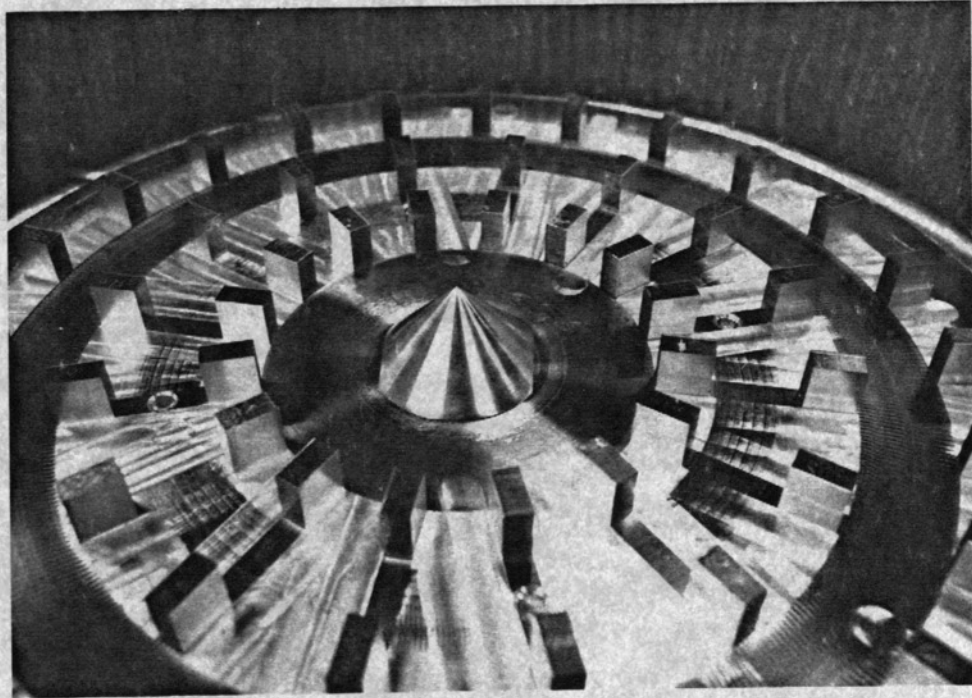


DESIGN OF THE TERMITE-100

A CELLULOSE SHREDDING MACHINE



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Design of the Termite 100
A Cellulose Shredding Machine

Tennessee Eastman Internship

The Termites

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Abstract

The objective of this project was to design a device to reduce the size of cellulose chips used in the cellulose esterification process. The chosen design incorporated a radial flow device which utilized mating rotor and stator disks with teeth milled into their surfaces in order to shear the cellulose apart. Due to the empirical nature of the process a prototype, the Termite 100, was built. Testing of the prototype was performed in order to determine the flow characteristics through the machine, the effects of the mixture consistency, the number of passes, and the axial clearance between the disks on chip size reduction. The reduction in chip size increased with the number of passes and decreased with increasing axial clearance. However, as the axial clearance was reduced, problems with clogging occurred. Modifications of the machine were proposed to overcome these feed problems and to stabilize operation. These design modifications incorporated rotation about a vertical axis to utilize gravity with an off center feed mechanism. This would allow the cellulose to enter a more active zone in the rotor. The Termite 100 established the plausibility of shredding cellulose with such a radial flow machine and broke ground in its empirical development.

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Introduction

The esterification of cellulose involves converting cellulose stock into cellulose acetate. One of the critical factors determining the time required for the entire process is the size of the cellulose chips entering the acetylator. The objective of this project was to design a device to reduce the size of cellulose chips making them more reactive in the acetylator.

Initial attempts were made to model the physical phenomena which occur during the shredding of cellulose. Some of the models investigated included a drag model, a friction model, an impact model, and a strain energy model. The applicability of these models to the cellulose mixture which consisted of solid cellulose, liquid reagent, and entrapped air was questionable. An attempt was also made to model the device using a pump theory. Again this effort was deemed impractical. Therefore, it was decided that the best way to obtain data was through experimentation.

After looking at an axial flow rotor and stator pulp beater, and a radial flow disk refiner, the chosen design employed a hybridization of both concepts. This involved two disks on which rows of radial teeth were milled. One of the disks rotated, while the other disk was stationary. Cellulose was sheared due to the small clearances between the teeth of the rotor and the stator. Machines for the processing of cellulose are generally developed empirically, thus it was necessary to design and build a prototype in order to determine the effectiveness of the design. In order to facilitate testing and accessibility, the prototype was initially designed to be mounted on a machine lathe. This allowed the testing of the blade configuration without the expense of building a complicated housing and drive system. Once the prototype was completed and assembled, testing was performed in order to determine the shredding effects on different cellulose and water mixtures. The mixing characteristics of the design were also evaluated by injecting a colored dye at different places within the device. This prototype was dubbed the "Termite 100".

Theory of Operation

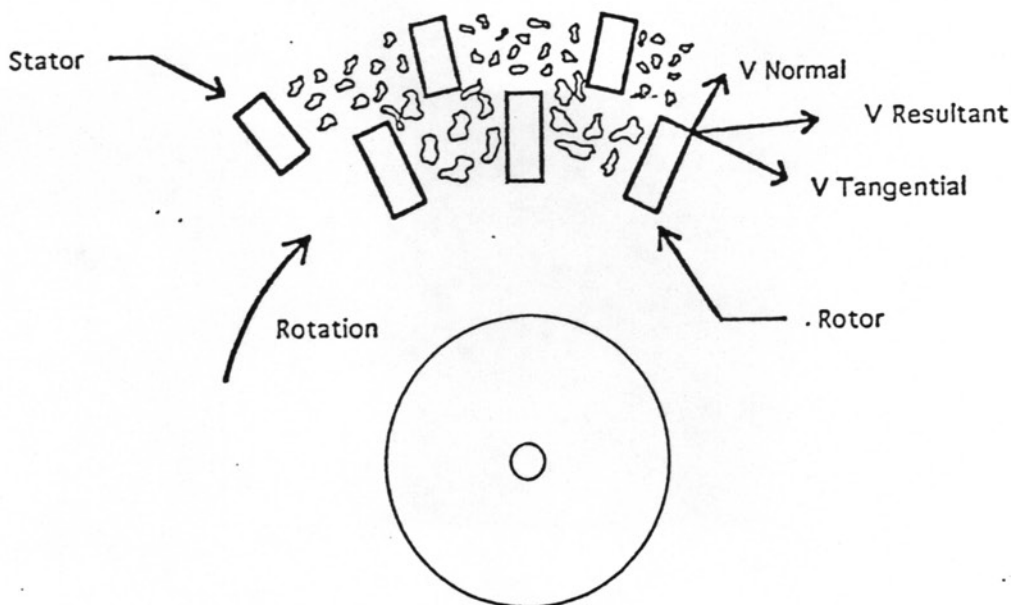
Flow through the Termite 100 is similar to that in a centrifugal pump. Chips of cellulose are accelerated tangentially by the rotor teeth and, due to centrifugal force, they slide radially outward across the face of the tooth and into the following row of stator teeth. An impact then occurs between the moving particle of cellulose and a stator tooth. Chips also experience friction and shear between the counter rotating surfaces. Using an impact model the energy input to the cellulose is related to the radius of the disks and the angular velocity where:

$$E = 0.5 \times M \times (r \times w)^2 \quad \text{where:}$$

E = energy
 r = radius
 w = radial velocity
 M = mass

Although activity in the machine is complicated and involves components of impact, friction, and transverse shear, this squared relationship offers potential for increasing or decreasing the amount of energy input to the material and would facilitate control of the process. Figure 1 helps explain the flow through the Termite 100.

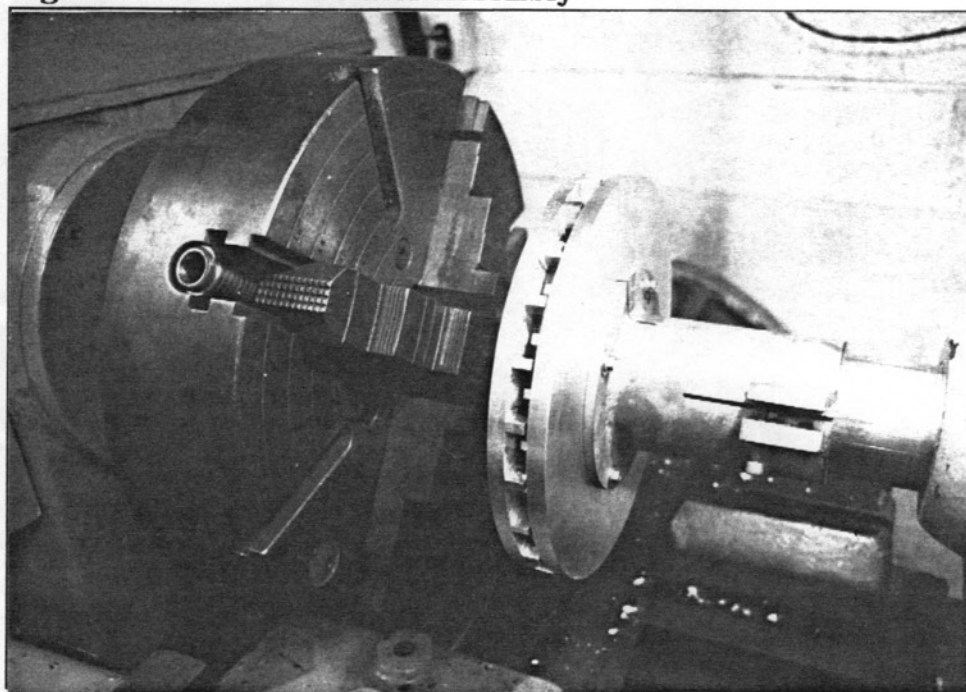
Figure 1 Centrifugal flow



Detail of Design

The Termite 100 consisted of two 12 in. diameter parallel disks with multiple arrays of annular blades. The rotor disk contained four arrays, while the stator disk contained three arrays. These blades rotated concentrically with clearances of $1/8$ in. The rotor was mounted in the lathe's chuck, while the stator was mounted on the tailstock, as shown in Figure 2. The rotor was attached to a flange welded

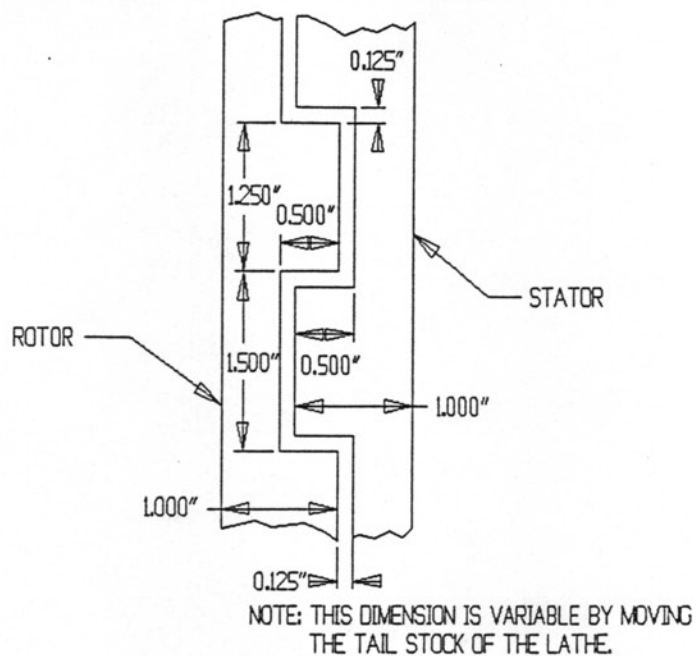
Figure 2 Rotor and Stator Assembly



to a 2 in. pipe running through the head stock of the lathe. Cellulose was fed through this pipe and into the shredding zone between the disks. The attachment of the stator to the tail stock insured a true center for both disks and allowed control of the axial clearance between the disks. Detailed drawings of the rotor and stator can be found in the appendices.

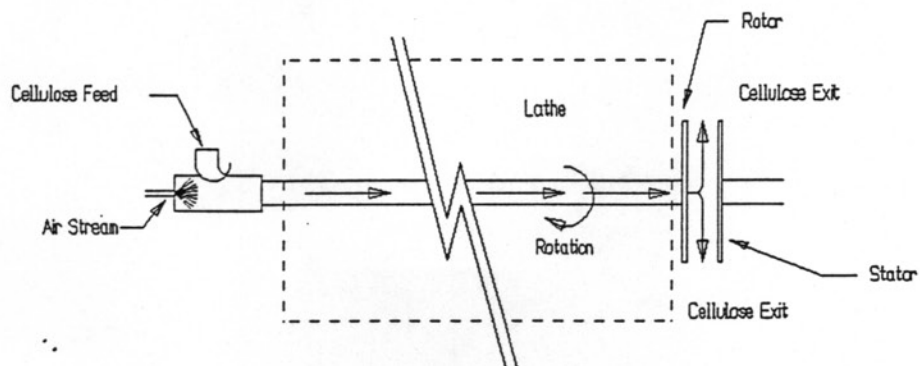
Radial teeth were milled into the surfaces of both disks. This geometry was not chosen in order to optimize the shape of the teeth, but to make the rotor and stator easier to manufacture. The opposing motion of these teeth created the shearing action needed to shred the cellulose fibers. The stator teeth had a thickness of $1/4$ in., a height of $1/2$ in., and a radial length of 1 in. The rotor teeth

Figure 3 Rotor and Stator Tooth Configuration



had the same thickness and height, but had a radial length of $1/4$ in. Figure 3 shows the alignment of the teeth with their clearances.

Figure 4 Flow Diagram

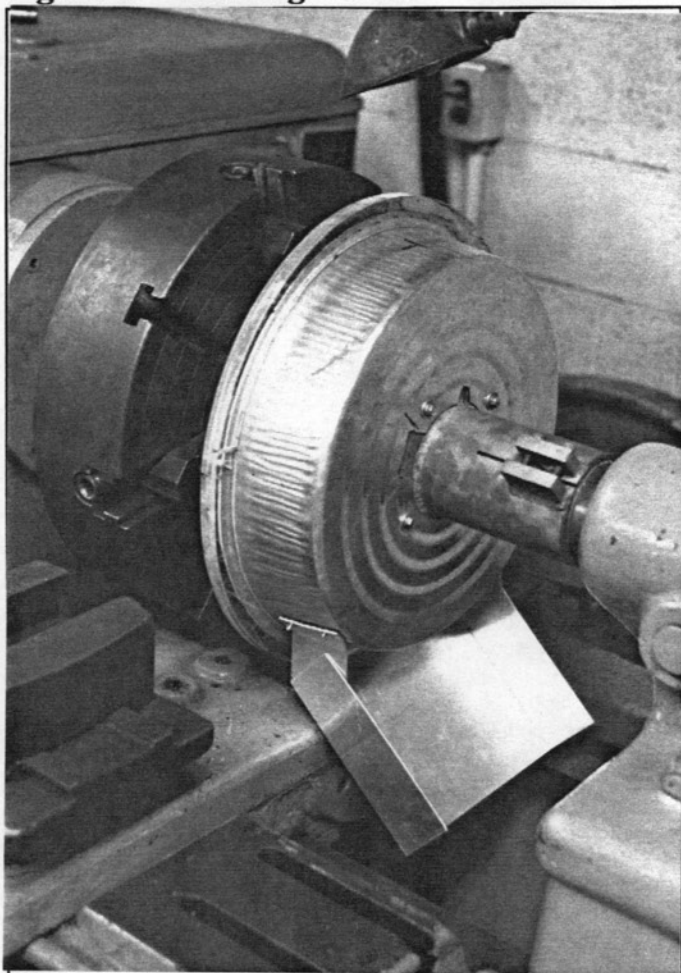


Initial attempts to feed the cellulose by means of a ram rod resulted in jamming of the pipe with compressed cellulose. For this reason an apparatus consisting of a PVC "T" joint was added to convey the cellulose into the shredding zone by means of an air stream. Figure 4 shows a schematic of this feed mechanism.

To test the mixing capability of the Termite 100 a small hole was drilled into the center of the stator. This hole allowed Rit dye (Scarlet # 5) to be injected by means of a syringe. A hole was also drilled into the "T" joint to allow dye injection upstream from the cellulose feed.

The shredding disks were enclosed with a sheet metal shield to collect the processed cellulose and deposit it in a hopper. A plexiglass window allowed monitoring of the exit flow from the disks. This is shown in figure 5.

Figure 5 Collecting Shield



Testing Procedure

Once the Termite 100 was manufactured, it was mounted onto the lathe which would drive the rotor stage. Testing was then performed in order to determine the shredding effects on various cellulose samples. All tests were performed at a rotational speed of 312 rpm, the maximum operating speed of the lathe. Using the air feed as previously described cellulose was added at a steady rate of approximately 0.1 lbm/min by hand (see Figure 6). Several parameters

Figure 6 Feed Mechanism



were investigated during testing such as water to cellulose ratio, axial blade clearance, and mixing characteristics. Samples varying from 100% cellulose to 16.7% cellulose by weight were tested for chip size reduction. The axial clearance between the rotor teeth and the stator disk was varied from 1/8 in. to 1/4 in. during these trials. Dry cellulose was run through the shredder four times in order to determine the benefits of multiple passes. The amount of mixing which occurred during the shredding process was determined by injecting a red dye through the center of the stator disk as cellulose was being shredded. This would simulate the addition of reagents during the shredding process. Tests

were run for dye flow rates of about $1.8 \text{ in}^3/\text{min}$ and $3.7 \text{ in}^3/\text{min}$ for dry cellulose and about $2.5 \text{ in}^3/\text{min}$ for a 33.3% cellulose mixture. Testing was concluded by injecting the dye directly into the air upstream from the cellulose. This was performed using approximately a $2.5 \text{ in}^3/\text{min}$ flow rate for a 25% cellulose mixture.

Data Analysis

The determination of the operational characteristics of the Termite 100 relied heavily upon the data collected during testing. Results were quantified by measuring the largest dimension of 50 chips randomly selected from each sample. These were then compared to control samples taken during testing. Data collected for the dry cellulose is presented in Table 1.

Table 1 - 100% Cellulose

sample description	average chip diameter (in)	percent reduction
control	0.465	-
1/4 in. clearance		
pass #1	0.455	2.15
pass #2	0.446	4.09
pass #3	0.366	21.29
pass #4	0.335	27.96
control	0.370	-
1/8 in. clearance	0.336	9.19

As shown by the data, chip size decreased with each successive pass through the shredder. This same result might be achieved by increasing the diameter of the disks and subsequently the number of arrays of teeth. The data also showed that the amount of shredding increased by about 7% with the smaller axial clearance. Table 2 shows the data for a 50% cellulose mixture.

Table 2 - 50% Cellulose

sample description	average chip diameter (in)	percent reduction
control	0.405	-
1/4 in. clearance	0.347	14.32
control	0.354	-
1/8 in. clearance	0.264	25.42

This data shows that decreasing the axial clearance from 1/4 in. to 1/8 in. almost doubled the reduction in the size of the cellulose chips. Table 3 shows the data collected from the 33.3% cellulose samples.

Table 3 - 33.3% Cellulose

sample description	average chip diameter (in)	percent reduction
control	0.384	-
1/8 in. clearance	0.290	24.48
3/16 in. clearance	0.339	11.72
1/4 in. clearance	0.331	13.80

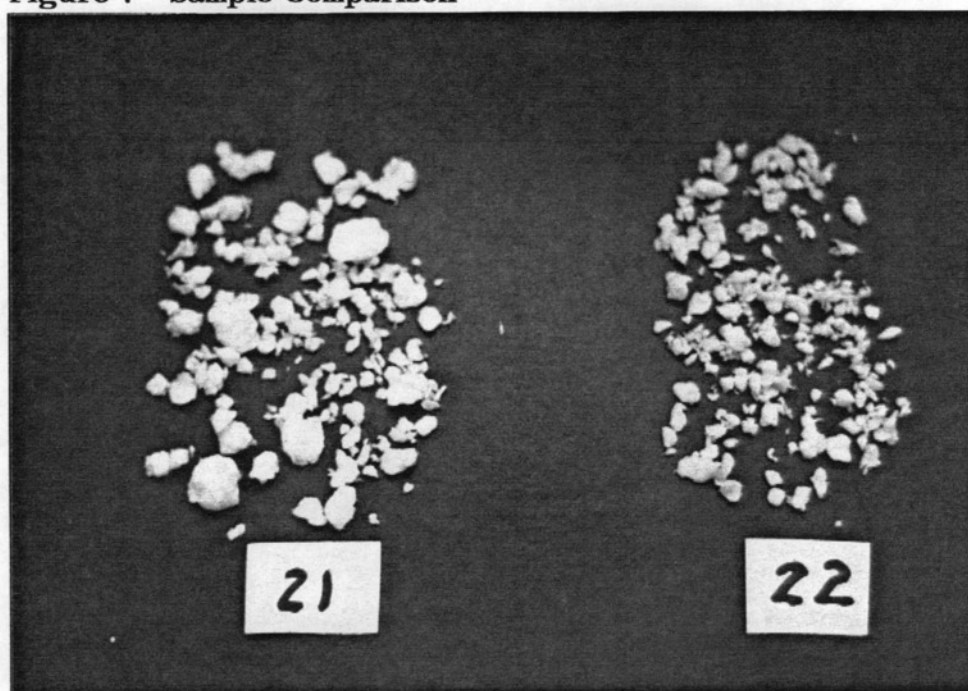
The largest percent reduction in chip size was for an 1/8 in. axial clearance. The percent reduction for the 1/4 in. and 3/16 in. clearances, however, were fairly close. Table 4 shows the remaining data collected for mixtures of 25%, 20% and 16.7% cellulose respectively. Figure 7 shows a comparison of the sample

Table 4 - Variable Water to Cellulose Mixtures

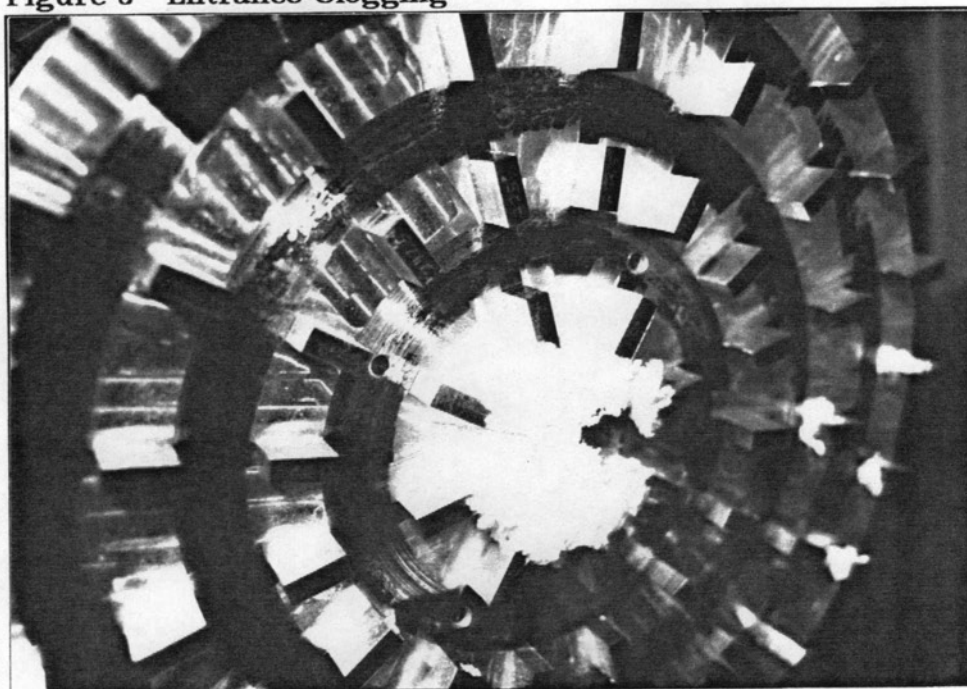
sample description	average chip diameter (in)	percent reduction
25% cellulose:		
control	0.468	-
3/16 in. clearance	0.305	34.83
20% cellulose%		
control	0.444	-
3/16 in. clearance	0.269	39.41
16.7% cellulose:		
control	0.249	-
1/8 in. clearance	0.168	32.53

produced for the 16.7% cellulose mixture with its control.

Although the quantitative data was an important result from the testing of the Termite 100, some of the most valuable information could not be described quantitatively. Such information included attempts at preventing the cellulose from clogging both in the feed pipe and at the entrance to the shredder. For example the ram rod feed mechanism was replaced by an air stream feed mechanism to correct a pipe clogging problem. A different clogging problem then arose as cellulose began to pack together and clog up on the rotor at the entrance to the shredding zone as shown in Figure 8. At the entrance to the disks the axial cellulose stream must be redirected into a radial flow. The small radius at this point imparts a relatively small centrifugal force to accomplish a redirection

Figure 7 Sample Comparison

of the flow. It was suspected that contact with the stator prevented rotational movement of the cellulose thus arresting centrifugal force and limiting the radial

Figure 8 Entrance Clogging

force component to the effects of gravity. This was not sufficient to move the cellulose through the transition area. Cellulose would then buildup as the air pressure would begin to pack the cellulose together. In the initial stages of testing, clogging eventually occurred with each test involving mixtures drier than 16.7% cellulose. It was found, however, that the 16.7% cellulose mixture would pack together to form a conical shape at the center of the stator face. Such a cone can be seen in Figure 9. Clogging did not occur for any sample in which

Figure 9 Cellulose Cone

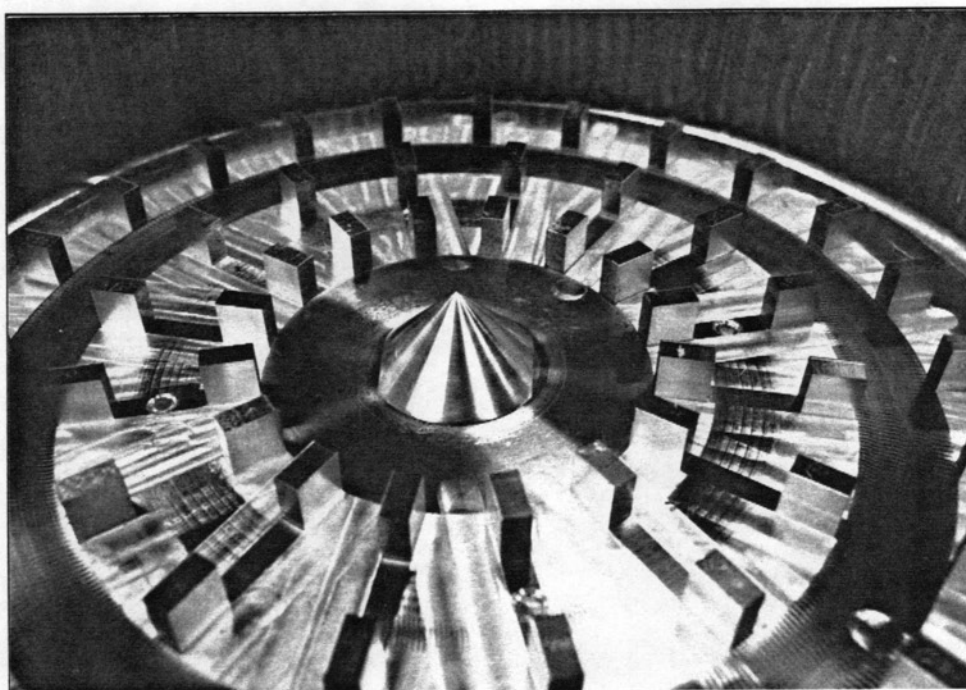


this cone of cellulose was present at the center of the stator. Therefore, an aluminum cone was designed to screw into a hole drilled at the center of the stator, shown in Figure 10. The first test with the newly added cone involved a 50% mixture with a clearance of $1/8$ in. Clogging quickly occurred. The horizontal clearance was then increased to $1/4$ in. As a result, clogging did not occur, although the resulting size of the processed chips was less than that found for a $1/8$ in. clearance. Throughout the remaining tests, clogging did not occur for any samples in which a clearance of $1/4$ in. or $3/16$ in. was used. Anytime a clearance of $1/8$ in. was used, however, clogging would eventually occur. It is

believed that the cone was a success due to the fact that as the mixture struck its sloped face, a radial component of velocity was imparted to the cellulose.

Tests were also performed in order to estimate the amount of mixing which would occur within the Termite 100. Dye was injected at the center of the stator for three different samples: dry cellulose with a dye flow rate of about

Figure 10 Cone Assembly



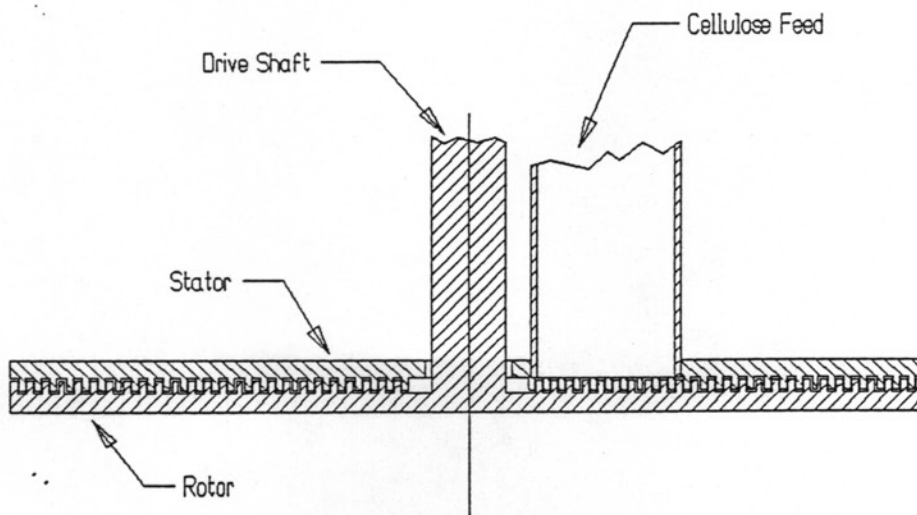
1.8 in³/min, dry cellulose with a dye flow rate of about 3.7 in³/min, and a 33.3% cellulose mixture with a flow rate of about 2.5 in³/min. Mixing seemed to be independent of the water to cellulose ratio of the samples as the dye was evenly dispersed throughout each sample. Approximately 80% of the chips contained dye, thus indicating that the dye had been fairly well distributed during the shredding process. Better dispersion of the dye, however, occurred with the upstream injection as 100% of the chips contained dye.

Recommendations

From observation of the Termite 100 in operation some problem areas were obvious. The most important of these involved feed rate, feed mechanism, and blade configuration. These observations have led the Termite group to some possible modifications to correct certain deficiencies in the prototype.

Of primary importance in a shredding device of this type is the feed mechanism. The original plunger method of feeding produced serious clogging of the pipe. The implementation of an air stream to carry the cellulose and a deflecting cone to assist the flow in making the transition from axial to radial direction resulted in some measure of success in feeding the stock. Operation was not totally reliable however and feed rate was critical in avoiding clogging. Rotating the machine 90° to establish a gravity feed would eliminate the need for the air stream and help to avoid packing of the material (see Figure 11). This

Figure 11 Gravity Feed Design

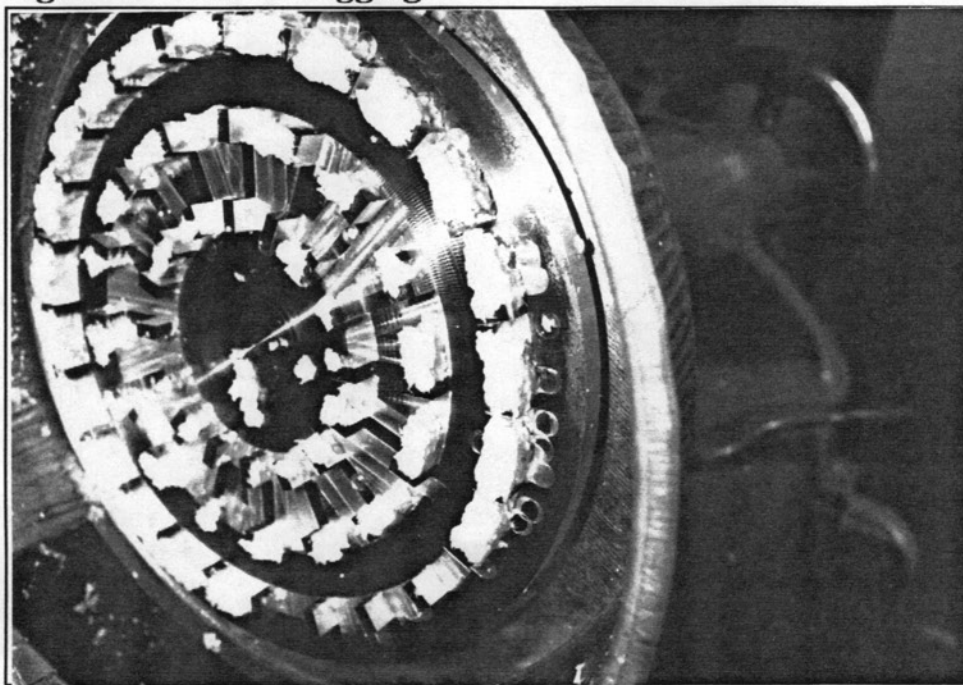


reorientation alone would not address the clogging problem where the cellulose experiences the 90° deflection from axial to radial flow. Exacerbating the situation at this transition zone is the small relative motion between the rotor and

stator in the center of the discs. By feeding the stock through the stator in a position off center from the axis of rotation the cellulose would be entering a region of greater tangential velocity and the material would be moved by a displacement pumping action thus clearing the way for more material. As no substantial clinging was observed on the rotor blades, it is believed that with a rotational speed of at least 300 rpm the rotor blades would be cleared of material by centrifugal force and be ready to accept more cellulose when one rotation is completed.

In the basic rotor stator configuration of the Termite 100 simple blade design was employed to simplify construction. After running the device for a short period of time build up of cellulose was observed on the stator blades as indicated in Figure 12. This led the group to question the dimensions of these

Figure 12 Stator Clogging



blades. By reducing the radial dimension of the stator blades and increasing the number of annular rings of both rotor and stator blades this potential for clogging would be reduced and the number of impacts and shear zones would be increased. Based on the data collected comparing the axial clearance between the disk, it was speculated that increasing the heights of the blades would increase

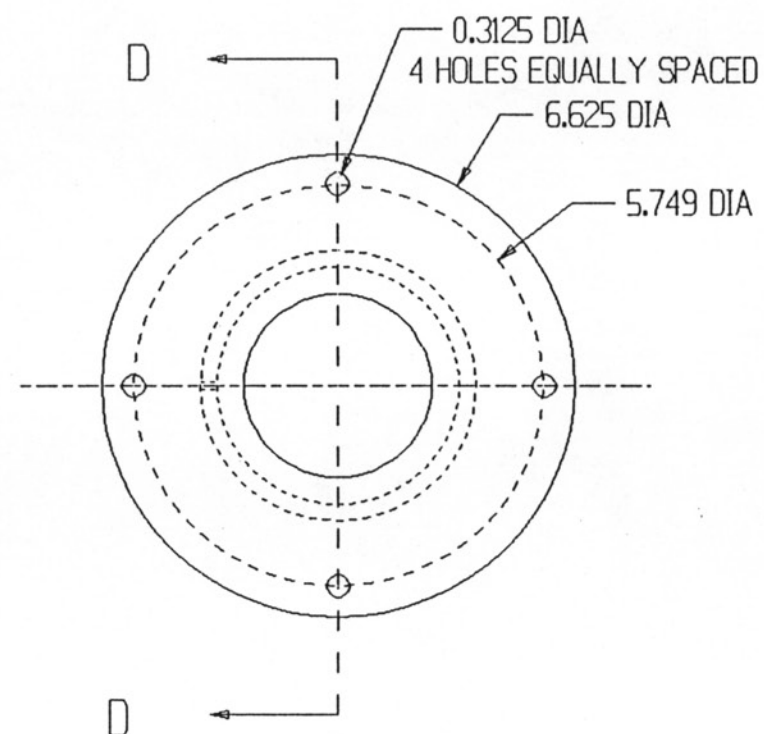
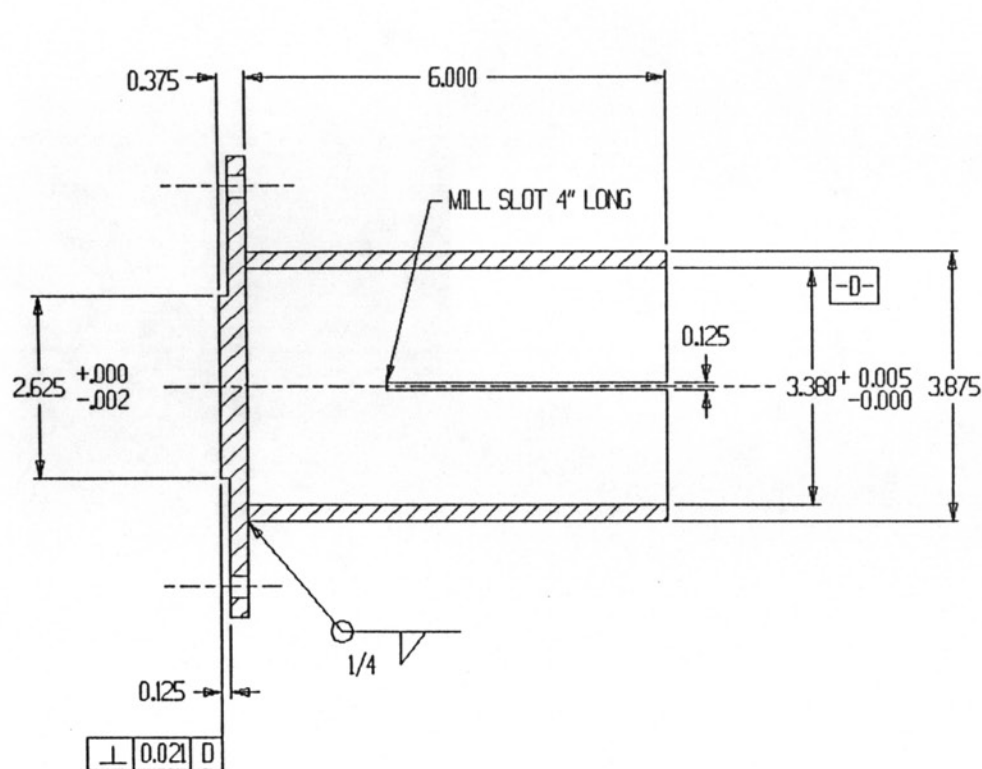
the radial flow area for the cellulose without reducing the shredding surface area.

The build up on stator blades could also be eliminated by producing a double rotating disc machine. By counter rotating one disc with respect to the other the problem of build up would be eliminated by the centrifugal force experienced by the cellulose. This configuration would result in a more complicated machine that would require center feed through a rotating pipe much like the feed in the Termite 100. Once again producing the problem of low mechanical activity at the critical entrance to the disk region. For these two reasons the use of thinner stator blades would probably be the better solution.

Appendices

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	MECHANICAL				MAE-ECC 124

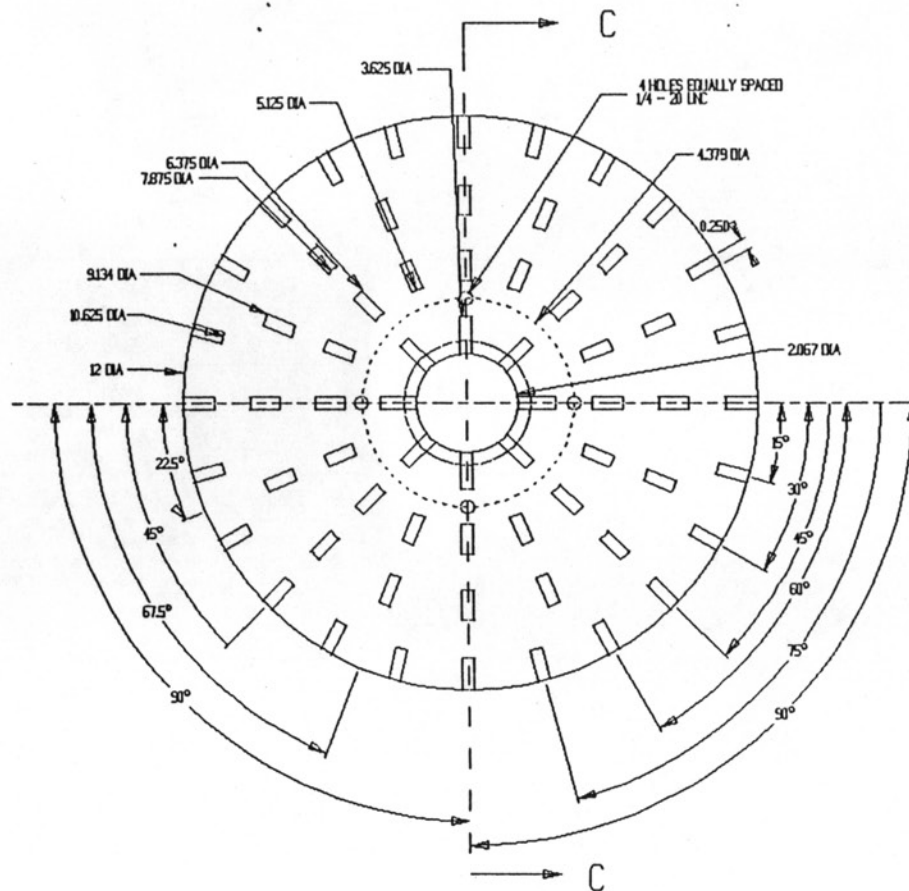
SECTION D-D



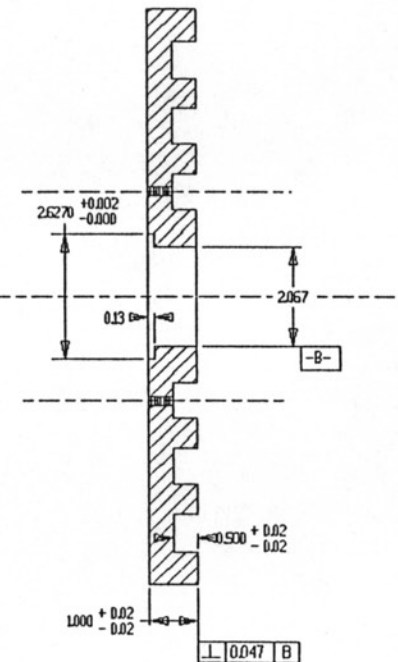
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		LINEAR +/-	0.0075	TITLE	STATOR FLANGE
		ANGLES +/-			
OTHER NOTES		RADII UNLESS NOTED		DESIGNER	GR#2
		EDGE / CORNER BREAKS	OUTSIDE MAX	CHECKED	AJE
IBMCAD FILE			INSIDE MAX	APPROVED	AJE
					3/3/94

THE TERMITE

REL FOR ASM QTY	TECHNICAL APPROVALS	INIT	DATE	EC #	P/N MAE-ECC 122
	MECHANICAL				



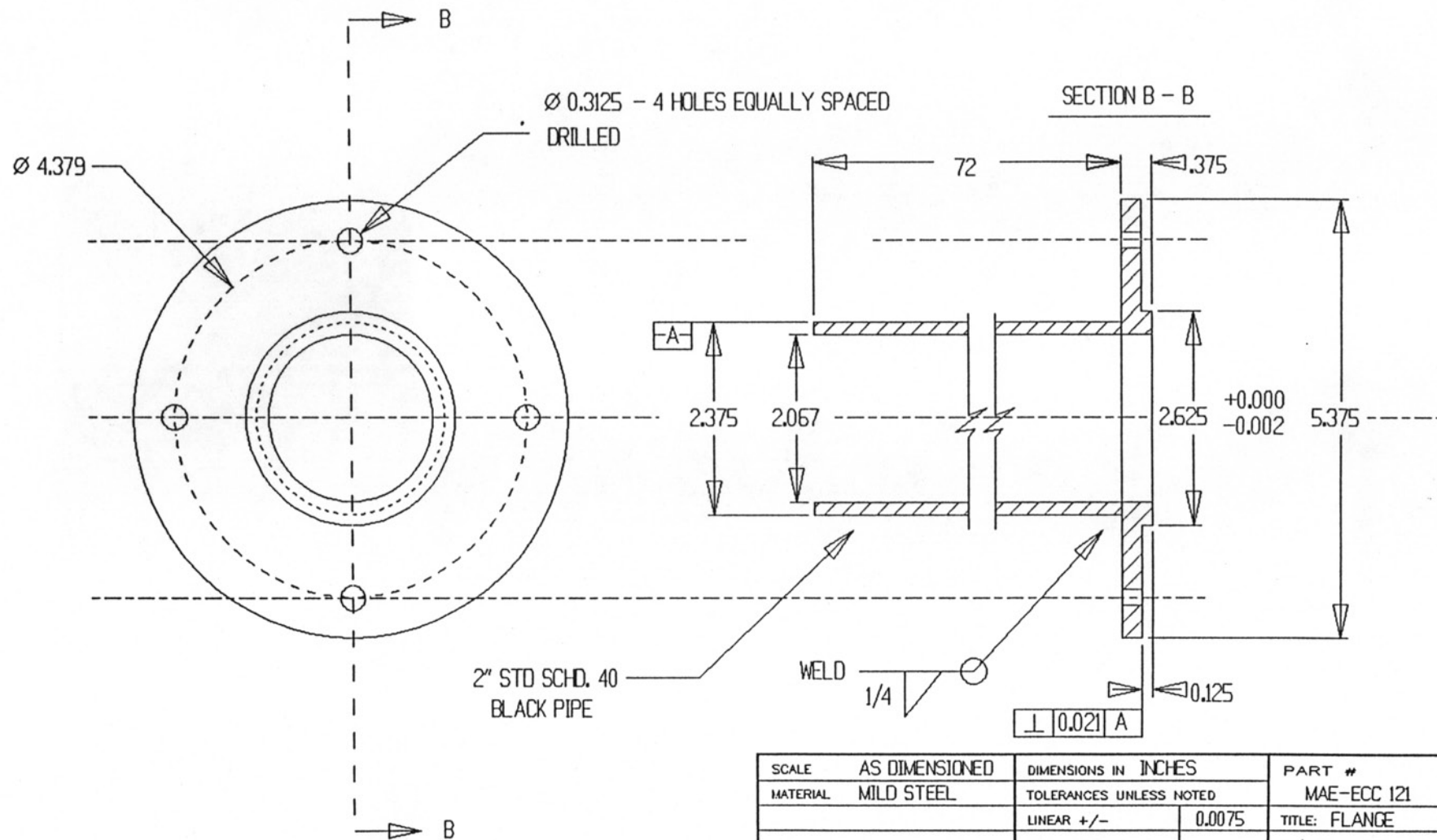
SECTION C - C



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		LINEAR +/-	0.0075	TITLE ROTOR		
		ANGLES +/-	°			
OTHER NOTES		RADII UNLESS NOTED		DESIGNER	GROUP #2	03 03 94
		EDGE / CORNER BREAKS	OUTSIDE MAX	CHECKED	AJE	
			INSIDE MAX	APPROVED	AJE	

THE TERMITES

REL FOR ASM	QTY	TECHNICAL APPROVALS			INIT	DATE	EC #	P/N	MAE-ECC 121	
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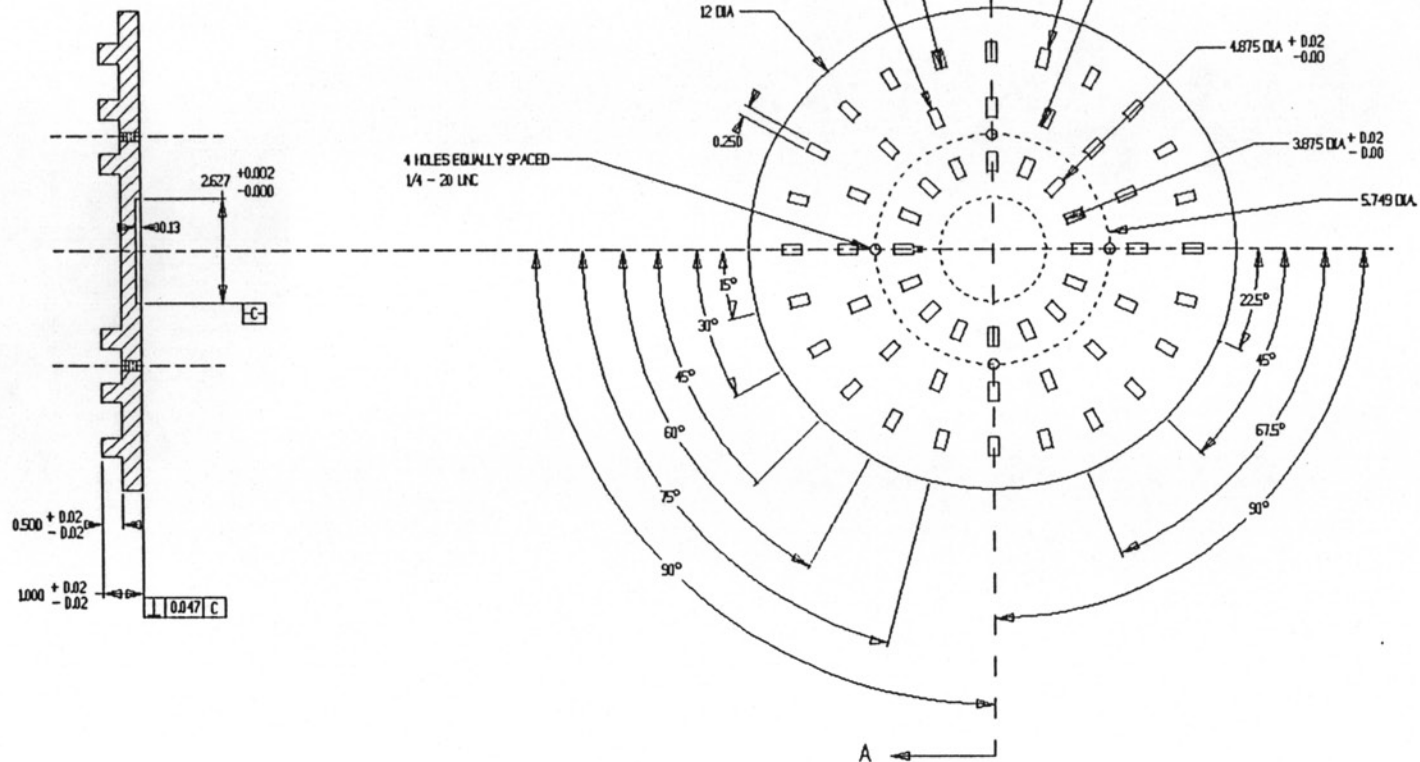


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		EDGE / CORNER BREAKS	OUTSIDE MAX	CHECKED	AJE 03 02 94
			INSIDE MAX	APPROVED	AJE 03 02 94

THE TERMITES

REL FOR ASM QTY	TECHNICAL APPROVALS	INIT DATE	EC #	P/N
	MECHANICAL			MAE-ECC 123

Section A-A



SCALE	AS DIMENSIONED	DIMENSIONS IN	INCHES	PART #	UT
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		ANGLES +/-	1°		
OTHER NOTES		RADII UNLESS NOTED		DESIGNER	GR#2
		EDGE/ CORNER BREAKS	OUTSIDE MAX INSIDE MAX	CHECKED	AJE
IBMCAD FILE				APPROVED	AJE
					3/3/94

THE TERMITES

Analysis of Prototype Testing Data

100% cellulose by weight:

sample description	average chip diameter diameter (in)	percent reduction
control	0.465	-
1/4 in. clearance		
1st pass	0.455	2.15
2nd pass	0.446	4.09
3rd pass	0.366	21.29
4th pass	0.335	27.96
control	0.370	-
1/8 in. clearance	0.336	9.19

50% cellulose by weight:

sample description	average chip diameter diameter (in)	percent reduction
control	0.405	-
1/4 in. clearance	0.347	14.32
control	0.354	-
1/8 in. clearance	0.264	25.42

33.3% cellulose by weight:

sample description	average chip diameter diameter (in)	percent reduction
control	0.384	-
1/8 in. clearance	0.290	24.48
3/16 in. clearance	0.339	11.72
1/4 in. clearance	0.331	13.80

25% cellulose by weight:

sample description	average chip diameter diameter (in)	percent reduction
control	0.468	-
3/16 in. clearance	0.305	34.83

20% cellulose by weight:

sample description	average chip diameter diameter (in)	percent reduction
control	0.444	-
3/16 in. clearance	0.269	39.41

16.7% cellulose by weight:

sample description	average chip diameter diameter (in)	percent reduction
control	0.249	-
1/8 in. clearance	0.168	32.53

Absorbitivity:

100% cellulose

1st pass - 3.7%
2nd pass - 11.1%
3rd pass - 11.1%
4th pass - 22.2%

50% cellulose

1/4 in. clearance - -18.0%

16.7% cellulose

1/4 in. clearance - 14.3%

Prototype Testing Samples Data

all testing done at 312 rpm

Sample: #1

Mixture: 1 part water, 1 part cellulose by weight

Horizontal clearance: 1/4 in.

Average chip diameter: 0.347 in.

Comments: no clogging occurred, feed rate of about 0.08 lbm/min, absorbed 1.46 mL/g of vinegar dye in cellulose

Sample: #2

Mixture: 1 part water, 1 part cellulose by weight

Average chip diameter: 0.405 in.

Comments: control for #1, absorbed 1.78 mL/g of vinegar dye in cellulose

Sample: #3

Mixture: dry cellulose

Horizontal clearance: 1/4 in.

Average chip diameter: 0.455 in.

Comments: 1st pass, no problems with clogging, absorbed 5.6 mL/g of vinegar dye in cellulose

Sample: #4

Mixture: dry cellulose

Horizontal clearance: 1/4 in.

Average chip diameter: 0.446 in.

Comments: 2nd pass, absorbed 6.0 mL/g of vinegar dye in cellulose

Sample: #5

Mixture: dry cellulose

Horizontal clearance: 1/4 in.

Average chip diameter: 0.366 in.

Comments: 3rd pass, feed rate of about 0.12 lbm/min, absorbed 6.0 mL/g of vinegar dye in cellulose

Sample: #6

Mixture: dry cellulose

Average chip diameter: 0.465 in.

Comments: control for #3, #4, #5, #7, absorbed 5.4 mL/g of vinegar dye in cellulose

Sample: #7

Mixture: dry cellulose

Horizontal clearance: 1/4 in.

Average chip diameter: 0.335 in.

Comments: 4th pass, absorbed 6.6 mL/g of vinegar dye in cellulose

Sample: #8

Mixture: dry cellulose

Horizontal clearance: 1/4 in.

Comments: dye added at 1.8 in³/min

Sample: #9

Mixture: dry cellulose

Horizontal clearance: 1/4 in.

Comments: dye added at 3.7 in³/min

Sample: #10

Mixture: 2 parts water, 1 part cellulose by weight

Average chip diameter: 0.384 in.

Comments: control for #11, #12, #13

Sample: #11

Mixture: 2 parts water, 1 part cellulose by weight

Horizontal clearance: 1/4 in.

Average chip diameter: 0.331 in.

Sample: #12

Mixture: 2 parts water, 1 part cellulose by weight

Horizontal clearance: 1/8 in.

Average chip diameter: 0.290 in.

Comments: clogging occurred again

Sample: #13

Mixture: 2 parts water, 1 part cellulose by weight

Horizontal clearance: 3/16 in.

Average chip diameter: 0.339 in.

Comments: dye added at 2.5 in³/min

Sample: #15

Mixture: dry cellulose

Average chip diameter: 0.370 in.

Comments: control for #16

Sample: #16

Mixture: dry cellulose

Horizontal clearance: 1/8 in.

Average chip diameter: 0.336 in.

Comments: clogging occurred, test run before the addition of the cone at the center of the stator

Sample: #17

Mixture: 2 parts water, 1 part cellulose by weight

Average chip diameter: 0.348 in.

Comments: control for #18

Sample: #18

Mixture: 2 parts water, 1 part cellulose by weight

Horizontal clearance: 1/8 in.

Average chip diameter: 0.265 in.

Comments: clogging occurred, test run before the addition of the cone at the center of the stator

Sample: #19

Mixture: 1 part water, 1 part cellulose by weight

Average chip diameter: 0.354 in.

Comments: control for #20

Sample: #20

Mixture: 1 part water, 1 part cellulose by weight

Horizontal clearance: 1/8 in.

Average chip diameter: 0.264 in.

Comments: clogging occurred, test run before the addition of the cone at the center of the stator

Sample: #21

Mixture: 5 parts water, 1 part cellulose by weight

Average chip diameter: 0.249 in.

Comments: control for #22, absorbed 0.49 mL/g of vinegar dye in cellulose

Sample: #22

Mixture: 5 parts water, 1 part cellulose by weight

Horizontal clearance: 1/8 in.

Average chip diameter: 0.168 in.

Comments: clogging occurred, test run before the addition of the cone at the center of the stator, the cellulose packed into its own cone at the center of the stator, absorbed 0.56 mL/g of vinegar dye in cellulose

Sample: #23

Mixture: 3 parts water, 1 part cellulose by weight

Average chip diameter: 0.468 in.

Comments: control for #24, #27 and #28

Sample: #24

Mixture: 3 parts water, 1 part cellulose by weight

Horizontal clearance: 3/16 in.

Average chip diameter: 0.305 in.

Sample: #25

Mixture: 4 parts water, 1 part cellulose by weight

Average chip diameter: 0.444 in.

Comments: control for #26

Sample: #26

Mixture: 4 parts water, 1 part cellulose by weight

Horizontal clearance: 3/16 in.

Average chip diameter: 0.269 in.

Sample: #27

Mixture: 3 parts water, 1 part cellulose by weight

Horizontal clearance: 3/16 in.

Comments: dye added upstream near the air stream and cellulose mixing point, flow rate of 2.5 in³/min

Sample: #28

Mixture: 3 parts water, 1 part cellulose by weight

Comments: dye on upstream again at 0.69 in³/min, sample was not shredded, just the dye and the cellulose were mixed together

