within said thirty (30) day period shall be an unqualified acceptance of the equipment and a waiver by the purchaser of any such claims.

14. **RETURNING PRODUCTS:** No K-Tron products are to be returned without first obtaining from K-Tron shipping instructions and a material return authorization. Returned products which K-Tron elects to accept for credit are subject to a minimum handling charge of fifteen percent (15%) of the net sales price in addition to any transportation charges paid by K-Tron. All such products shall be properly packed to reach K-Tron without damage. Any costs incurred by K-Tron to put returned products in first class condition shall be charged to the purchaser.

15. **GARANTEE OF NON-INFRINGEMENT:** K-Tron warrants and guarantees that the purchase or use of K-Tron products will not infringe on any patent issued by the United States of America.

16. **MANUALS:** K-Tron's policy is to supply one (1) instruction-maintenance manual for a single unit and three instruction manuals for a system. (Each manual includes one set of drawings.) Additional manuals are available on an individually quoted basis.

17. **DRAWINGS:** Three copies or one reproducible dimension outline and interconnection drawing are supplied. Additional drawings are available on an individually quoted basis.

18. **WARRANTY:**

**K-TRON WARRANTS ALL K-TRON PRODUCTS AGAINST DEFECTS IN MATERIAL
AND WORKMANSHIP FOR ONE (1) YEAR FROM THE DATE OF SHIPMENT.**

K-Tron warrants that all of its products as manufactured are in good working condition and consist of good quality material. K-Tron will furnish free of charge any part that fails because of defective materials or workmanship within the above stated warranty period. Labor for all required service is chargeable on a Demand Service basis.

This warranty shall be void if the equipment is damaged during shipment, has been altered, subjected to misuse or installed improperly by anyone other than K-Tron's personnel.

K-Tron makes no warranty with respect to components or accessory equipment furnished that is not of its own manufacture. K-Tron agrees to repair or replace all of these components within the limits of the component manufacturer's warranty.

PURCHASER RESPONSIBILITY: All electrical equipment furnished under this contract shall conform to the latest applicable standards of the National Electrical Code as recommended by the National Fire Protection Association. However, when state, county, municipal, or local power company electrical codes may take precedence, it shall be brought to the specific attention of K-Tron for proper consideration. Electrical equipment for use in Canada shall be manufactured under Canadian Standards Association recommendations, but, again, where provincial, municipal, or local power company electrical and safety conditions differ, it must be brought to the specific attention of K-Tron.

K-TRON LIABILITY is limited to the original purchase price of the K-Tron product. The foregoing warranty is in lieu of all other warranties or guarantees expressed or implied and of all other obligations or liabilities on the part of K-Tron, whether in contract or in tort. Under no circumstances will K-Tron be responsible for any consequential or contingent damages due to errors in weighing or failure of the equipment supplied by K-Tron to perform properly.

REPRESENTED BY
D. D. FOSTER COMPANY
 335 FIRST STREET
 PITTSBURGH, PA. 15215
 (412) 781-2221

K-Tron Summary: All-Digital Loss-in-Weight Systems

An increasingly popular method of gravimetrically feeding and batching solid and liquid materials, K-Tron Loss-in-Weight systems deliver high accuracy, provide tailored material handling capabilities and offer total material containment. For feeding or batching bulk solid materials, K-Tron offers fifteen basic Loss-in-Weight models plus a broad choice of Twin Screw, Single Screw and Vibratory metering elements to handle nearly any material at rates from less than 1 lb/hr to over 70,000 lb/hr. Six Liquid Loss-in-Weight models span gravimetric flow rates from less than 1

lb/hr to over 12,000 lb/hr. With K-Tron's exclusive Digital Transmitter load cell and Series 7100 or K-10 Control, all systems are designed to assure highly stable, trouble-free operation. Additionally, all units feature advanced mechanical design, stainless steel material contact surfaces, temperature and vibration insensitivity and rugged construction. For more detailed information on the Loss-in-Weight systems and controls of interest to you, simply request, by number, the corresponding K-Tron Specification Sheet.

Loss-in-Weight System Controllers:

Series 7100 Feeder Control: All-digital CMOS logic design with four-digit setpoint selector for $\pm 0.25-1.0\%$ accuracy dry or liquid flow rate control. LED readout displays setpoint, scale weight, metering element speed, and mass flow. Ten status indicators show operational mode and alarm conditions. Six-digit totalizer accumulates throughput. Request Specification Sheet No. 430.

K-10 Feeder System Control: Designed to program and control an entire feeding system from a single point, K-10 Control is compatible with all

K-Tron loss-in-weight, weigh-belt and volumetric feeders. Up to twelve feeders may be controlled simultaneously from a single K-10. Any system configuration, from one stand-alone to fully coordinated multi-ingredient proportioning systems, is possible.

The centralized programming/display unit, or KDU, consists of a twenty-three key, sealed touchpad with a five-inch CRT display, providing total operator/system interface capability. Supporting feeder electronics, consisting of one control unit and one motor drive unit per feeder, are rack mounted and may be easily isolated from hostile process environments. Compact in design, all the electronics required to support even a sophisticated twelve-feeder system may be accommodated in a single, six-foot control enclosure. Request Specification Sheet 460.

Loss-in-Weight Systems:

Model LW35

Twin Screw: Specially developed to control an extremely broad range of bulk solids including floodable or cohesive powders, dusty, hygroscopic, fibrous, flaked, granular and pelletized materials, durable K-Tron Twin Screw Loss-in-Weight systems offer strong material handling capability and highly accurate gravimetric performance. A choice of six models covers feed rates to 15,000 lb/hr while a selection of paired metering elements tailors the system to meet the demands of the material.

Model	LW20	LW35	LW65	LW65	LW90	LW90
Maximum Hopper Capacity (cu ft)	2	15	25	200	125	200
Feed Rate Range (lb/hr)*	0.25-400	2.3-2,915	31.5-9,500	31.5-9,500	400-15,000	400-15,000
Weigh System Type	platform	platform	platform	suspension	platform	suspension
Specification Sheet No.	200 210	201 211	203	204		

*Based on 50 lb/cu ft and 12 or fewer refills/hr

(continued on back page)

How Loss-In-Weight Works...

While K-Tron's Loss-In-Weight feeders are mechanically simple for improved reliability, the secret to their exceptional performance lies in sophisticated control. To more fully understand the workings and capabilities of K-Tron's Loss-In-Weight systems, refer to the diagram below.

The desired feed rate, represented on the diagram as a series of small steps, is entered on the controller. The slope of the steps is a direct representation of setpoint (i.e., weight of delivered material per unit time). Increasing the setpoint increases the slope, and reducing the setpoint results in a shallower slope. The "steps," magnified for clarity, are in reality so small and exist for such a brief time, the moment-to-moment targeted weight appears to be a smoothly decreasing value. The step-like nature of the setpoint ramp results from the accurate, discrete, digital nature of the control logic.

Beginning at t_0 , note that the feeder's hopper is filled with material since the sensed weight is w_{rc} , the desired weight at refill completion. As the setpoint ramp decreases with time, the actual sensed weight follows the ramp by making frequent comparisons of sensed to desired weight, with required changes in weight being brought about by small changes in metering speed. For example, sensed weight at t_1 is less than the desired weight. Since the feeder has delivered too much material (leaving the system lighter than it should be at t_1), a corrective signal will slow the metering screw so that it delivers material at a lower rate. Similarly, at t_2 , the sensed weight is greater than the desired weight. In this case, the feeder has delivered too little material and is now heavier than it should be at t_2 . The feeder will be commanded to increase its feed rate, bringing it once again onto the setpoint ramp.

When the sensed weight decreases to an adjustable, preset value (w_{rr}), a refill request indication is given, triggering the refill device. When the adjustable, preset refill complete weight level (w_{rc}) has been achieved, command is given to shut down the refill device. If, for some reason, the system ever experiences a condition where the total weight is greater than w_0 , an overrange alarm will be activated, placing the system in volumetric control until the applied weight is brought to a value less than w_0 .

Under ideal weighing and feeding conditions this simple and straightforward approach to feed rate control is fully satisfactory. However, most actual process conditions pre-

sent a less-than-ideal environment for weight measurement. Normal, yet unpredictable disturbances complicating precise weight measurement include in-plant environmental effects such as transmitted vibration from neighboring machinery and equipment, passing vehicles, or even air currents. Bumping the feeder or dropping or lifting extraneous weights onto or from the feeder also contaminates the weight measurement. Vibrational noise is created within the feeder itself, too, as the metering screw and bin agitator rotate. The use of shock mounts and flexible inlet/discharge connections help to lessen many of these effects, but without further refinement to the basic loss-in-weight operating principle, the feeder's performance potential remains limited by the hostility of the application and its environment.

K-Tron has succeeded in developing such a control refinement, resulting in the ability to consistently maintain high gravimetric accuracy even in exceptionally hostile environments.

The conventional approach to loss-in-weight operation necessitates reverting from gravimetric to volumetric control whenever a disturbance of some magnitude is sensed. Return to gravimetric control occurs only after the disturbance has subsided. In noisy environments the feeder can, thus, frequently spend undesirably long periods in volumetric control. K-Tron's advancement, termed dynamic interactive environmental modeling, results in the feeder's ability to extract from each environmentally contaminated weight measurement that portion most nearly representing actual material weight loss. This extraction process is made possible through the mathematical modeling of weight measurement-noise sources both internal and external to the feeder. Each feeder's own unique internal noise signature (which is independent of any external environment) is modeled at the factory. Once the feeder is installed and exposed to the actual process environment, external noise sources are automatically modeled and continually updated, providing the feeder with the means by which it can make informed moment-to-moment adjustments to the measured system weight in light of the ever-changing and "noisy" process environment. Precision performance is now possible in process environments previously thought to be too hostile for accurate weight measurement.

K-10 Feeder System Control

K-10 Control is designed to provide the ultimate freedom in configuring, programming and controlling your K-Tron feeding system. The result is a revolutionary approach possessing unexcelled control capability with the flexibility to meet your current and future needs — all in a convenient, operator-oriented package.

K-10 Feeder System Control provides these and more outstanding features:

- Controls up to twelve feeders simultaneously
- Compatible with all K-Tron loss-in-weight, weigh-belt and volumetric feeders
- Powerful, multi-microprocessor-based operation
- Controls any system configuration from stand-alones to sophisticated multi-ingredient proportioning operations

- Interfaces easily with other process equipment
- Sealed, 23-key touchpad for all programming and operational entries
- Full host/supervisory computer communications capability
- Complete, on-screen system and feeder status reports
- On-screen operator prompts, menus and support text
- Detailed, instant-access system/feeder alarm diagnostics
- Programming security lock-outs
- Compact, rack-mounted feeder electronics with modular circuit boards
- Fully expandable as your needs grow

Series 7100 Individual Loss-in-Weight Feeder Controller

MASS/VOLUMETRIC CONTROL INDICATION — monitors control mode.

OVERRANGE INDICATOR — monitors scale overload conditions. The display flashes and the feeder is automatically placed under Volumetric Control until the overload condition is corrected.

LARGE FOUR-DIGIT LED DISPLAY — for maximum readability. Leading zero suppressed.

CONTROL MODE SELECTOR SWITCH — places feeder into operation in Mass Control or, if ever needed, Volumetric Control.

SETPOINT CONTROL — enables feed rate to be set easily on a four-digit thumbwheel switch.

SIX-DIGIT ELECTROMECHANICAL COUNTER — totalizes material throughput. Blockable reset bar enables counter to be resettable or nonresettable.

LOCAL/RATIO DISPLAY — Indicates if feeder is under Local or Ratio (Remote) Control. Ratio Control allows feeder to accept input from another master setpoint. Local/ Ratio Mode Selector is internal to prevent unintentional switching.

OVER- AND UNDER-FEED ALARM LIGHTS — monitor alarm conditions such as when motor speed or flow rate deviate significantly from setpoint. Display indicates cause of alarm. Programmable delay energizes alarm relay to activate annunciator or system shutdown.

REFILL COMPLETE/REQUEST INDICATORS — monitor hopper contents for manual or automatic refill. Refill REQUEST and COMPLETE weight levels are adjustable to control refill device or provide adequate warning for manual refill.

DISPLAY CONTROL — Indicates setpoint, mass flow and loading in either English or Metric units. Also displays motor speed. Separate function checks do not interrupt feeder operation.

Model LW500 Suspension Scale

Single Screw: K-Tron Single Screw Loss-in-Weight Systems offer both open and closed flight metering elements to gravimetrically control a range of free-flowing, slightly floodable or compacting powders in addition to many pelletized, granular, fibrous or flaked materials. K-Tron's three Single Screw Loss-in-Weight models span a total flow rate range of from 0.15 to over 50,000 lb/hr.

Model	LW200	LW500	LW500
Maximum Hopper Capacity (cu ft)	15	25	200
Feed Rate Range (lb/hr)*	0.15-5,000	15.0-12,000	15.0-51,250
Weight System Type	platform	platform	suspension
Specification Sheet No.	230	233	234

*Based on 50 lb/cu ft and 12 or fewer refills/hr. Consult factory for feed rates to 70,000 lb/hr.

Model LW3-V4/160

Vibratory: For those applications demanding gravimetric control of free-flowing, abrasive or fibrous materials with minimum through-the-feeder degradation, K-Tron Vibratory Loss-in-Weight Systems reliably provide high accuracy at rates from 30 to 8,000 lb/hr. A choice of fully enclosed vibrating cylindrical tubes or rectangular trays enables the system to be tailored to the specific flow characteristics of the process material.

Model	VLW3-15A	VLW3-47A	VLW3-AE
Maximum Hopper Capacity (cu ft)	1	5	5
Maximum Feed Rate (lb/hr)*	290	880	2,850
Specification Sheet No.	270	270	270

*Based on 50 lb/cu ft and 12 or fewer refills/hr.

Model LLW3-20

Liquid: Where liquid materials must be fed or batched gravimetrically rather than volumetrically, K-Tron Liquid Loss-in-Weight systems can provide highly accurate control at rates to over 12,000 lb/hr. The metering element (a pump or control valve usually mounted separate from the weighed supply tank) may be user specified and/or supplied to meet the precise requirements of the material and application. Supply tanks are all stainless steel and are sized to provide the flow rate capacities listed below.

Model	LLW3-10	LLW3-20	LLW3-30	LLW4-55	LLW4-100	LLW4-200
Supply Tank Capacity (gal)	10	20	30	55	100	200
Maximum Feed Rate (lb/hr)*	800	1,600	2,400	4,400	8,000	12,650
Specification Sheet No.	260	260	260	260	260	260

*Based on a specific gravity = 1 and 12 or fewer refills/hr. Minimum rate limited by selected metering device.

K-TRON CORPORATION

Routes 55 and 553, Pitman, NJ 08071; Tel: (609) 589-0500; FAX: (609) 589-8113

K-Tron Model LW500 All-Digital Loss-in-Weight System

suspension scale design

Specifications

FUNCTION: Depending upon controller employed — to provide accurate, high-rate gravimetric flow control of pellets and free-flowing bulk solid materials that tend to compact (feeder), or to provide precise, high-weight batch delivery (batcher).

AVAILABLE METERING SCREWS:

OPEN-FLIGHT SINGLE SCREWS: for free flowing, non-flooding powders; granular, pelletized, fibrous and flaked materials.

CLOSED-FLIGHT SINGLE SCREWS: for free-flowing and slightly floodable or compacting/sticky powders; granular, pelletized, fibrous and flaked materials.

FEED RATES: The average attainable minimum/maximum flow rates (based on 50 lb/cu ft and 15 or fewer refills/hr) and maximum non-crushable particle size for each available metering screw type and pitch are given in the table below. Specific flow rate range depends upon selected gear reduction.

Screw Type	Min Rate* (lb/hr)	Max Rate* (lb/hr)	Particle Size** (in)
65mm Open Flight (P1)	30	4000	0.35
65mm Open Flight (P2)	15	2750	0.35
65mm Closed Flight (P1)	30	4000	0.35
65mm Closed Flight (P2)	15	2750	0.35
100mm Open Flight (P1)	110	15250	0.55
100mm Open Flight (P2)	55	7500	0.55
100mm Closed Flight (P1)	110	15250	0.55
100mm Closed Flight (P2)	55	7500	0.55
150mm Open Flight (P1)	380	51250	0.80
150mm Open Flight (P2)	190	25250	0.80
150mm Closed Flight (P1)	380	51250	0.80
150mm Closed Flight (P2)	190	25250	0.80

*Values are based on materials with relatively uniform flow characteristics; therefore, stated feed rates fall approximately halfway between those obtained on cohesive and floodable materials. Values can vary noticeably depending on the material flow properties, particle size and head pressure.

**The dimension at which 80% of friable particles of the stated size will pass through the metering device without crushing or degradation.

DESIGN ACCURACY: FEEDER REPEATABILITY: ± 0.25 to 1% of sample average (depending upon material characteristics) at 2 Sigma based on thirty consecutive samples taken over one minute, thirty screw revolutions, or 1% of net supply hopper capacity, whichever is greater.
FEEDER LINEARITY: $\pm 0.25\%$ of set rate based on ten con-

secutive samples taken over one minute, thirty screw revolutions or 1% of net supply hopper capacity, whichever is greater, over a range of 20:1 from full scale. **BATCHER PRECISION:** ± 0.1 to 1% of batch size depending on material characteristics and cycle time selected.

TURNDOWN: 20:1 from full scale.

DESIGN STABILITY: With a properly maintained unit, the above design accuracies reflect long-term performance and include hopper refill cycles.

DUAL LOAD CELLS: Exclusive, patented Digital Mass Transmitters meet the performance requirements of the U.S. National Bureau of Standards' Handbook No. 44 and have been certified by the governments of Switzerland and West Germany as attaining the following performance: $\pm 0.003\%$ repeatability, $\pm 0.03\%$ linearity, $\pm 0.03\%$ stability over an 18-month period, and 0.0005 inches full scale deflection. Full five-year warranty from date of shipment.

 

KTRON

ELECTRICAL OPTIONS: Intrinsically safe design to meet Division 1, Class I, Group D and Class II, Groups E, F & G (see Specification Sheet No. 501); Chemical duty motors for washdown service; 50Hz operation.

Covered by Patents in U.S.A. and Foreign Countries. Specifications Subject to Change Without Notice. Printed in U.S.A.

K-Tron Model LLW All-Digital Liquid Loss-in-Weight System

Specifications

FUNCTION: Depending upon controller employed — to provide accurate gravimetric flow control of liquids (feeder), or to provide precise batch delivery (batcher).

METERING DEVICE: Pump or control valve dependent upon application.

FEED RATES: The average attainable maximum flow rates (based on a specific gravity = 1 and 12 or fewer refills/hr) along with available tank capacities are given in the table below. Minimum rates are limited by the selected metering device.

Model	Tank Capacity (gal)	Max Rate (lb/hr)	Max Rate (gal/hr)
LLW3 10	10	800	96
LLW3 20	20	1600	192
LLW3 30	30	2400	288
LLW4 55	55	4400	528
LLW4 100	100	8000	960
LLW4-200	200	12650	1518

DESIGN ACCURACY: FEEDER REPEATABILITY: ± 0.25 to 1% of sample average (depending upon material characteristics) at 2 Sigma based on thirty consecutive samples taken over one minute or 1% of net supply tank capacity, whichever is greater. FEEDER LINEARITY: $\pm 0.25\%$ of set rate based on ten consecutive samples taken over one minute or 1% of net supply tank capacity, whichever is greater, over a range of 10:1 from full scale. BATCHER PRECISION: ± 0.1 to 1% of batch size depending on material characteristics and cycle time selected.

TURNDOWN: 10:1 from full scale.

DESIGN STABILITY: With a properly maintained unit, the above design accuracies reflect long-term performance and include hopper refill cycles.

LOAD CELL: Exclusive, patented Digital Mass Transmitter meets the performance requirements of the U.S. National Bureau of Standards Handbook No. 44 and has been certified by the governments of Switzerland and West Germany as attaining the following performance: $\pm 0.003\%$ repeatability, $\pm 0.03\%$ linearity, $\pm 0.03\%$ stability over an 18 month period, and 0.0005 inches full scale deflection. Full five year warranty from date of shipment.

WEIGH-BRIDGE: Enclosed, fully accessible, dust-tight and splash-proof, damped lever system with low deflection to avoid hysteresis. Available in net ranges of 66, 132, 330, 660 and 1320 lb.

CONTROL: For multi-feeder systems: Model K-10 Feeder System Control. For individual feeders: Model 7100 All-Digital Loss-in-Weight Feeder Controller or Model 7110 All-Digital Loss-in-Weight Feeder Controller.

STANDARD SUPPLY TANKS: 10, 20, 30, 55, 100 and 200 gal capacity.

REFILL: Manual or automatic. Control indication is given for refill required and refill complete status.

MATERIALS OF CONSTRUCTION: Material contact surfaces: Series 300 stainless steel, matte finish. Non-contact surfaces: mild steel, Polane polyurethane paint. Gaskets/Seals: neoprene, Viton, Buna N. Unit is designed for quick disassembly.

TEMPERATURE LIMITS: Ambient: 32°F to 120°F. Process material: 0°F to 150°F.

ELECTRICAL POWER REQUIREMENTS: For 115V supply: 105-125VAC @ 60/50Hz. For 230V supply: 210-250VAC @ 60/50Hz. Single phase. Power consumption dependent upon metering device.

PUMP/CONTROL VALVE DRIVE: Dependent upon application.

APPROXIMATE SHIPPING WEIGHT: Dependent upon application.

MECHANICAL OPTIONS: Flexible connections for inlet and vent; tank access ports; immersion heaters; tank insulation; sanitary construction; high-temperature option (150°F to 250°F); low-temperature option (-10°F to 32°F).

ELECTRICAL OPTIONS: Intrinsically safe design to meet Division 1, Class I, Group D and Class II, Groups E, F & G (see Specification Sheet No. 501); Chemical duty motors for washdown service.

NOT TO BE USED AS A CERTIFIED PRINT

MODEL	TANK	A	B	C	D	E	F
LLWF 3 LLWB 3	10 GAL	457 (18.0)	222 (8.75)	63.5 (2.5)	590.6 (23.25)	114.3 (4.5)	962 (37.87)
	20 GAL	457 (18.0)	432 (17.0)	63.5 (2.5)	800 (31.5)	114.3 (4.5)	1171 (46.12)
	30 GAL	457 (18.0)	800 (31.50)	63.5 (2.5)	1188.4 (46.0)	114.3 (4.5)	1540 (60.62)
LLWF 4 LLWB 4	55 GAL	609.6 (24.0)	800 (31.5)	89 (3.5)	1194 (47.0)	152.4 (6.0)	1394 (62.75)
	100 GAL	762 (30.0)	908 (35.75)	101.6 (4.0)	1314.5 (51.75)	190.5 (7.5)	1715 (67.5)
	200 GAL	914.4 (36.0)	1117.6 (44.0)	127 (5.0)	1549.4 (61.0)	228.6 (9.0)	1249 (78.75)

K-Tron Model LLW All-Digital
Liquid Loss-In-Weight System

KTR·N

Routes 55 and 553, Pitman, NJ 08071; Tel: (609) 589-0500; TLX: 83-1675

REPRESENTED BY
D. D. FOSTER COMPANY
 335 FIRST STREET
 PITTSBURGH, PA 15215
 (412) 781-2221

K-Tron K-10S Individual Feeder Controller

Specifications

FUNCTION: Depending on the control algorithm specified, to provide precise and reliable all-digital, single-ingredient control for continuous or batch weigh-belt or loss-in-weight feeding applications, as well as PID for volumetric or other applications. K-10S may be used for dedicated feeder control or, when used with K-Tron's K-10 Feeder System Control, for dedicated display.

MAIN FEATURES:

- High-performance, microprocessor-based design with reliable CMOS components and LSI technology
- Field-proven, state-of-the-art control algorithms
- Compatible with all K-Tron Weigh-Belt, Loss-In-Weight and Volumetric Feeders
- Continuous or batch operation of gravimetric feeders
- Three user-selectable control modes to accommodate any system configuration
- Backlit, scrolling, 4 line by 20-character, high-visibility, super-twist LCD matrix display
- Simple to use, 23 key, sealed touchpad
- Dedicated LED status indicators for monitoring convenience
- Complete alarm monitoring capabilities
- Compact, modular, fully integrated construction with on board power supply
- Communicates with host computer and K-Tron K-10 Feeder System Control
- Self diagnostics
- Fast random access to programming variables
- AC or DC operation

CONTROL ALGORITHMS: Select from five available modular control algorithms to suit your specific feeding need. Each field-proven algorithm is fully featured and compatible with all K-Tron feeder models within its indicated equipment class:

- WBF — weigh-belt continuous feeding (for all weigh-belts)
 WBB — weigh-belt batch feeding (for all weigh-belts)
 LWF — loss-in-weight, continuous feeding (for single screw, twin screw, vibratory and liquid applications)
 LWB — loss-in-weight batch feeding (for single screw, twin screw, vibratory and liquid applications)
 PID — proportional/integral/derivative control (may be used for volumetric feeding or other applications)

CONTROL MODES: A choice of three user-selectable control modes is available to specify the source and form of setpoint or batch size entry:

- LOCAL — setpoint or batch size is entered at the touchpad directly in engineering units
 RATIO — setpoint is entered at the touchpad in percent of an external signal
 DIRECT — setpoint is received as an external 0-10kHz signal

DISPLAY: High-visibility, scrolling, super-twist LCD backlit display with 4 line by 20 character matrix field allows convenient, detailed performance monitoring.

- Line 1 — displays gravimetric or volumetric operation, the selected control mode (local, ratio or direct), special conditions such as loss-in weight rezero or weigh-belt auto zeroing, and finally, at the far right, the control algorithm installed

Line 2 — displays feed rate setpoint or desired batch size as appropriate.

Line 3 — displays all other appropriate display parameters via the scrolling keys

Line 4 — displays the assigned function of the four variable function keys (F1-F4) located beneath the display

Separate operating the programming display modes avoid operator confusion. In the programming mode lines 3 and 4 are used to provide direct random access to all available set-up parameters. All parameter selection and numerical entry is quickly and easily accomplished via the touchpad.

OPERATING DISPLAY PARAMETERS:

ITEM	CONTROL ALGORITHM				
	WBF	WBB	LWF	LWB	PID
Setpoint	X		X		X
Massflow	X	X	X	X	X
Net Weight			X	X	
Drive Command	X	X	X	X	X
Totalizer	X	X	X	X	X
Speed	X	X	X	X	X
Alarm	X	X	X	X	X
Feed Factor			X	X	
Belt Loading	X	X			
Belt Speed	X	X			
Batch Size		X		X	
Batch Del		X		X	
Batch %		X		X	
Batch Count		X		X	

CONTINUOUS STATUS INDICATORS: For ease of monitoring, six dedicated, color-coded LEDs continuously indicate run or stop condition, host computer control, K-10 Feeder System Control, alarm presence and display mode.

NOT TO BE USED AS A CERTIFIED PRINT

NOTES:

1. WHEN DISPLAY UNITS ARE MOUNTED ONE ABOVE THE OTHER OR SIDE TO SIDE, A MIN SPACE OF 76 (3.00) IS REQUIRED FOR PROPER COOLING.
2. PANEL CUTOUT: 117 x 117 (4.62 x 4.62)

K-10S Individual
Feeder Controller

KTR·N

TOUCHPAD: Twenty three key front panel with special overlay to withstand industrial chemicals. Key domes are stainless steel on gold plated pads and are rated for 500,000 strokes. Front panel is rated NEMA 4.

ALARMS: Alarm conditions immediately illuminate the alarm LED status indicator. Upon expiration of the programmable alarm delay, the indicator blinks and the alarm relay drops out. Display line 2 begins to alternate the setpoint (or batch size, as appropriate) with an alarm description. Function keys f3 and f4 are used to acknowledge or clear the alarm as desired. All alarm limits are user programmable.

AVAILABLE INPUTS: Run enable/inhibit command input, external ratio/remote setpoint, local/remote control, gravimetric/volumetric operation, alarm shutdown command.

AVAILABLE OUTPUTS: All operating display parameters plus others depending on control algorithm. Consult factory for complete listing.

LOGIC OUTPUTS: All relay outputs rated for 10 amps @ 250VAC. Open collector bit outputs: 12V @ 250ma max.

OPERATING/STORAGE TEMPERATURE LIMITS: 32-113°F (0-45°C)/11-131°F (-10-55°C)

HUMIDITY RANGE: 0-90% non-condensing

INPUT VOLTAGE: 24VDC nominal (21-27VDC range) or 24VAC @ 47-63Hz nominal (20-40VAC range)

HOST INTERFACING: To K-10 Feeder System Control: RS485 9-bit protocol @ 2400 baud; to host computer: via 8 bit protocol serial link.

Routes 55 and 553, Pitman, NJ 08071; Tel: (609) 589-0500; FAX: (609) 589-8113

K-Tron Model LLW All-Digital Liquid Loss-in-Weight System

Specifications

FUNCTION: Depending upon controller employed — to provide accurate gravimetric flow control of liquids (feeder), or to provide precise batch delivery (batcher).

METERING DEVICE: Pump or control valve dependent upon application.

FEED RATES: The average attainable maximum flow rates (based on a specific gravity = 1 and 12 or fewer refills/hr) along with available tank capacities are given in the table below. Minimum rates are limited by the selected metering device.

Model	Tank Capacity (gal)	Max Rate (lb/hr)	Max Rate (gal/hr)
LLW3 10	10	800	96
LLW3 20	20	1600	192
LLW3-30	30	2400	288
LLW4 55	55	4400	528
LLW4-100	100	8000	960
LLW4 200	200	12650	1518

DESIGN ACCURACY: FEEDER REPEATABILITY: ± 0.25 to 1% of sample average (depending upon material characteristics) at 2 Sigma based on thirty consecutive samples taken over one minute or 1% of net supply tank capacity, whichever is greater. FEEDER LINEARITY: $\pm 0.25\%$ of set rate based on ten consecutive samples taken over one minute or 1% of net supply tank capacity, whichever is greater, over a range of 10:1 from full scale. BATCHER PRECISION: ± 0.1 to 1% of batch size depending on material characteristics and cycle time selected.

TURNDOWN: 10:1 from full scale.

DESIGN STABILITY: With a properly maintained unit, the above design accuracies reflect long-term performance and include hopper refill cycles.

LOAD CELL: Exclusive, patented Digital Mass Transmitter meets the performance requirements of the U.S. National Bureau of Standards' Handbook No. 44 and has been certified by the governments of Switzerland and West Germany as attaining the following performance: $\pm 0.003\%$ repeatability, $\pm 0.03\%$ linearity, $\pm 0.03\%$ stability over an 18 month period, and 0.0005 inches full scale deflection. Full five-year warranty from date of shipment.

WEIGH-BRIDGE: Enclosed, fully accessible, dust-tight and splash-proof, damped lever system with low deflection to avoid hysteresis. Available in net ranges of 66, 132, 330, 660 and 1320 lb.

CONTROL: For multi-feeder systems: Model K-10 Feeder System Control. For individual feeders: Model 7100 All-Digital Loss-In-Weight Feeder Controller or Model 7110 All-Digital Loss-In-Weight Feeder Controller.

STANDARD SUPPLY TANKS: 10, 20, 30, 55, 100 and 200 gal capacity.

REFILL: Manual or automatic. Control indication is given for refill required and refill complete status.

MATERIALS OF CONSTRUCTION: Material contact surfaces: Series 300 stainless steel, matte finish. Non-contact surfaces: mild steel, Polane polyurethane paint. Gaskets/Seals: neoprene, Viton, Buna N. Unit is designed for quick disassembly.

TEMPERATURE LIMITS: Ambient: 32°F to 120°F. Process material: 0°F to 150°F.

ELECTRICAL POWER REQUIREMENTS: For 115V supply: 105-125VAC @ 60/50Hz. For 230V supply: 210-250VAC @ 60/50Hz. Single phase. Power consumption dependent upon metering device.

PUMP/CONTROL VALVE DRIVE: Dependent upon application.

APPROXIMATE SHIPPING WEIGHT: Dependent upon application.

MECHANICAL OPTIONS: Flexible connections for inlet and vent; tank access ports; immersion heaters; tank insulation; sanitary construction; high-temperature option (150°F to 250°F); low-temperature option (-10°F to 32°F).

ELECTRICAL OPTIONS: Intrinsically safe design to meet Division I, Class I, Group D and Class II, Groups E, F & G (see Specification Sheet No. 501); Chemical duty motors for washdown service.

NOT TO BE USED AS A CERTIFIED PRINT

MODEL	TANK	A	B	C	D	E	F
LLWF 3 LLWB 3	10 GAL	457 (18.0)	222 (8.75)	63.5 (2.5)	590.6 (23.25)	114.3 (4.5)	962 (37.87)
	20 GAL	457 (18.0)	432 (17.0)	63.5 (2.5)	800 (31.5)	114.3 (4.5)	1171 (46.12)
	30 GAL	457 (18.0)	800 (31.50)	63.5 (2.5)	1168.4 (46.0)	114.3 (4.5)	1540 (60.62)
LLWF 4 LLWB 4	55 GAL	609.6 (24.0)	800 (31.5)	89 (3.5)	1194 (47.0)	152.4 (6.0)	1594 (62.75)
	100 GAL	762 (30.0)	908 (35.75)	101.6 (4.0)	1314.5 (51.75)	190.5 (7.5)	1715 (67.5)
	200 GAL	914.4 (36.0)	1117.6 (44.0)	127 (5.0)	1549.4 (61.0)	228.6 (9.0)	1949 (76.75)

K-Tron Model LLW All-Digital
Liquid Loss-in-Weight System

KTR·N

K-TRON CORPORATION

Routes 55 and 553, Pitman, NJ 08071; Tel: (609) 589-0500; TLX: 83-1675

NOT TO BE USED AS A CERTIFIED PRINT

MODEL	CU FT (DIA)	d	e	f	g	A	B	C	D	F	J	L	M	P
LWF H 4 500	15	15	15	15	15	15	15	15	15	15	15	15	15	15
LWF H 6 500	25	25	25	25	25	25	25	25	25	25	25	25	25	25

K-Tron Model LW500 All-Digital Loss In-Weight System Suspension Scale Design

WEIGH-BRIDGE: Enclosed, fully accessible, dust-tight and splash proof, damped lever system with low deflection to avoid hysteresis. Available gross ranges of 1320, 2640, 4400 and 8800 lb.

CONTROL: Model 7100 or Model 7110 All-Digital Loss-In-Weight Feeder Controller (see Specification Sheet No. 430 or 431). Model 8100 All-Digital Loss-In-Weight Batch Controller (see Specification Sheet No. 441).

STANDARD HOPPERS: 15, 25, 40, 75, 125, or 200 cu ft capacity supply hoppers mate to the unit's agitated or non-agitated bin. The 1.6 cu ft capacity agitated portion of the hopper is integral to the metering device and is self-purging with screw at the bottom.

AGITATOR: Independent motor-driven, four-flight design to prevent bridging/ratholing, and achieve a consistent material density for accurate metering.

REFILL: Manual or automatic. Control indication is given for refill required and refill complete status.

MATERIALS OF CONSTRUCTION: Material contact surfaces: Series 300 stainless steel, matte finish. Non-contact surfaces: mild steel, Polane polyurethane paint. Gaskets/Seals: neoprene, Viton, Buna N. Unit is designed for quick disassembly.

TEMPERATURE LIMITS: Ambient: 32°F to 120°F. Process material: 0°F to 150°F.

ELECTRICAL POWER REQUIREMENTS: For 115V supply: 105-125VAC @ 60Hz. For 230V supply: 210-250VAC @ 60Hz. Single phase. 2100VA power consumption.

MOTORS: Screw drive motor: 3/4hp, 90VDC, TEFC, 1800rpm with armature current feedback controlled by K-Tron patented Digi-Drive® digital servo amplifier and magnetic speed pickup. Agitator drive motor: 1/2hp, 115/230VAC, TEFC, 1725rpm. Meets Division 2, Class II, Groups E, F & G.

APPROXIMATE SHIPPING WEIGHT: 2700 lb.

MECHANICAL OPTIONS: Flexible Inlet, vent and discharge connections; flow aid devices; access doors in hopper; sanitary construction; high-temperature option (150°F to 250°F); low-temperature option (-10°F to 32°F). Unit is also available in a non-agitated configuration as Model LW510 Suspension Scale (reference drawing No. D-0575-00003).

ELECTRICAL OPTIONS: Intrinsically safe design to meet Division 1, Class I, Group D and Class II, Groups E, F & G (see Specification Sheet No. 501); Chemical duty motors for washdown service; 50Hz operation.

K-TRON CORPORATION

20 Warrick Ave., Glassboro, NJ 08028; Tel: (609) 881-6500; TLX: 83-1675
7965 E. Redfield Rd., Scottsdale, AZ 85260; Tel: (602) 998-0343; TLX: 16-5034

K-Tron Model LW500 All-Digital Loss-in-Weight System

suspension scale design

Specifications

FUNCTION: Depending upon controller employed -- to provide accurate, high-rate gravimetric flow control of pellets and free flowing bulk solid materials that tend to compact (feeder), or to provide precise, high-weight batch delivery (batcher).

AVAILABLE METERING SCREWS:

OPEN-FLIGHT SINGLE SCREWS: for free-flowing, non-flooding powders; granular, pelletized, fibrous and flaked materials.

CLOSED-FLIGHT SINGLE SCREWS: for free-flowing and slightly floodable or compacting/sticky powders; granular, pelletized, fibrous and flaked materials.

FEED RATES: The average attainable minimum/maximum flow rates (based on 50 lb/cu ft and 15 or fewer refills/hr) and maximum non-crushable particle size for each available metering screw type and pitch are given in the table below. Specific flow rate range depends upon selected gear reduction.

Screw Type	Min Rate* (lb/hr)	Max Rate* (lb/hr)	Particle Size** (in)
65mm Open Flight (P1)	30	4000	0.35
65mm Open Flight (P2)	15	2750	0.35
65mm Closed Flight (P1)	30	4000	0.35
65mm Closed Flight (P2)	15	2750	0.35
100mm Open Flight (P1)	110	15250	0.55
100mm Open Flight (P2)	55	7500	0.55
100mm Closed Flight (P1)	110	15250	0.55
100mm Closed Flight (P2)	55	7500	0.55
150mm Open Flight (P1)	380	51250	0.80
150mm Open Flight (P2)	190	25250	0.80
150mm Closed Flight (P1)	380	51250	0.80
150mm Closed Flight (P2)	190	25250	0.80

*Values are based on materials with relatively uniform flow characteristics; therefore, stated feed rates fall approximately halfway between those obtained on cohesive and floodable materials. Values can vary noticeably depending on the material flow properties, particle size and head pressure.

**The dimension at which 80% of friable particles of the stated size will pass through the metering device without crushing or degradation.

DESIGN ACCURACY: FEEDER REPEATABILITY: ± 0.25 to 1% of sample average (depending upon material characteristics) at 2 Sigma based on thirty consecutive samples taken over one minute, thirty screw revolutions, or 1% of net supply hopper capacity, whichever is greater.
FEEDER LINEARITY: $\pm 0.25\%$ of set rate based on ten con-

secutive samples taken over one minute, thirty screw revolutions or 1% of net supply hopper capacity, whichever is greater, over a range of 20:1 from full scale. **BATCHER PRECISION:** ± 0.1 to 1% of batch size depending on material characteristics and cycle time selected.

TURNDOWN: 20:1 from full scale.

DESIGN STABILITY: With a properly maintained unit, the above design accuracies reflect long-term performance and include hopper refill cycles.

DUAL LOAD CELLS: Exclusive, patented Digital Mass Transmitters meet the performance requirements of the U.S. National Bureau of Standards' Handbook No. 44 and have been certified by the governments of Switzerland and West Germany as attaining the following performance: $\pm 0.003\%$ repeatability, $\pm 0.03\%$ linearity, $\pm 0.03\%$ stability over an 18-month period, and 0.0005 inches full scale deflection. Full five-year warranty from date of shipment.

Model LW500 Suspension Scale

Single Screw: K-Tron Single Screw Loss-In-Weight Systems offer both open and closed flight metering elements to gravimetrically control a range of free flowing, slightly floodable or compacting powders in addition to many pelletized, granular, fibrous or flaked materials. K-Tron's three Single Screw Loss-In-Weight models span a total flow rate range of from 0.15 to over 50,000 lb/hr.

Model	LW200	LW500	LW500
Maximum Hopper Capacity (cu ft)	15	25	200
Feed Rate Range (lb/hr)*	0.15-5,000	15.0-12,000	15.0-51,250
Weight System Type	platform	platform	suspension
Specification Sheet No.	230	233	234

*Based on 50 lb/cu ft and 12 or fewer refills/hr. Consult factory for feed rates to 70,000 lb/hr.

Model LW3-V4/180

Vibratory: For those applications demanding gravimetric control of free-flowing, abrasive or fibrous materials with minimum through-the-feeder degradation, K-Tron Vibratory Loss-In-Weight Systems reliably provide high accuracy at rates from 30 to 8,000 lb/hr. A choice of fully enclosed vibrating cylindrical tubes or rectangular trays enables the system to be tailored to the specific flow characteristics of the process material.

Model	VLW3-15A	VLW3-47A	VLW3-AE
Maximum Hopper Capacity (cu ft)	1	5	5
Maximum Feed Rate (lb/hr)*	290	880	2,850
Specification Sheet No.	270	270	270

*Based on 50 lb/cu ft and 12 or fewer refills/hr.

Model LLW3-20

Liquid: Where liquid materials must be fed or batched gravimetrically rather than volumetrically, K-Tron Liquid Loss-In-Weight systems can provide highly accurate control at rates to over 12,000 lb/hr. The metering element (a pump or control valve usually mounted separate from the weighed supply tank) may be user specified and/or supplied to meet the precise requirements of the material and application. Supply tanks are all stainless steel and are sized to provide the flow rate capacities listed below.

Model	LLW3-10	LLW3-20	LLW3-30	LLW4-55	LLW4-100	LLW4-200
Supply Tank Capacity (gal)	10	20	30	55	100	200
Maximum Feed Rate (lb/hr)*	800	1,600	2,400	4,400	8,000	12,850
Specification Sheet No.	260	260	260	260	260	260

*Based on a specific gravity = 1 and 12 or fewer refills/hr. Minimum rate limited by selected metering device.

Routes 55 and 553, Pitman, NJ 08071; Tel: (609) 589-0500; FAX: (609) 589-8113

REPRESENTED BY
D. D. FOSTER COMPANY
335 FIRST STREET
PITTSBURGH, PA 15215
(412) 781-2221

K-Tron DFT Digital Force Transducer

PURPOSE: Employed in all K-Tron Weigh Belt and Loss-In-Weight Feeders, the DFT Digital Force Transducer provides accurate, stable and reliable digital weighing under a broad range of operating conditions.

MAIN FEATURES:

- Direct digital weighing
- Excellent repeatability and stability
- High resolution
- Ultra low deflection
- High tolerance to vibration and electrical noise
- Electronic linearization
- Electronic temperature compensation
- Stiff, rugged construction
- No dampers required

PRINCIPLE OF OPERATION: The DFT exploits the dependency of a vibrating wire's resonant frequency on its tension to measure applied loads. Through mechanical means the applied load is transmitted to the wire, causing a change in its resonant frequency from which the value of the applied load may be computed.

Employing the principle of induction the wire is electronically excited to vibrate at its resonant frequency. A magnetic field, provided through the use of permanent magnets, is created across the wire's plane of vibration. (The wire possesses a rectangular cross section to constrain vibration to a single plane.) The wire is electrically conductive and is connected at its ends to an exciter circuit. Through special feedback techniques the exciter circuit simultaneously senses the wire's frequency and produces an alternating current in the wire to maintain resonant vibration, regardless of its frequency value. Because a high vibration frequency is desirable to avoid signal contamination, the wire is pre-stressed and forced to vibrate at its second harmonic (two antinodes) at all times.

The wire's resonant frequency is not a linear function of applied tension but, in practice, is almost parabolic. To calculate the applied load from the sensed frequency, microprocessor-based regression techniques are used. To assure the utmost precision, linearization coefficients for each DFT are individually established at the factory and reside in a plug-in EEPROM.

Of the possible environmental sources of error only temperature variations require compensation. The effects of ambient magnetic fields, changes in atmospheric pressure, relative humidity, etc. have been found to be negligible. To adjust for changes in ambient temperature a thermal sensor is installed within the DFT. Each DFT's thermal response characteristics are determined through testing at manufacture, and appropriate coefficients are registered in the EEPROM for continuous electronic temperature compensation.

REPEATABILITY: $\pm 0.01\%$ of full scale

LINEARITY: $\pm 0.01\%$ of full scale

STABILITY: $\pm 0.03\%$

RESOLUTION: 1,000,000

MAXIMUM LOAD AT DFT: 13.2lb (6.0 Kg)

OPERATING TEMPERATURE RANGE: 14°F to 140°F
(-10°C to 60°C)

STORAGE TEMPERATURE RANGE: -13°F to 178°F
(-25°C to 80°C)

COMPENSATED TEMPERATURE SENSITIVITY: $\pm 0.0006\%/^{\circ}\text{F}$
($\pm 0.001\%/^{\circ}\text{C}$)

VIBRATION SUPPRESSION: 35-40dB at 0.1G from 0-40Hz

SHOCK TOLERANCE: 75G in all directions (without recalibration); 150G in all directions (with recalibration)

SIGNAL TRANSMISSION: differential; 3300ft
(1000m) maximum

CREEP: 0.003% of full scale (20 min at 72 °F (22 °C))

HYSTERESIS: 0.003% max

WARM-UP TIME: zero

POWER CONSUMPTION: 0.2 watt

ENCLOSURE RATING: NEMA 4

WARRANTY: Full five-year warranty from date of shipment

Routes 55 and 553, Pitman, NJ 08071; Tel: (609) 589-0500; TLX: 83-1675

K-Tron Material Test Lab

The justification and design stages of any process system always present the most critical questions. While some of these questions can be answered by estimations and suppositions based upon known facts, others are serious bottlenecks which can jeopardize an entire project.

K-Tron Corporation offers to test process materials to answer critical process questions in areas such as material flow characteristics, storage considerations, bin design and selection of flow aid devices; what effect handling will have on the material and what the best configuration of the feeding equipment is for a particular product or group of products; determining the return on investment by considering the cost of the process material and the benefits of accurately controlling the feed rate of the ingredient into the process.

BASIC TEST PROCEDURE: The K-Tron test program starts with a visual analysis of the process material. From this analysis and previous experience, the equipment configuration is selected. Any potential problems such as material flow are noted and corrective action is taken.

Equipment performance is typically based upon 30 consecutive one-minute catch samples for continuous feeders, or 30 batches for batchers, taken at the stated minimum and maximum operating rates or batch sizes. Based upon the collected data, statements of the linearity and repeatability are generated.

LINEARITY AND REPEATABILITY DEFINED: The linearity of the unit is a measure of the feeder's ability to deliver, on the average, the desired flow rate throughout the unit's full range of operation. Repeatability is a measure of the degree to which the feeder discharges a constant flow of material over short time periods at a given flow rate setting.

MAKING TEST ARRANGEMENTS: All of the details are coordinated through the local K-Tron Sales Representative. He will ask for the following information to insure a successful test:

1. Material name, chemical composition and trade name, if any
2. Material density
3. Unusual properties or known problems
4. Whether degradation or pulverization of the product is helpful or harmful to the process use
5. Whether a single unit will be required to handle multiple materials
6. For continuous feed systems: the minimum and maximum required feed rates. For batch feed systems: the minimum and maximum batch sizes, time to complete a batch, and the frequency of the batch cycle

He will also ask for a material safety data sheet, if available. He will convey this information to the factory and establish possible test dates. The test will be tentatively scheduled on the date the customer selects. All test materials must be received at K-Tron five working days before the assigned test date. If the material is not received in this time period, the test will be cancelled and must be rescheduled.

AMOUNT OF MATERIAL REQUIRED: A minimum of 5 cu ft of material is required to test the following models: W300, LW20, LW35, LW200, T20, T35, and S200. A minimum of 10 cu ft of material is required to test the following models: W600,

LW85, LW500, T65, and S500. 20-40 cu ft of material is required to test the following models: LW90 and T90. Please consult the factory for material amount requirements for Model W1000 and all liquid loss-in-weight feeder applications. After testing is completed, all materials will be returned to the customer, freight collect. Please note that K-Tron cannot guarantee the product will not be degraded or contaminated during testing.

SHIPPING TEST MATERIALS: When the test is scheduled, it will be assigned a test number which must appear on the shipment. Ship materials prepaid to:

K-Tron Corporation
Rt. 55 & 553
Pitman, NJ 08071
Attention: Test Lab
Test No. TXX-XXXX

COSTS INVOLVED: K-Tron offers this service on a no-charge basis, providing the test does not require the purchase or rental of auxiliary equipment. The customer's responsibilities are to provide the process material and incur all shipping charges both to and from the K-Tron plant in Pitman, NJ.

LENGTH OF TIME FOR TESTING: After all pre-test information has been received and evaluated, an estimate of the time

required will be given. As a guideline, tests involving up to three different materials on various equipment configurations can be completed in one day.

The customer's presence for one day is strongly recommended. We suggest arrival on the evening prior to the scheduled date, and departure not before 4:30 p.m. on the day of the test. In planning flight times, allow for a 45-minute ride between K-Tron and the Philadelphia airport.

Below is a typical schedule:

7:30- 8:00am Breakfast meeting at the hotel with
K-Tron sales personnel to discuss
possible concerns
8:00- 8:15am Travel to K-Tron
8:15- 8:30am Review of the equipment configuration
8:30-12:00pm Equipment performance trials
12:00- 1:00pm Lunch
1:00- 3:30pm Equipment performance trials
3:30- 4:30pm Meeting to review the test data and
discuss additional equipment re-
quirements

For directions to the K-Tron plant and other helpful travel information, please ask the Sales Representative for the brochure "Welcome to K-Tron."

Routes 55 and 553, Pittman, NJ 08071; Tel: (609) 589-0500; TLX: 83-1675

REPRESENTED BY
D. D. FOSTER COMPANY
335 FIRST STREET
PITTSBURGH, PA 15215
(412) 781-2221

K-Tron Service, Training and Warranty

Customer Service

Prior to shipment, K-Tron products are carefully checked and all critical adjustment points are factory-marked. Due to the precise and sophisticated nature of the equipment, K-Tron provides a number of services designed to assist your plant in operating and maintaining K-Tron products. All services are optional and can be arranged by contacting the factory or your local K-Tron representative.

START-UP SERVICE: A K-Tron factory-trained serviceman will come to your plant to assist with equipment start-up. This service is of particular value when personnel are not familiar with K-Tron products.

Service Prices:

\$608.00 per eight-hour day
\$ 76.00 per hour
\$114.00 per hour overtime
\$152.00 per hour Sundays and holidays
plus transportation and living expenses

Travel Time Prices (door to door):

\$ 68.00 per hour
\$102.00 per hour overtime
\$136.00 per hour Sundays and holidays

DEMAND SERVICE: Service by K-Tron factory-trained personnel is available day or night at the same prices stated above.

Operator and Maintenance Training

With the steadily increasing capabilities of K-Tron's advanced feeders and microprocessor-based control systems, operator and maintenance training has never been more important. The K-Tron Institute of Feeder Technology, located at K-Tron headquarters in Pittman, NJ, was founded to respond to this growing need. Its aim: to provide basic and advanced working knowledge of volumetric and gravimetric feeder equipment including operating and maintenance procedures.

Targeted to the practical interests of project and process engineers, maintenance personnel and key operators, each seminar combines informative presentations with effective hands-on training. KIFT offers in depth one, two and three day seminars on a broad range of feeder-related subjects -- from the feeder basics to the many detailed aspects of control, operations, maintenance, system integration, data communications and more. Classes are held regularly at the K-Tron Tech Centers modern and comfortable training theater, outfitted with the latest state-of-the-art, multi-media audio visual tools. For maximum customer convenience, on-site training at your plant is also available.

With many years of feeding experience -- both in the field and at the factory -- KIFT instructors are highly qualified, seasoned professionals who combine theory and practice to instill useful, comprehensive understanding.

Consider KIFT training. It's a positive pay-off investment for the smooth, reliable operation of your process. For more information including current course descriptions, schedules and rates call Dave Wilson, V.P. and Director, at (609) 589-0500.

Warranty

K-Tron warrants all K-Tron products against defects in material and workmanship for one (1) year from the date of shipment. In addition, K-Tron's Digital Mass Transmitter and Digital Force Transmitter are warranted against defects in material and workmanship for five (5) years from the date of shipment. K-Tron warrants that all of its products as manufactured are in good working condition and consist of good quality material. K-Tron will furnish free of charge any part that fails because of defective materials or workmanship within the above stated warranty period. If warranty service is required, the purchaser will be charged for transportation and living expenses only.

This warranty shall be void if the equipment is damaged during shipment, has been altered, subjected to misuse or installed improperly by anyone other than K-Tron's personnel or designated agents.

K-Tron makes no warranty with respect to components or accessory equipment furnished that is not of its own manufacture. K-Tron agrees to repair or replace all of these components within the limits of the component manufacturer's warranty.

PURCHASER RESPONSIBILITY: All electrical equipment furnished under this contract shall conform to the latest applicable standards of the National Electrical Code as recommended by the National Fire Protection Association. However, when state, county, municipal or local power company electrical codes may take precedence, it shall be brought to the specific attention of K-Tron for proper consideration. Electrical equipment for use in Canada shall be manufactured under Canadian Standards Association recommendations, but again, where provincial, municipal, or local power company electrical and safety conditions differ, it must be brought to the specific attention of K-Tron.

K-TRON LIABILITY: K-Tron liability is limited to the original purchase price of the K-Tron product. The foregoing warranty is in lieu of all other warranties or guarantees expressed or implied and of all other obligations or liabilities on the part of K-Tron, whether in contract or in tort. Under no circumstances will K-Tron be responsible for any consequential or contingent damages due to errors in weighing.

APPENDIX G

PITT MILL PUBLICATIONS

REPORTS

EXPORTEch Company, Inc., Quarterly Technical Progress Reports
September 28 - December 31, 1988
January 1 - March 31, 1989
April 1 - June 30, 1989
July 1 - September 30, 1989
October 1 - December 31, 1989

PUBLICATIONS

J. T. Hagy and R. R. Oder, "Pitt Mill Demonstration," Proc. of 14th International Conference on Coal and Coal Slurry Technology, Clearwater, FL (April, 1989), pp. 473-482.

PRESENTATIONS

J. T. Hagy and R. R. Oder, "Pitt Mill Demonstration," presented as a poster at the 6th Annual Pittsburgh Coal Conference, Pittsburgh, PA (September 27, 1989).

J. T. Hagy and R. R. Oder, "Pitt Mill Demonstration," presented at the Fifth Annual Coal Preparation, Utilization and Environmental Control Contractors Conference, Pittsburgh, PA (August 2, 1989).

END

DATE FILMED

01 / 07 / 91