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ENERGY CONSERVATION POTENTIAL OF PORTLAND CEMENT PARTICLE SIZE DISTRIBUTION CONTROL -- PHASE III IMPROVED CONTROL OF THE FINISH GRINDING PROCESS IN CEMENT MANUFACTURE

CTL Contract No. CR7913/4330

QUARTERLY REPORT
July 1, 1985 to September 30, 1985

by
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Technical Progress Report
July 1, 1985 - September 30, 1985

Energy Conservation Potential of Portland Cement
Partical Size Distribution Control
Phase III

Improved Control of the Finish Grinding Process in Cement Manufacture

I. OBJECTIVE AND SCOPE

The main objective of Phase III is to develop practical economic methods of controlling the particle size distribution of portland cements using existing or modified mill circuits with the principal aim of reducing electrical energy requirements for cement manufacturing.

The work of Phase III, because of its scope, will be carried out in 10 main tasks, some of which will be handled simultaneously.

<u>Task 1</u> will acquire suitable clinker and gypsum, characterize both materials, and deliver 40-50 tons clinker and 2-3 tons gypsum to each of two subcontractors, Allis-Chalmers (A-C) Corporation at Oak Creek, WI, and Kennedy Van Saun (KVS) at Danville, PA. Half of the clinker and gypsum delivered to Allis-Chalmers will be crushed to -10 mesh and delivered to Construction Technology Laboratories (CTL) at Skokie, IL, for use in subsequent tasks.

<u>Task 2</u> will utilize the crushed clinker and gypsum in the CTL closed circuit pilot ball mill to establish baseline conditions. This task will provide matrix and test plans for the subsequent tasks involving grinding operations at CTL, A-C, and KVS. Instruments and feeders will be calibrated and checked.

<u>Task 3</u> will utilize the CTL pilot ball mill to determine if changes in mill operating parameters can effect particle size distribution so as to produce a controlled cement that will save grinding energy and also provide good performance.

<u>Task 4</u> will study the performance of a high efficiency air classifier relative to production of the kind of controlled particle size distribution cement that was developed in Phases I and II of this project. This task includes purchase and erection of specified classifier equipment.

<u>Task 5</u> will study the effects of gypsum on the performance of the grinding operation and particularly its effects on air classification.

<u>Task 6</u> will study use of semi-air swept grinding technology to arrive at some optimum set of operating parameters that will produce a controlled particle size distribution cement.

Task 7 will handle data developed by prior tasks and will integrate the information into a mathematical model designed to establish operating parameters which will lead to particle size distribution control and energy savings.

Task 8 involves the A-C pilot roller mill which will develop data leading to optimum operating conditions required to produce controlled particle size distribution cements.

Task 9 will select cement samples from the most promising operations and perform standard cement and mortar tests.

Task 10 manages the project and provides required reports and technology transfer.

II. SUMMARY OF PROGRESS

Task 1

Task 1 is complete.

Task 2

Task 2 is complete.

Task 3

Task 3 is 70 precent complete by 30 September 1985. The test matrix required three different mill speeds, three different mill volume loadings, and three different ball size distributions. It was determined that mill speed and volume loading within reasonable limits had little to no effect on cement particle size distribution and that mill speed had little effect on production rate. However, it was found to date that one ball size distribution came closer to the desired particle size distribution curve and increased capacity at the same time. Apparently, potential energy savings might be available when this ball size distribution is used.

Task 4

The dust collector, fan, and air volume measuring device were delivered. Installation of the entire system is scheduled for the week of November 4, 1985.

Task 6

Work on Task 6, semi-air swept milling is complete except for the subcontractor's report.

Task 8

Task 8 is complete. A specific cement produced from the roller mill series of runs was selected by CTL by means of particle size distribution analysis, cube strength performance, and workability. A large quantity of this cement was produced in the roller mill for concrete tests as a future part of this project. A final report was submitted by the subcontractor.

III. DETAILED PROGRESS

JANUARY 1 TO SEPTEMBER 30, 1985

Task 3: Effects of Changes in Ball Charge

Task 3 consists of fifty-four grinding runs on the closed circuit ball mill system, with particle size analyses (by SediGraph) of the associated products. As in the previous task, the time per run required to attain equilibrium and the number of runs required to find acceptable conditions for a given test limited the number of test cases which could be studied. A summary of grinding run statistics for Task 3 is given in Table 1.

The effect of mill speed is shown by comparsions of product size distributions produced at two mill rotational speeds, 45 rpm and 38 rpm (80% and 68% of critical speed, respectively). Tabluated results of size analyses for these runs are given in Table 2. While products produced at the lower mill rotational speeds have slightly narrower size distributions, these differences appear too small to affect cement strength. Additional runs for evaluation of the effects of mill speeds have been cancelled to conserve raw materials, and because work to-date indicates no statistically different results would be obtained at different rotational speeds.

The effect of volume ball loading of the mill on product size distribution is determined by analysis of the mill and its power requirements with ball loadings of 25%, 35%, and 40%. Mill dimensions and internals preclude operation at greater than 40% ball loading. In Task 3, thirty-three grinding runs utilizing the original ball size distribution at 80% of the critical mill speed were conducted to assess the effect of variations in ball loading. While the power measurements have not yet been analyzed, the data suggest that there is an optimum ball loading which is below the maximum loading used. The maximum production rate allowed by the mill system increases with increasing ball loading. However, the data suggest that the incremental production capacity made available by increasing the ball loading above about 25% is less than the incremental ball loading. A 40% by weight increase in ball loading produced an increase in production capacity of less than 20%.

For assessment of the effect of ball size distribution, sixteen grinding runs were conducted with ball size distributions significantly different from the standard. While the results of the varied ball size runs have not been fully analyzed, some preliminary conclusions have been made. As expected, higher void volumes lead to shorter mill residence times. The short residence times result in higher circulating loads. Conversely, the smaller balls used in the tests (1/2-in. to 3/4-in. ball size) resulted in longer mill residence times and lower circulating loads.

An additional observation worth noting is that the production capacity of the mill appears to be related to the ball size distribution. The larger ball sizes permitted significantly higher production levels. Moreover, at the higher production levels, the Blaine specific surface areas were also somewhat higher. Probably the most interesting observation is that, while the product of the large ball size charge was finer than the product of the standard ball change at the same mill feed rate and ball volume load, the level of fines production did not appear significantly greater. This may partly be the result of higher separator efficiencies at higher loadings. With the small ball size charge, high specific surface area products were also obtained. The latter products had higher levels of fines than those produced by standard and large ball sizes. Representative product particle size tabulations for ball size variations are given in Table 3.

While the above highlights suggest some interesting observations, the data must be evaluated in greater depth before definitive conclusions regarding the effects of ball change variations on grinding efficiency and product particle size can be reached.

Task 4: Performance of High Efficiency Classifier

Subtask 4(a): In the reporting period, the dust collector, dust collector fan, and air volume measuring apparatus were delivered. The contractor, C-E Raymond, completed engineering drawings for the installation of the conversion assembly of the existing classifier. When finished, the equipment will consist of a new interior configuration of the existing classifier, a new duct to carry finished fine powder to the dust collector, a new dust collector to separate the fine powder from air, and a new discharge pipe containing air volume measuring equipment for control of the system. Installation is scheduled for the second week of November 1985.

Task 6: Semi-Air Swept Milling

A detailed report of work performed under subcontract by L. G. Austin of Pennsylvania State University (PSU) is included in this report as Appendix 1. Seven open circuit air-swept mill grinding runs were conducted at Kennedy Van Saum (KVS) facilities. Several batch pilot mill tests were also conducted at PSU, but the results were found to be internally inconsistent and the tests will be repeated in the next reporting period.

Results obtained by use of an 8-in. batch mill during the previous reporting period were correlated with results from the 1 meter KVS mill run in batch mode. Inconsistencies were found due to inadequate clinker storage procedures at KVS. Consequently, some 8-in. mill runs will be repeated at PSU with the clinker stored at KVS. Results of air-swept mill runs conducted at KVS were used to determine parameters required for computer modeling planned in the future.

Task 8: Roller Mill Investigation

This task was completed August 30, 1985

The objective of this task in the overall project was to develop data and information on the performance of a typical roller mill used in the grinding of cement. While some research has been carried out in Germany on using roller mills for grinding cement, very little information is available on roller mill production of cement suitable for the U.S. cement market which is somewhat different than that of Germany.

Roller mills are widely used in the world cement industry for grinding raw materials, but only one full-size roller mill is continuously operating on cement clinker. Use of this equipment for finish grinding of cement has been discouraged in the U.S. because the particle size distribution of the typical roller mill cement has not led to performance suitable for the high performance U.S. market, and also, replacement of existing ball mills with roller mills is economically unattractive. However, indications are that 15% to 20% energy reduction could be realized by using roller mills instead of ball mills for finish grinding.

Task 8 of this current project sought to produce a particle size distribution (PSD) controlled cement that would be able to participate in the U.S. cement market and at the same time enjoy energy reduction benefits.

The investigation was carried out by Allis-Chalmers Corporation Process Research and Test Center at Oak Creek, Wisconsin, as a subcontract to the current project. Allis-Chalmers has a pilot Pfeiffer MPS32 Roller Mill which was extensively modified to produce cement of the particle size distribution outlined by CTL and developed in Phase II of this project. Fig. 1 shows a comparison between the normal raw grinding set-up and the cement grinding set-up used in this project. Operation parameters were varied per an established experimental matrix and the resultant product was analyzed by SediGraph particle analyzer, and Blaine specific surface. Several selected cements that seemed to meet the PSD curve criteria were tested at CTL laboratories for cement performance.

Because Task 8 is one part of a many-faceted comminution program, comparisons of results from this pilot study will not be available until the final report of the total project is written.

Of the 41 test cements produced in Task 8, three were selected for further study based on analysis of the PSD curves and the Blaine specific surface area. Of the three, one was selected as typifying the PSD cement we were seeking based on size analysis and cement performance. This cement is designated AC-P39.

Table 4 shows the particle size distribution of the selected cement produced by the roller mill identified as AC-P39. Also on Table I are two cements identified as MCC274 and MCC275 ground in a ball mill along with the best performing cement designated RB2137B developed in Phase I of this project. This table indicates the Blaine specific surface area of each of these cements and the D50 size which is the m size at which half the particles are finer and the other half are coarser.

Table 5 presents physical properties of the cements outlined in Table 4 as well as two other candidate cements from Allis-Chalmers. The data are based on producing paste cubes from the cements. Paste cubes are test specimens made of cement and water, cast into 1-in. cubes, and used to determine relative strength potential of cement. From the paste made for strength tests, other test data are derived, such as setting time and workability. Paste cubes are used for rapid, preliminary appraisal data; ASTM C 109 cubes and concrete tests are more definitive and will be performed later in the project.

The Allis-Chalmers program varied roller mill parameters such as roll loading, table speed, air volume, classifier speed, and percent bypass to produce 41 different trial cements in an effort to match the criterion PSD curve established by CTL in Phases I and II of the current DOE project.

Data on the cements indicated that three cements chosen from the 41 Allis-Chalmers samples had acceptable PSD criteria and of the three, one gave the best performance, AC-P39. Table 4 compares three roller mill cements to two ball mill ground cements, MCC274 and MCC275, and the standard PSD controlled cement RB2137B developed in Phase I of this project. The best roller mill cement, AC-P39, has a Blaine specific surface of 3180 cm^2/g, the standard PSD controlled cement 2940 cm^2/g, and the two ball milled cements both 3360 cm^2/g. It can be seen that the roller mill cement and the standard PSD controlled cement each has very comparable size distributions whereas the two ball-milled cements are quite different. Blaine specific surface area is 180 cm^2/g higher for the ball-milled cements.

Table 5 shows relative strengths of cements based on paste cubes for the roller mill cements, the ball-milled cements, and the standard PSD cement RB2137B. Selection of AC-P39 was based on 28-day strength and workability. Despite a lower Blaine specific surface, AC-P39 produced higher 28-day strengths than the ball-milled cements.

A large quantity of AC-P39 was made by Allis-Chalmers for complete mortar and concrete testing which will be done later in the project.

Using raw data, without benefit of rigorous analysis or comparisons with the other tasks of this project, there seems to be about 15% reduction in grinding energy required for equivalent cement performance using the roller mill instead of ball mill grinding. As the other tasks are completed and as the data are refined through mathematical analysis, this figure will be firmed up. This will be accomplished in Task 7 and Task 10 (the final report).

Task 10: Administration and Report

While there has been some slippage in Task 3, principally due to a late start caused by slippage of Task 2, the elapsed time of Task 3 should be as scheduled.

Total expenditures to-date indicate that about 90% of funds obligated through Modification A005 are spent. This has been brought to the attention of Mr. Marshall Garr, Contract Officer for DOE. Estimates show 100% expenditure will occur at the middle of November. Further funding must be forth coming shortly to keep the project progressing.

IV. FUTURE PLANS

The outside contractor will start installing the high efficiency classifier modification called for in Task 4 the first week of November. It is planned to have the system operational by November 18, 1985. We contemplate starting Task 5 concurrently with Task 4 to save time and regain our schedule position. Task 5 will be started the first week of November. Data continues to be accumulated from the various grinding tests and runs. These data will, at an appropriate time, be transmitted to Dr. L. G. Austin for analysis as part of the final report.

Table 1. Task 3 run summary.

DATE	RUN#	FEEDER SETTING	FEED #/HR	PRODN #/HR	FAN RPM	#BLD.	AUX. FAN OUT/IN/#	CIRC. LB/MIN	CR/FEED %	DAMP F/C	BLAINE sqcm/g	BALL LD. (NOM. %)	BALL BSD S/M/L	MILL RPM
8-22	3-1	3.0	99	96	1400	8	OUT/2	5.5	334	F	2984	35	M	44
8-23	3-2	3.0	99	96	1400	8	OUT/2	6.0	364	F	2890	35	M	44
8-27	3-3	3.0	99	94	1400	8	OUT/2	13.0	789	F	3084	35	H	38
8-28	3-4	3.0	99	89	1400	8	OUT/2	13.5	819	F	3050	35	M	44
8-29	3-5	3.0	99	87	1400	8	OUT/2	11.5	698	C	2950	35	M	44
9-3	3-6	2.0	82	80	1100	8	OUT/2	6.0	441	F	3074	35	M	44
9-3	3-7	2.0	82	64	1400	8	OUT/2	7.0	515	F	3382	35	M	44
9-4	3-8	2.0	82	71	850	8	OUT/2	5.0	368	F	3370	35	M	44
9-5	3-9	2.0	82	71	850	8	OUT/2	4.5	331	C	3627	35	M	44
9-5	3-10	2.0	82	61	850	8	OUT/2	6.5	478	F	3213	35	M	38
9-6	3-11	2.0	82	77	850	8	OUT/2	3.0	221	C	2705	35	M	38
9-9	3-12	2.0	82	84	850	8	OUT/2	5.5	404	C	2745	35	M	44
9-10	3-13	2.0	82	87	850	8	OUT/2	4.0	294	C	2561	35	M	38
9-10	3-14	1.5	74	82	850	8	OUT/2	2.5	202	F	2924	35	M	44
9-11	3-15	1.0	67	63	850	8	OUT/2	2.5	223	F	2572	35	M	44
9-12	3-16	2.0	82	74	1400	8	OUT/2	3.0	221	F	3070	35	M	44
9-13	3-17	2.0	82	96	850	8	OUT/2	4.5	331	F	3327	35	M	44
9-16	3-18	2.0	82	78	750	8	OUT/2	3.4	250	F	3042	35	M	44
9-18	3-19	3.0	99	97	1100	8	OUT/2	12.5	758	F	2873	25	M	44
9-19	3-20	2.0	82	86	850	8	OUT/2	5.5	404	F	2723	25	M	44
9-20	3-21	2.0	82	74	1250	8	OUT/2	5.7	419	F	2701	25	M	44
9-23	3-22	3.5	109	96	1100	8	OUT/2	10.8	595	F	2511	25	M	44
9-24	3-23	1.5	74	62	700	8	OUT/2	3.1	251	F	2621	25	M	44
9-25	3-24	1.0	67	54	850	8	OUT/2	2.6	232	F	2499	25	M	44
9-26	3-25	0.0	56	52	1400	8	OUT/2	2.8	303	F	2487	25	M	44
9-27	3-26	0.0	56	49	650	8	OUT/2	2.2	238	F	2805	25	M	44
9-30	3-27	0.0	56	31	650	2	OUT/2	3.9	421	F	4180	25	M	44
10-1	3-28	3.0	99	81	850	8	OUT/2	5.5	334	F	2770	45	M	44
10-2	3-29	3.0	99	96	850	8	OUT/2	21.7	1316	F	2643	40	M	44
10-3	3-31	3.0	99	94	1100	8	OUT/2	6.0	364	F	2759	40	M	44
10-4	3-32	3.0	99	93	1400	8	OUT/2	5.8	352	F	2943	40	M	44
10-5	3-33	3.0	99	101	725	8	OUT/2	5.1	309	F	2960	40	M	44
10-8	3-34	2.5	90	91	725	8	OUT/2	4.0	267	F	2832	40	M	44
10-10	3-35	1.0	67	40	850	4	OUT/2	5.8	517	F	3788	25	L	44
10-11	3-36	3.0	99	67	850	4	OUT/2	19.4	1177	F	3425	25	L	44
10-14	3-37	3.0	99	75	850	4	OUT/2	20.3	1231	F	3315	35	L	44
10-15	3-38	4.3	126	50	850	4	OUT/2	34.2	1631	F	3198	35	L	44
10-16	3-39	4.0	120	42	950	4	OUT/2	31.8	1591	F	3029	35	L	44
10-17	3-40	4.0	120	71	850	6	OUT/2	23.7	1186	F	2970	35	L	44
10-18	3-41	4.0	120	60	1150	6	OUT/2	29.3	1466	F	2870	35	L	44
10-21	3-42	4.0	120	61	975	6	OUT/2	21.3	1066	F	2877	35	L	44

Table 1. Task 3 run summary (continued).

DATE	RUN#	FEEDER SETTING	FEED #/HR	PRODN #/HR	FAN RPM	#BLD.	AUX. FAN OUT/IN/#	CIRC. LB/MIN	CR/FEED %	DAMP F/C	BLAINE sqcm/g	BALL LD. (NOM. %)	BALL BSD S/M/L	MILL RPM
10-22	3-43	4.0	120	43	850	4	OUT/2	30.0	1501	F	3177	35	L	44
10-22	3-44	3.5	109	48	850	4	OUT/2	26.6	1465	F	3170	35	L	44
10-23	3-45	3.5	109	66	750	4	OUT/2	32.9	1812	F	3210	35	L	44
10-24	3-46	3.0	99	75	850	8	OUT/2	2.5	149	F	2484	25	S	44
10-25	3-47	1.0	67	48	850	4	OUT/2	2.5	219	F	3419	25	S	44
10-28	3-48	2.0	82	69	850	4	OUT/2	3.9	287	F	3300	25	S	44
10-28	3-49	2.5	90	68	800	4	OUT/2	8.2	548	F	3150	25	S	44
10-28	3-50	3.8	114	100	850	4	OUT/2	9.5	499	F	3347	35	S	44
10-30	3-51	3.0	99	72	850	4	OUT/2	21.0	1274	F	3100	25	M	44
10-30	3-52	3.0	99	66	725	4	OUT/2	20.3	1231	F	3108	25	M	44
10-31	3-53	3.8	114	62	850	4	OUT/2	15.9	835	F	3252	35	M	44
10-31	3-54	3.8	114	86	850	2	OUT/2	18.7	982	F	3228	35	M	44

Table 2. Product cement size distributions produced at two mill rotational speeds.

RUN#	FEED RATE lb/hr	Mill Speed % of Crit.	PRODUCT sqcm/g	+100um %	<44um %	D50 um	3-30um %	<7um %	<1um %	<.8um %	<.6um %
3-3	99	68	3080	2	97	17	73	23	2	1	0.7
3-4	99	80	3060	1	95	16	73	24	2	1	0.7
3-8	82	80	3370	2	97	15	72	27	2	2	1.3
3-10	82	68	3210	1	96	16	70	24	2	2	1.0
3-11	82	68	2700	3	89	18	62	23	2	1	0.5
3-12	82	80	2750	1	85	20	55	24	2	2	1.0

Table 3. Product cement size distributions produced by various ball loadings and ball sizes.

RUN#	FEED RATE lb/hr	Mill Ball* SIZE/LOAD%	PRODUCT sqcm/g	+100um %	<44um %	D50 um	3-30um %	<7um %	<1um %	<.8um %	<.6um %
3-38	126	L/35%	3200	1	98	16	77	23	2	2	1.0
3-53	114	M/35%	3250	2	99	16	76	23	1	1	0.3
3-50	114	S/35%	3350	2	97	16	76	24	3	2	1.5
3-36	99	L/25%	3430	2	96	15	76	26	2	2	1.0
3-51	99	M/25%	3100	1	97	17	71	23	3	2	1.4
3-49	90	S/25%	3150	1	98	16	76	24	3	2	1.6

* Nominal ball size distributions:

L: 50% 1.625-1.375 inch; 50% 1.375-1.125 inch
M: 30% 1.625-1.375 inch; 30% 1.375-1.125 inch; 25% 1.125-.875 inch; 15% .875-.625 inch
S: 50% .875-.625 inch; 50% .625-.375 inch

TABLE 4

construction technology laboratories

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Proj. No. CR7913/4330

Proj. Title DOE III

Proj. Mgr. S. W. Tresouthick

Initials ______ Date ______

Particle Size Distribution Analysis by SediGraph 5000E

Sample I.D.	Blaine, cm^2/g	Particle Size Distributions: +100µm %	<44µm %	D50 µm	3-30µm %	<7µm %	<1µm %	<0.8µm %	<0.6µm %
AC-P39 (roller)	3184	1.0	96.2	13.9	81.0	23.2	1.3	1.0	0.5
RB2137B (ball)	2940	1.7	96.3	14.9	85.0	22.0	1.3	0.5	0.2
MCC275 (ball)	3360	2.3	93.4	12.3	64.5	30.7	5.8	3.5	2.0
MCC274 (ball)	3360	2.0	92.2	13.9	62.2	30.0	4.5	3.8	2.0
AC-P3 (roller)	2937	0.4	92.2	15.0	65.0	19.3	1.0	0.5	0.2
AC-P32 (roller)	3763	1.8	97.8	12.6	83.0	27.2	1.5	1.0	0.5

Work Performed By ______ Date ______ Approved ______

TABLE 5

CEMENT DESIGNATION	GRINDING METHOD	W/C	PASTE WORKABILITY	COMPRESSIVE STRENGTH OF PASTE CUBES (PSI)			
				1d	3d	7d	28d
AC-P3	Roller Mill	.40	Fluid	570	2000	4850	8580
AC-P32	Roller Mill	.48	Workable	1310	3600	5930	9620
AC-P39	Roller Mill	.48	Workable	850	2890	4820	9900
MCC274	Ball Mill	.50	Workable	1580	--	6470	9800
MCC275	Ball Mill	.50	Workable	1290	--	3940	7680
RB2137B	Ball Mill	.50	Workable	1720	5250	6500	9275

MPS-32 ROLLER MILL

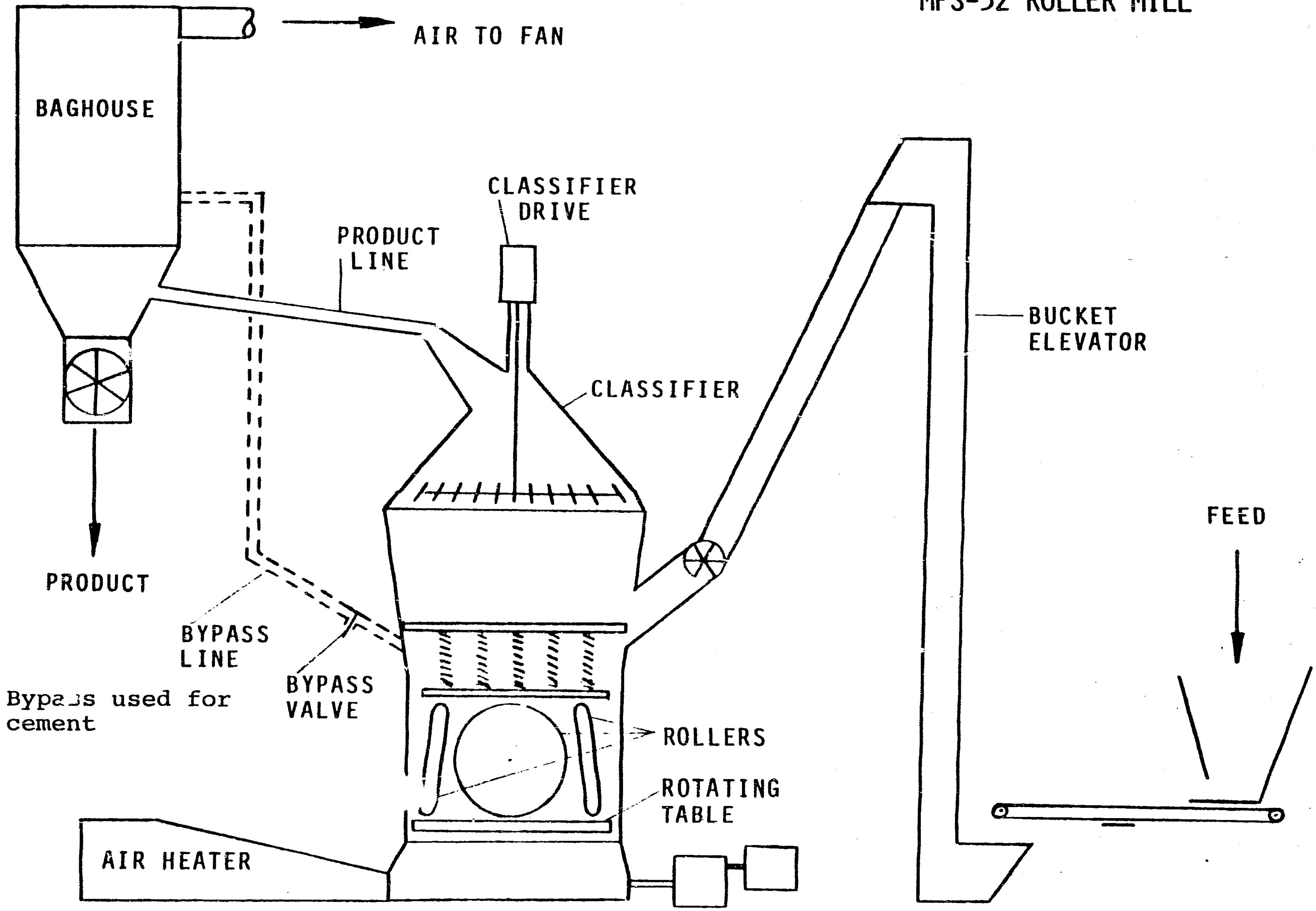

FIGURE 1.

- END -

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