PN-ABF-781
67591

R E P O R T

MILLING FULL FAT SOY FLOUR

ICAR/CIAE - Bhopal, India

8-28 February 1990

Consultant Report by

C.E. (Chuck) Walker, Ph.D.

Soybean Processing and Utilization Subproject

Agricultural Research Project (386-0470)

Implementation Order No. 38

Contract No. 386-00000-C-00-5039-00

WINROCK INTERNATIONAL
1611 North Kent St.
Arlington, VA 22209

MILLING FULL FAT SOY FLOUR

SOYBEAN PROCESSING AND UTILIZATION (SPU) PROJECT

ICAR/CIAE - BHOPAL, INDIA

CONSULTING ACTIVITIES REPORT

BY

C.E. (CHUCK) WALKER, Ph.D.
KANSAS STATE UNIVERSITY, U.S.A.

TO

WINROCK INTERNATIONAL AGRICULTURAL
DEVELOPMENT, CONTRACTOR TO US AID

8 FEBRUARY TO 28 FEBRUARY
1990

TABLE OF CONTENTS

		Page No.
1.	Executive Summary	1
2.	Overview	2
	a) Objectives - overall project b) Project Description c) Progress to date d) Objectives - this trip e) Progress - this trip	
3.	Recommendations	4
	a) Equipment Design - General Considerations b) Probable Mill Design c) Future Research Recommendations d) Training Recommendations	
4.	Acknowledgements	9
Appendices		10
	1. Terms of Reference	11
	2. Daily activities summary	12
	3. Experimental Data: Figures & Tables	17

EXECUTIVE SUMMARY

The objective of this US-AID sponsored trip was to design a mill capable of grinding 100 kg/hr of Trypsin inhibitor, and urease, inactivated soybean splits ("Dhal") into a full fat flour less than I.S. 30 mesh (300 microns). The mill was to be operable under village-scale conditions, with capital costs and energy consumption to be minimized and capable of operating four hours between cleanings. Sanitary design and maintenance simplicity were important.

Tests were conducted on three small commercial mills, a hammer mill, a stone burr mill and a pin-disk mill. Energy consumption, particle size and freedom from plugging were observed. Grain breaking strengths were also measured as a function of moisture content, as was net specific power consumption (watt-hours per kilogram) by a small, instrumented, fixed-hammer will.

The splits should be milled as dry as possible (6 to 8% moisture seems a reasonable compromise) by an impact mill with a screen having 3/4 to 1 mm perforations. A design for a screened pin-disk mill was suggested, combining the advantages of a hammer mill with those of a pin-mill.

It is recommended that a small commercial pin mill be purchased for further tests (outline provided), concurrently with the construction of a prototype as designed. Subsequent experiments should lead to a satisfactory final design meeting all objectives.

I recommend that cooperation between CIAE and the commercial milling industry continue to be developed. For example, the pin-mill tests were only possible because a local mill permitted use of their equipment. This approach shall be continued for the mutual benefit of both CIAE and the industry.

It is also recommended that Mr. B.S. Bisht be sent to Kansas State University for an 8 to 10 wk milling training period.

OVERVIEW

(a) The over-all objectives of the Soybean Processing and Utilization Project (SPU) are the improvement of the local population's nutritional stature through increased consumption of soybeans and their derived products. Products are being developed which are culturally acceptable, and processes defined for home and village scale manufacture of these products. When necessary, commercial equipment will be specified, or designs developed for producing the equipment locally. The high fat content and high quality protein would provide both needed calories and essential amino acids to compliment a vegetarian (cereal based) diet.

(b) This particular portion of the S.P.U. is concerned with the development of a suitable milling process(es) and equipment for the production of - 30 I.S. screen size flour from full fat (20 to 22% fat) soyabeans, from medium fat (6 to 8%) expeller cake, and from low fat (1%) hexane extracted flakes.

(c) To date, a hot aqueous treatment has been developed to destroy the urease and trypsin inhibitor naturally present in soya, and equipment & procedures have been developed to dehull and to split the soya beans, producing a product resembling dhal from pigeon peas. The splits could also be milled into a fullfat flour which can be incorporated with the 95 to 98% extraction wheat flour into traditional breads (roti, nan, etc.)

Full fat soya flour is difficult to make on a large scale because high pressures, sheer or high temperatures will rupture the oil cells, making a 'sticky' product that plugs the mill, blinds screens and will go rancid very rapidly under the ambient conditions (high humidity and moisture) normally present in India.

A small stone burr mill had been developed, but was difficult to clean, and heated the ground flour rather badly. It has insufficient capacity to justify installation and operation by a village scale entrepreneur. A small (commercial) hammer mill had been purchased, but also heated the product, was difficult to clean, and quickly blinded part of the screen. It also suffered a build-up of product on internal surfaces which are a sanitary problem, and which also caused product heating and a steady reduction in the capacity, requiring that it be shut-down frequently for cleaning.

(d) The objectives of this consultancy trip were to review the progress to date, to examine the equipment available or potentially available, to conduct any tests necessary, and to make recommendations for the design of equipment capable of producing - 30 I.S. mesh full-fat soya flour from treated 'splits'. The system was to have a capacity of 100 kg/hr, be capable of operating for 4 hr between cleaning, and be easy to clean and of sanitary design. It should avoid heat or other damage to the flour, be as energy efficient as practical, and construction, maintenance and safe operation should be as simple as possible.

It was also an objective to acquaint the local researchers with various types of milling equipment and processes commercially used, and to discuss the principles involved.

(e) During this trip I visited some commercial mills, toured the CIAE, identified their capabilities, and developed a short-term research plan.

We conducted tests on three different mills, the stone burr mill, the hammer mill, and a screened pin-disk mill. This last mill was originally intended to pulverize sugar, and was located at but presently un-used by the Central India Flour Mills Plant. It was the closest that we could find to the high speed pin mills normally used commercially for the production of very fine powders, including full fat soy flour.

We measured the specific energy consumption (total and net) in Watt-hours per kilogram of beans, the capacity in kilograms per hour, and the product screen size distribution for each. We also measured the effects of changing screen size on the hammer mill, and of single vs multiple passes.

We also measured the fracture force required at various bean moisture contents, via Instron and hardness tester. In addition, we used a very small, instrumented, hammer mill to measure the work input to the beans at various moisture contents. The object was to define the acceptable moisture range for milling, consistent with production practicalities.

An impact mill design was developed which should meet the objectives of this consultancy trip. Technical Details and relevant data are provided in Part 3, "Recommendations", and in the Appendix.

RECOMMENDATIONS

a) Equipment Design - General Considerations

1) Do Not use 'Shear-pressure' type mills, such as differential-speed roller or stone-burr mills. They are characterized by a large product temperature rise and a crushing type action which tends to release oil. The resultant sticky flour blinds sieves, and will probably have a shorter shelf life.

2) Do use an impact type mill, such as a hammer or Pin-disk mill, which produces fine particles that are more freely flowing.

3) Mill the treated splits as cool and at as low a moisture content as practical. The more brittle grain produces a finer meal with less energy consumption. (Fig. 2a, 2b) (e.g. the net specific energy consumption at 5% m.c. is less than 1/2 that at 15% m.c., yet there are one-half again as many fines). Milling energy must be balanced against drying energy, but 6% to 8% m.c. appears to be a reasonable range.

4) Suitable pin-mill equipment is available commercially (Entoleter, Alpine, Sprout-Bauer, Kek, Mikropul and others). Catalog information has been left with Mr. Bisht. I recommend the purchase of one of these units for further studies and engineering evaluation.

5) Include a size-control feature in the mill system. Three basic alternatives are possible. An internal air-classifier as used by Entoleter, an internal screen as used in hammer mills, or an external sifter system.

The external sifter represents an additional piece of equipment, but is relatively simple and inexpensive. The coarse fraction (+ 30 I.S. mesh) must either be recycled through the mill, or used for other purposes, such as high moisture porridges. (They are too coarse and hard to be used in most breads).

The internal re-circulating air classifier system is the 'Best', capable of producing a very uniform, narrow-size range, particle size distribution. It is available only on the most sophisticated and highest-priced equipment, however, and may not be practical for a simple low-cost system.

Internal screens, as in a hammer-type mill, must have openings greater than 0.5mm. This size produces the desired particle size, but also blinds badly. The through-put rate drops, power consumption rises and the product heats, so the mill must be disassembled and cleaned frequently. Screens with 1.5 and 2mm openings work well, with no blinding, but produce sufficient coarse particles to require an external sifter, as discussed above. Preliminary work indicates that a 3/4 to 1 mm screen is promising, but needs to be verified with additional experiments. This approach may be the most cost-effective for a 100 kg/hr village scale mill.

6) Conduct additional milling studies to optimize temperature and moisture conditions. Also vary speed and screen parameters. Measure product feed rates vs power consumption, screen gross area, perforation size and net-free area. Study round vs slotted screens.

7) Use this test data to design a village scale mill.

8) Ultimate mill design must be quickly and easily disassembled for cleaning. Sanitation must be a major consideration. It must provide significant air flow, cooling the product and reducing screen blinding.

b) Probable Mill Design, to be researched and verified

1) Pin-disk type mill (See Appendix Fig.3)

2) Five rows rotor pins, inner ones round, outer-most rectangular

3) Four rows stator pins, all round

4) Pin diameter = 1cm, except outer row = 1cmx2cm. All have 7.3cm exposed length

5) Rotor: Outer diameter 28 cm; dynamically balanced at 5000 rpm

6) Screen: 360 degree coverage, 30 cm diameter x 9 cm wide. Slotted perforation, 0.75 mm narrow dimension.

7) Pin-Pin clearance = 2.5 mm. Pin-opposing plate clearance = 2.0 mm.

8) Design based upon side opening stator with slip out screen. No tools required to open stator door or to remove screen. Double locking nut to remove rotor. Rotation direction to prevent loosening during acceleration or operation. Screen, stator and rotor all keyed for exact re-alignment after cleaning.

9) Rotor, stator and pin assembly of high strength carbon steel. Stress analysis to be applied to pins at double anticipated rotation and load, ensuring safe operation. Note that at 5000 rpm, rotor peripheral velocity = 14,400 ft/min. Commercially available equipment operates upto 3 times this velocity.

10) Probable Net Power: 100 kg/hr x 35 w-hr/kg =3500 Watts. Assuming 50% efficiency, connected horse power= approximately 5.

c) Future Research Recommendations

1) Evaluate available hammer and pin mill, by the following scheme (Table 4)

- three moisture contents, in the range 6%, 8% and 10% w.b.

- three mill and feed temperatures, 30 degree C, 45 degree C, and 60 degree C

- three screen hole diameters (constant free area), 3/4 mm, 1mm, 1.5 mm.

2) Constant feed rate (load motor to about 70% rated capacity). Accurately measure and record feed rate.

3) Monitor power (watts) vs time. Start recording after mill and rotor are at no-load equilibrium. Record power for a minimum of 1 min. prior to beginning feed (establish baseline), record continuously during feeding phase and 'clean-out' phase, and for 1 min. after reaching constant 'No-load' level again, to verify and re-establish base line. (See Fig. 4 example sketch). If a strip chart or recording watt-hour meter is not available, record readings manually each 10 sec. during the run (5 min. minimum) of accurately known sample size.

4) Record product temperatures <u>in</u> and <u>out</u>.

5) Integrate power curve to calculate total and net (no-load corrected) specific power consumption, Watt-hours/kg

6) Calculate feed rate, kg/hr, both total <u>and</u> per unit free screen area.

7) Perform sieve analysis with 100, 85, 60, 50, 30 and 15 I.S. screens. Start with a constant sample weight (e.g. 100g aliquot) from well blended total sample, sift by an exactly repeatable pattern for a fixed time. Do in duplicate. (sifting to be more violent, like the Tyler Ro-tap, then the very slow equipment currently in use). Report results as % of total recovered weight remaining on each sieve, and in pan.

   Also calculate both average size and total % passing #30 (300 micron) as generally acceptable for flour.

8) Use Response Surface Methodology Analysis (RSM), i.e. multiple second order regression with first term interactions, for all experimental results as a function of the three independent continuous variables (such as moisture, temperature, screen size or rotor speed). Use the resultant equations and contour graphs to select optimum and acceptable operating ranges, and to design final configuration.

   Note that 3 levels each of 3 variables will require 27 independent runs , if a complete block is performed. Experiments should be triplicated to reduce experimental error (81 runs). An RSM incomplete block may be used, requiring only 11 conditions, but may be used <u>only</u> if preliminary experiments have shown a high degree of reproducability. (See Fig.5).

9) <u>Rotor Speed</u> is another variable which should be studied. This is <u>especially important</u> for pin-mills, and might be substituted for screen opening, in a non-screened pin mill, or added as a fourth variable. Note that for proper use of an RSM design, all independent variables must be 'continuous', and the three levels should be evenly spaced over the known satisfactory operating range.

10) All data collected, such a % moisture and sieve analysis, must be by standard and reproducable methods. Use a constant starting sample size, fixed time, temperatures, agitation frequencies, etc. Refer to appropriate ASTM, AOAC or AACC Standard methods, and the Chemical Engineers Handbook, McGraw Hill (Ed. by Perry).

d) Training Recommendations

I recommend that Mr. BS Bisht be sent to the USA for 8 to 10 weeks to observe flour milling and soybean processing, and to conduct additional tests.

Six weeks should be spent at Kansas State University doing research with and observing a wide variety of milling equipment. Timing should coincide with one of the several milling short-courses scheduled through the year.

Time and funds should also be allocated to spend the balance of the time briefly visiting North Dakata State University (Department of Cereal Science and Food Technology,) the University of Nebraska (Food Processing Centre), Iowa State University (Dept. of Food Technology and value Added Processing center), and the University of Illinois (Dept. of Food Science).

He should also visit the Wenger Company, in Sabetha, KS, the U.S.D.A. - Northern Regional Research Centre in Peoria, IL, and several commercial soybean and maize processing operations.

ACKNOWLEDGEMENTS

I wish to acknowledge the support of CIAE Director, Dr. N.S.L. Srivastava, and the time that he took to provide an overall perspective, and S.P.U. Project Director, Dr. Nawab Ali for helping to identify the specific objectives to be addressed during this brief trip.

Mr. B.S. Bisht was the project senior scientist and process engineer with whom I worked the most closely, and who was responsible for seeing that the actual work was accomplished swiftly and smoothly. To him belongs the credit for any success we enjoyed.

Dr. A.P. Gandhi and Dr. K.C. Joshi who also befriended me, permitted a more profitable and productive experience than I might otherwise have had. Dr. L.S. Wei, of the University of Illinois, also consulting at CIAE, also helped me in adjusting rapidly to a new situation.

The Winrock Foundation, including Mrs. Bhatt in Washington, D.C., Dr. C. McClung and Mr. Srinivasan in New Delhi, and their staff, are acknowledged for administering the US AID funded project, and for so ably handling the many logistical details quickly and smoothly. I especially thank Miss Lissyamma V. Joseph who so ably and efficiently typed this final report.

Finally, I would be remiss if I did not acknowledge Mr. Shabbir Husain who provide much assistance to me, and to the many others at the CIAE who gladly helped a sometimes confused visitor to complete his assignment.

C.E. (Chuck) Walker, PhD

SPU Project
Milling Full Fat Soya Flour

APPENDICES

1. Terms of Reference
2. Daily Activities Summary
3. Experimental Data: Figures & Tables

APPENDIX 1

TERMS OF REFERENCE

Dr. C.E. Walker
SHORT-TERM CONSULTANT - SPU PROJECT
FEBRUARY 8 - MARCH 1, 1990

During the two-and-a-half week assignment in India, Dr. Walker will perform the following duties:

1. To hold discussion with the Project Director-SPU and the Director, CIAE, Bhopal, and to evaluate status and needs of the sub-project.

2. To identify and evaluate the different milling equipment available in the SPU Sub-project.

3. To develop suitable milling technology and equipment for soybean.

4. To formulate performance evaluation and test code development for soybean milling equipment.

5. To submit written report summarizing consultancy activities and recommendations to the sub-project.

6. To give an oral de-briefing to ICAR/USAID and Winrock before departure from New Delhi.

APPENDIX 2

Daily Activities Summary:

Monday, 5 Feb.'90	-	Fly from Manhattan, KS, USA TO JFK Airport, New York and depart for Frankfurt.
Tuesday, 6 Feb.'90	-	Arrive Frankfurt. Remain overnight.
Wednesday, 7 Feb.'90	-	Depart Frankfurt enroute Delhi.
Thursday, 8 Feb.'90	-	Arrive Delhi
	-	Read Project background materials provided by Winrock. Visited Winrock Officers (Srinivasan and Dr. A. Colin McClung).
	-	Discussed Project.
	-	Visited USAID Offices (John A. Becker) and discussed over-all objectives.
Friday, 9 Feb.'90	-	Fly Delhi to Bhopal (Bisht)
	-	Meet with CIAE Director N.S.L. Srivastava, and tour facilities, meeting support staff.
Saturday, 10 Feb.'90	-	Visit Central India Flour Mills and Bakery (Mr. D.K. Vakil).
	-	Visit G.S. Dahl and Oil Mills (Mr. Agrawal)
		(Bisht, Joshi and Wei)
Sunday, 11 Feb.'90	-	Rest Day

Monday, 12 Feb.'90

- Met with Project Director, Dr. Nawab Ali. Defined Project objective for this trip to "Do necessary experimental work and preliminary design, construction and demonstration of a 100 kg/hr mill for fullfat soya flour from soy 'splits' produced from the existing anti-trypsin inhibitor treatment process".

- Identified parameters that are to be met

- Visited with SPU staff. They described their portion(s) of the project. Made suggestions for research to solve some problems. (Patil, Jha, Singh, Kulkarni, Sinha, Gandhi and Bargale).

Tuesday, 13 Feb.'90

- Examined interiors of Hammer and stone burr mills after milling extrusion cooked soy beans, for causes of plugging and identified need for sanitary design and different screen..

- Examined in detail other equipment and identified possible equipment available for experimental purposes.

- Selected initial trials on:

  a) Pin mill
  b) Instron and Hardness Tester crushing test (variable moisture)

  c) Attrition mill (stone burr)
  d) Hammer mill with added air.

- Brief runs on soya splits, followed by dis-assembly and examination, to be scheduled.

Wednesday, 14 Feb.'90	-	Examined interior of 5 hp Hammer mill after use.
	-	Made suggestions for changes (Rotation, screen and air)
	-	Conducted milling of soya splits, (Full fat) and made flour successfully, without blinding screen. Need to continue fine-tuning conditions. Entire mill needs redesigned for cleaning and sanitation acceptability.
Thursday - 15 Feb., 1990	-	Conducted milling tests on medium scale pin-disk mill at Central India Flour Mills. (Abhay Kandya). Principle works. Needs better cleaning design. Sieve does not blind. Product feels less oily, and low heating as compared with hammer mill.
Friday - 16 Febn., 1990	-	Conducted milling tests on 10 inch burr mill, at CIAE. Low capacity and high temperature increase. Sanitary design un-acceptable for food use. Dressing and alignment of stone surfaces is a problem.
Saturday - 17 Feb., 1990	-	Crushed soy dhal of different moisture contents with Hardness tester and Instron. Observed results with microscope.
Sunday - 18th Feb., 1990	-	Rest Day
Monday - 19th Feb., 1990	-	Finished Instron tests on beans of different moisture contents. Analysed data. Conducted sieve analysis and moisture analysis on samples milled last week.

Tuesday, 20 Feb., 1990	-	Did calculations on sieve analysis. Wrote on report. Planned tomorrow's experiments. Visited Local 'Village Scale' miller (125 kg/hr, stone mill). Stone dressing techniques are simple but inadequate. Mill difficult to clean.
Wednesday, 21 Feb., 1990	-	Wrote on report and did calculations
	-	Conducted power consumption experiments on soybeans at different moisture contents, in small instrumented Fixed-Hammer mill.
	-	Visited with Dr. Jambunathan of ICRISAT.
Thursday, 22 Feb '90	-	Attended opening Session of the "Industrywise conference in the Field of Crop Protection Equipment"
	-	Discussed SPU - milling progress with research group.
	-	Did calculations and additional report writing.
Friday, 23 Feb '90	-	Analyzed Moisture & Particle size data.
	-	Calculated Energy Consumption
	-	Designed/specified Mill to meet objectives. Pin-disk mill with screen.
	-	Prepared Figures & Tables for report.
Saturday 24. Feb.'90	-	Visited Surya Agroils Ltd., Salamatpur (Soya Plant). (Menon, Tata, & Krishnan)
	-	Visited Britannia Industries Ltd. Soya Complex, Vidisha. (Krishna & Sharma).

Sunday, 25 Feb.'90	-	Wrote on Report. Met with Dr. Srivastava, CIAE Director.
Monday 26, Feb'90	-	Complete report - first draft.
	-	Discussion with Dr. Nawab Ali, Project Director.
	-	De-briefing with entire SPU group. (ca. 30 people)
Tuesday 27, Feb.'90	-	Fly Bhopal to Delhi
	-	Meet with Winrock Staff
	-	Term-in Report for typing.
	-	Corrections & Additions.
Wednesday 28 Feb'90	-	Complete de-briefing - Delhi US AID and ICAR.
Thursday 1 March'90	-	Fly Delhi - Manhattan, KS

APPENDIX 3

Experimental Data

List of Tables

1.Data: Soy Dhal through three small commercial mills

2. First break strength, Soy Dhal at various moisture contents

3. Small Hammer Mill tests on Dhal splits at different moistures, with 1.5 mm screen perforations

4. Randomized Complete Block Experimental Design Recommendations

List of Figures

1. Particle Size Distribution through small commercial mills.

2a. Net Specific Power Consumption as a function of Moisture Content.

2b., Percent Fines (-300 micron) as a function of Moisture Content.

3. Suggested Pin-Mill Design

4. Showing How to Integrate Energy Requirements

5. Incomplete Block Design for 3 variable/3 Level Experiment.

Table 1

Test Results Summary

Soy Dhal through three small commercial Mills

Mill:	Hammer			Pin-Disk			Stone Burr		
Speed, RPM	3000			2600			740		
Size	Screen width 4"			Screen width 3½"			Stones Diameter 10"		
	Screen diameter (180°) 12"			Screen diameter (360°) 12"					
Screen Hole Size	2mm		0.5mm	0.5mm			N.A.		
Test:	1 Pass	2 Pass	1 Pass	#1	#2	#3	#1	#2	#3
Kg/min.*	1.82	-	0.83	0.89	0.51	0.71	0.31	0.29	0.43
Watt-hr/kg	11.1	-	25.2	25.3) 6.6)	**50.8	43.6	29.8	34.7	28.1
Screen Analysis:	%	%	%	%	%	%	%	%	%
+ 100	0.9	-	-	1.1	-	-	-	-	0.5
- 100 + 85	4.0	1.2	-	2.6	-	-	0.9	0.2	0.7
- 85 + 60	3.0	1.4	-	0.7	-	-	0.9	0.6	0.5
- 60 + 50	13.3	8.2	-	1.5	6.2	2.9	8.2	4.5	4.2
- 50 + 30	18.4	19.1	0.2	17.3	19.4	15.5	14.8	15.3	10.6
- 30 + 15	20.0	19.4	25.9	61.8	15.2	22.7	21.1	22.1	23.6
- 15 (Pan)	40.4	50.7	73.9	15.0	59.2	58.9	54.1	57.3	59.9
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Weight Avg. Dia., microns	304	237	133	277	205	188	221	199	196
- 30 total flour, %	60.4	70.1	99.8	76.8	74.4	81.6	75.2	79.4	83.5
Temp. rise, °C (Not equilibrium)	7	-	16	-	-	-	13	18	23

* Eventual target = 100 kg/hr

** Appears to be error in data collected. Watt-hr/kg does not agree with weight-average diameter

Table 2

Single-split First Break strength

Soydhal at various moisture contents

Sample No.	Instron Force, kg			Hardness tester, kg			% Moisture
	n	$\bar{x}$	s	n	$\bar{x}$	s	
1*	- Plastic Flow, No end point-			10	6.24	1.95	15.22
2	5	3.78	1.12	10	2.24	0.57	10.47
3	5	3.46	1.33	10	2.66	0.23	9.42
4	5	4.05	0.89	10	2.73	0.42	8.29
5	5	4.21	0.61	10	2.89	0.82	5.81
6	5	4.33	0.90	10	3.32	0.87	6.00
7	5	4.12	0.48	10	3.56	1.30	5.24
8	5	4.04	0.54	10	3.84	1.17	5.25

* Plastic flow at high moisture contents. Therefore results un-certain.

Linear Regression, Hardness tester value Vs % Moisture Content:

$$Kg = 4.72 - 0.23\,\%\,M.C. \qquad r = -0.49$$

Linear Regression, Instron value Vs % Moisture Content:

$$Kg = 4.74 - 0.10\,\%\,M.C. \qquad r = -0.46$$

Table 3

Small Hammer Test Mill on Soy Dhal Splits at Various Moisture Contents

Rotor: 3000 RPM, 5" diameter, four 2 1/4" wide fixed Hammers
Screen: 5 1/2" diameter, 150 degree, 1 3/4" wide, 1.5 mm holes.

Sample	% Moisture	g/min	Watt.hr/Kg*	%-30IS	Rise** deg.C
A	2.78	142.9	35.1	71.13	9
H	3.12	214.6	22.6	65.23	13
K	5.00	187.3	27.1	71.76	14
B	5.57	176.7	28.5	70.50	4
G	5.60	171.2	28.5	63.78	15
F	5.73	136.2	37.3	72.83	12
I	6.16	187.3	24.9	70.10	16
D	6.20	190.8	24.4	71.88	9
J	8.43	107.1	49.5	60.00	17
E	10.81	95.2	52.8	53.93	10
C	13.50	100.0	61.3	53.50	10

Linear Regression: N.S.P. = 12.17 +3.54 (%M.C.). r= 0.86

%Fines = 78.11 -1.85 (%M.C.) r= -0.81

* Net specific power,NSP, after subtracting "No-Load" power, in watt-hours per kilogram

** Mill Temperature Not yet at equilibrium. Ambient Temperature = 23 degree C.

Note: Experiments performed in sample alphabetical order, but reported in this table by increasing moisture contents.

Table 4

Randomized Complete Block Experimental Design

Run I.D.	Temperature	Screen Size	Moisture
1	L	L	L
2	"	"	M
3	"	"	H
4	"	M	L
5	"	"	M
6	"	"	H
7	"	H	L
8	"	"	M
9	"	"	H
10	M	L	L
11	"	"	M
12	"	"	H
13	"	M	L
14	"	"	M
15	"	"	H
16	"	H	L
17	"	"	M
18	"	"	H
19	H	L	L
20	"	"	M
21	"	"	H
22	"	M	L
23	"	"	M
24	"	"	H
25	"	H	L
26	"	"	M
27	"	"	H

Notes: (1) L.M & H represent Law, Medium and High values for each variable.

(2) though theoretically desirable, a completely randomized design is not practical because of time required to reach temperature equilibrium and to change screen sizes. Therefore, run all at low, then medium and finally at high temperatures. Within a given temperature, the order of screen sizes is to be randomized. All moistures to be randomized and run before changing screens.

(3) Always run one "throw-away" sample (do <u>not</u> collect data) each time temperature and/or screen is changed.

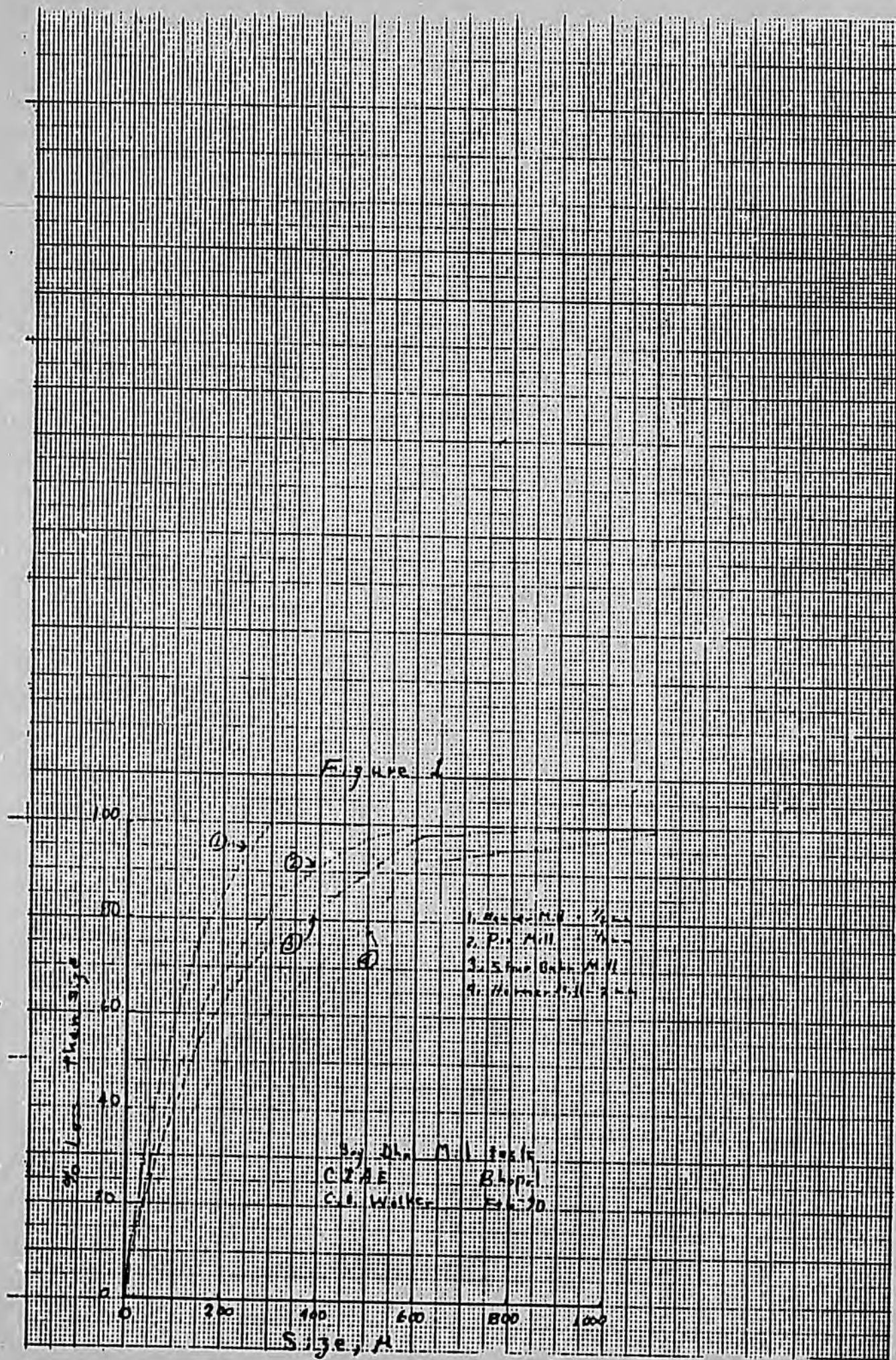
Figure 1
100
80
60
40
20
0
% Less than size
0
200
400
600
800
1000
Size, μ
1
2
3
4
2. Pin Mill
3. 5 Pin Bar Mill
C.I.A.E.
Bhopal
C.L. Walker

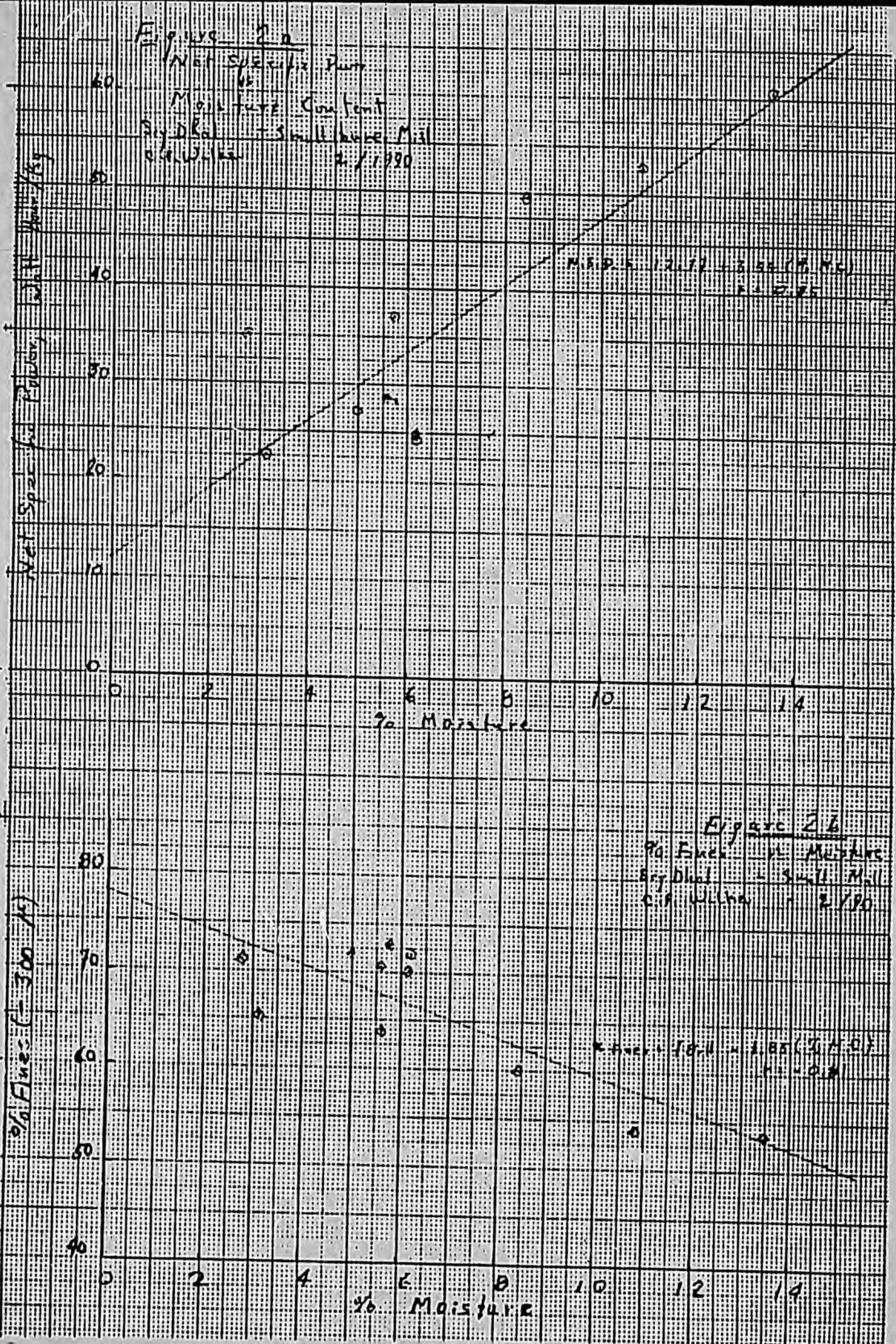
Figure 2a
Net Specific Power
vs
Moisture Content
Net Specific Power, Watt Hour/Kg
% Moisture
Figure 2b
% Fines vs Moisture
% Fines (-300 μ)
% Moisture

Fig.3

Suggested Pin-Mill Design
(Not to scale)

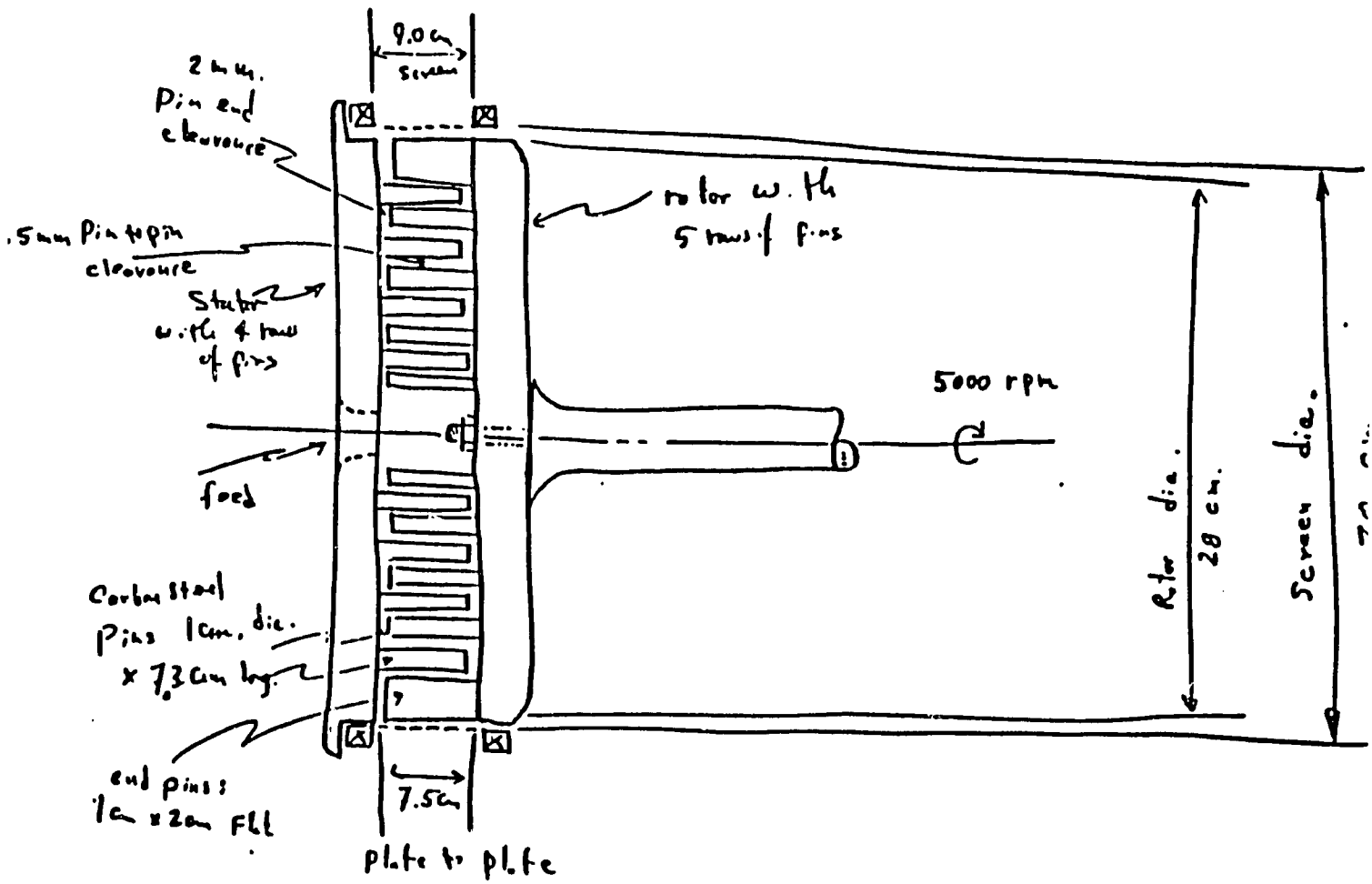

Fig.4

Showing Integration of Milling Energy Required by Sample.
(Plot Points Each 10 Sec.)

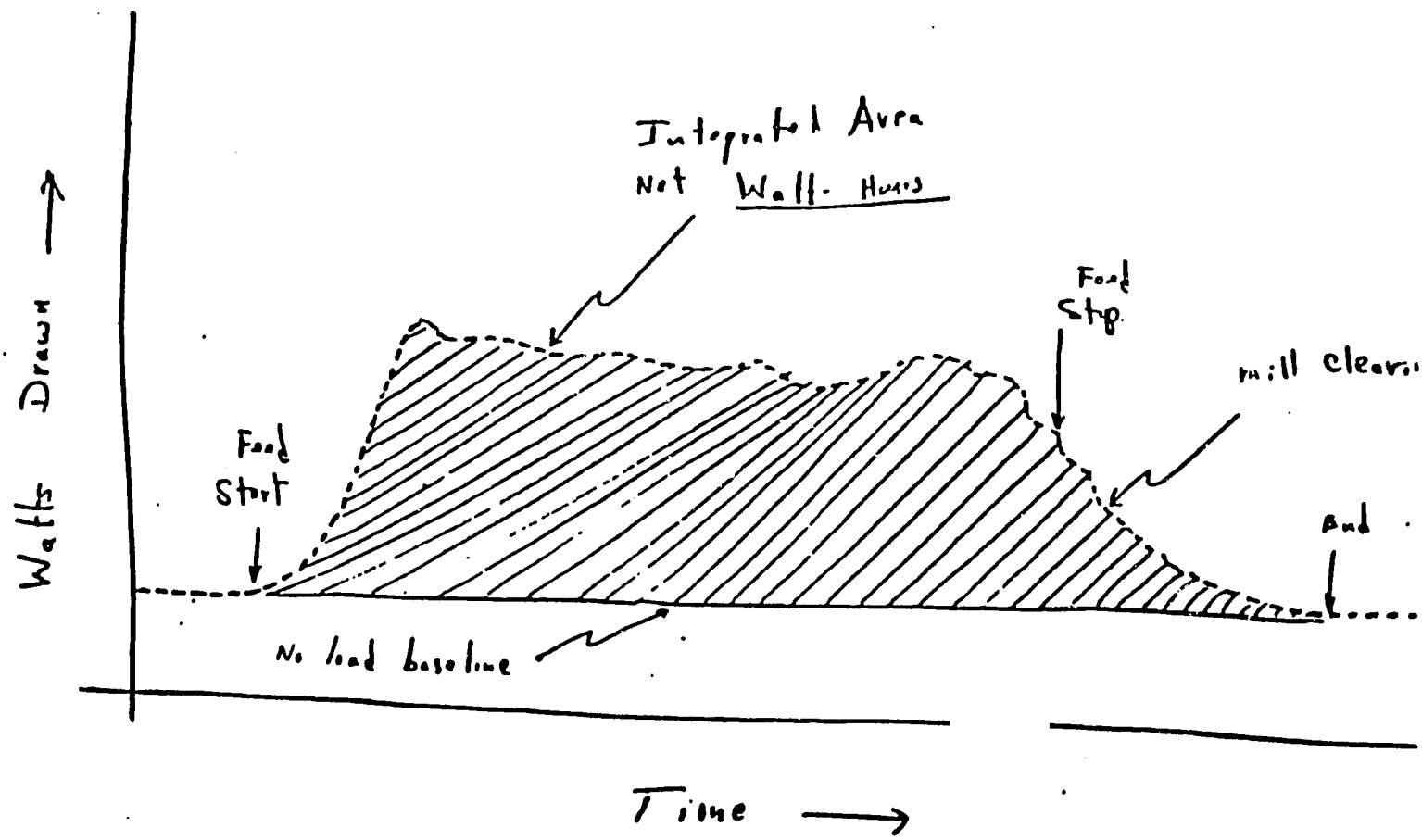

Figure 5

Incomplete Block Design for three variable, 3 Levels
Suitable for Response Surface (RSM) Analysis

Variable X

		X_1			X_2			X_3		
VAR	Y_1	Z_1	Z_2	Z_2	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3
IAB	Y_2	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3
LE "Y"	Y_1	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3

Where X,Y&Z = the three Independent Variables, and 1,2 & 3 represent the three levels or magnitudes, Law, Medium & High.

A Complete block design would require all 27 combinations, or cells. An RSM incomplete-block would use only those combinations circled. A minimum of 9 are required to solve the equations required, but 2 extra are usually assigned to the center cell, for a full total of 11 experimental runs, instead of 27.