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Report number **PROGRESS REPORT NO. 4**

MICROWAVE-VACUUM DRYING SYSTEM (MIVAC)*

MASTER

PROGRESS REPORT #4

ERDA CONTRACT NO. E(11-1)-2918

Revision date

Revision letter

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***Patent Applied For**

(before contract)

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1.0 INTRODUCTION

This progress report presents the results of activities performed in partial fulfillment of ERDA Contract No. E(11-1)-2918 during the period September 1977 through May 1978. The goals during this period were as follows:

- (1) Redesign the dryer from the 48 kilowatt size to a 12 kilowatt size to make it compatible with the revised statement of work.
- (2) Procure, fabricate and check components for the dryer.
- (3) Assemble the dryer and perform functional tests of the dryer assembly.

2.0 DESIGN

The design drawing of the dryer is shown in McDonnell Drawing T-055718 (attached). The basic functional elements are the vacuum vessel, the product chute and metering assembly, the vacuum pumping and vapor removal system, the microwave generation and application system, and the product sampler system.

2.1 VACUUM VESSEL. The vacuum vessel is three feet in diameter and approximately twenty-five feet long. The volume of the upper and lower hoppers is approximately nineteen bushels each. Ten-inch diameter knife-gate valves are provided to admit grain to the upper hopper and remove it from the lower hopper. The nominal volume of the empty vessel is 150 cubic feet. The vessel is of welded construction and made of 5086 aluminum alloy. This material is a "marine" alloy commonly used for ships, tanks, trucks and other equipment exposed to corrosive environments.

2.2 PRODUCT CHUTE AND FEEDER ASSEMBLY. Three sizes of product chute have been provided. They are ten, six and four inches in diameter. The purpose of the three different sizes is to permit the flexibility to assess the effects of energy density and penetration depth on grain quality and drying uniformity. Two types of chute material are provided (polypropylene and polyester fabric) in each of the three sizes. This provides redundancy in the event of chute damage and allows some assessment of the relative merits of the different materials. The maximum and minimum nominal power density in the product for each of the chute sizes is shown in Table 1.

The product feeder assembly is a small section of a standard Aeroglide Corporation power discharge unit. The rotor is driven, through a rotary vacuum seal, by a variable D.C. motor drive.

The drive motor is smoothly variable from 0.1 to 3.0 rpm. This provides a product flow variation from 0.4 to 12 bushels per hour. This provides a residence time of each grain kernel in the microwave cavity that can be varied from 3.5 minutes to more than four hours.

The reason for this variability is to provide the capability to determine the optimum operating parameters for many different products. In general, the quality of the product is improved at low drying rates. However, the size of a dryer (and consequently its capital cost) is decreased by increasing the drying rate. The trade-off between the quality and cost factors can be explored using the built-in variability of this test device.

2.3 VACUUM PUMPING AND VAPOR REMOVAL SYSTEM. The vacuum pumping system is shown schematically on sheet 9 of T-055718. The Beech-Russ vacuum pump has a nominal volumetric capacity of fifty cubic feet per minute.

At this rate the pressure in the tank can be reduced to the operating pressure of 20 Torr in about 12 minutes.

The pump is expected to only remove the air from the vacuum vessel. The steam evolved from the grain is condensed on the inner wall of the vessel, runs down into a collection gutter and is then channeled down to the condensate collection tank. The condensate tank may be isolated from the main chamber by a valve, drained, and then returned to service without affecting the system operation.

The walls of the vacuum vessel are continuously cooled with water from a spray ring located at the top of the tank. The cooling water is collected in a channel at the bottom and piped away to a drain.

2.4 MICROWAVE GENERATION AND APPLICATION SYSTEM. Two identical microwave power supplies, Model S6-F, manufactured by Cober Electronics, Inc., are used to transform 480 volt electrical power into microwaves at 2450 $\pm$ 50 megahertz. The microwaves are then transmitted via waveguide into the interior of the vacuum vessel. A teflon window at the end of each waveguide allows the microwaves to be transmitted into the vacuum inside the vessel. The interior of the vacuum vessel functions as a cavity applicator for the microwave energy. The product travels through the cavity via the fabric chute which is positioned along the central axis of the cavity. The microwave radiation passes through the chute fabric and is absorbed by the moisture in the product. The water vapor evolved then passes out through the porous cloth and is condensed on the inside wall of the vacuum vessel.

2.4.1 System Efficiency. As discussed in Progress Report Number 2, the anticipated efficiency of the power supplies selected for this apparatus is

47.5 percent. Figure 1 shows the anticipated losses in each part of the apparatus. The anticipated overall efficiency of this experimental unit is about 39%. As was pointed out in Progress Report Number 2, the equipment for this experimental unit was selected on the basis of compatibility with project scope and budget goals and its efficiency is not representative of projected commercial dryers.

3.0 FABRICATION AND ASSEMBLY

3.1 VACUUM VESSEL FABRICATION AND LEAK TESTING. The main shell was rolled and welded from 3/8 inch thick, four-foot by twelve-foot plates of 5086 aluminum alloy. The flanges were cut from 1.25 inch thick 5083 aluminum plate. The vacuum vessel was assembled by welding.

The vacuum vessel was tested for leaks using the pressure decay method. The test setup is shown schematically in Figure 2. The test was performed as per the specified leak test procedure T-055815. The pressure in the vessel increased less than 0.3 Torr (0.006 psi) in 24 hours. The corresponding leak rate was at least ten times lower than the specified acceptable rate (T-055759, paragraph 5).

3.2 COMPONENTS FABRICATION, ASSEMBLY AND ERECTION. The product feeder, the condensate collection cone, the upper hopper cone and the associated drive and instrument components were installed and functionally verified.

The support structure for the dryer was designed and fabricated by Aeroglide under contract to the USDA. This structure was erected at Aeroglide's facilities in Raleigh and the vessel installed in this structure. The microwave power supplies and the main control console were positioned and the waveguide and wiring were routed. The microwave windows and tuners were installed and the product chute was installed. Figure 3 shows the vessel as installed for functional testing.

4.0 FUNCTIONAL TESTING

The purpose of erecting the dryer at Raleigh was to optimize the arrangement of the equipment for the available space in the structure and to discover any problems while we had the manufacturing capability available to correct them.

Three separate tests were performed; (1) a batch test with corn, (2) a batch test with Vermiculite Insulation Material and (3) a continuous flow test with corn.

4.1 BATCH TEST WITH CORN. Only one microwave power supply was used for this preliminary test. Corn having a moisture content of approximately 15% was placed in the product chute. The chamber was evacuated to 20 Torr and the condenser cooling water was turned on. The one microwave power supply was turned on and the tuner adjusted for minimum power reflection. The power supply output was then increased to full output (6 kw) and maintained for 30 minutes. The reflected power when operating at full output was 20 to 50 watts. Drying of corn was evident in this test; however the moisture reduction achieved in this functional test was not analyzed.

4.2 BATCH TEST WITH VERMICULITE. Because of the low moisture of the corn available for these tests it was decided to use wet vermiculite for initial tests at full power. Four gallons of water were mixed into about seven (volumetric) bushels of vermiculite. The wet vermiculite was then used to fill the product chute. The dryer was evacuated to a pressure of 17 Torr and both power supplies were turned up to full power. These operating conditions were maintained throughout the forty-five minutes of the test. At the termination of this test the dry vermiculite was removed using the product feeder, and the water was drained from the condensate tank.

4.3 CONTINUOUS TEST WITH CORN. For this test the product chute and upper hopper were completely filled with corn. The measured moisture content of the corn varied from 13.5% to 18%. This variation was suitable for a functional test but the data cannot be used for performance evaluation.

The dryer was evacuated to 30 Torr, the condenser cooling water was turned on, the power supplies were adjusted to full output and the product feeder was operated at a rate equivalent to approximately ten bushels per hour. The dryer was operated a total of 70 minutes.

During grain removal from the lower hopper following drying, it was noted that the amount of grain that had been fed through the chute was less than calculated for the selected feeder operating speed. Further investigation revealed that the combination of a nail in the grain and a loose set-screw on the feeder drive mechanism caused grain flow to stop during the run. As a consequence the grain remaining in the chute was dried more than intended. Some of the grain removed from the chute had a measured moisture content of as low as 8.2%. None of the grain, not even that which was

over-dried, showed any evidence of heat damage. One gallon of condensed water was removed from the condensate collection tank.

4.4 COMMENTS AND CONCLUSIONS. The functional tests performed give confidence that the unit will perform as expected when installed and tested under more controlled conditions at the USDA site in Tifton, Ga. The microwave power supplies successfully delivered their full output into a common cavity with minimum reflected power or mutual interference. The condensing system successfully absorbed the steam generated by full output from the power supplies. The condensing system performed acceptably even though only 60% of the design cooling water flow rate was available in this temporary setup. The waveguide and tuner section performed as expected. The teflon window worked well and showed no evidence of heating or deterioration.

The problem that caused the product to stop feeding is not uncommon in grain dryers but precautions must be built in to the dryer to prevent recurrence. Therefore we are investigating installation of a positive flow interlock system or implementation of operating procedure changes prior to routine operation in Tifton, Ga.

The MIVAC System and its support structure will be disassembled, the structure will be painted, the system parts labeled and shipped to the USDA Coastal Plain Research Station, Tifton, Ga. in June 1978. Total erection of the MIVAC system is scheduled to be completed during July 1978. System operational evaluation will follow completion of erection.

FIGURE 1 - SYSTEM EFFICIENCY ANALYSIS

FIGURE 2 - VESSEL LEAK TEST SETUP

FIGURE 2

FIGURE 3 - MIVAC DRYER AS INSTALLED FOR FUNCTIONAL
TESTING AT AEROGLIDE CORPORATION IN RALEIGH, NORTH CAROLINA

D4E-591538-1

FIGURE 3

MCDONNELL DOUGLAS CORPORATION

TABLE 1 - CHUTE SIZE VERSUS POWER DENSITY

	<u>Chute Size</u>		
	<u>10"Dia.</u>	<u>6"Dia.</u>	<u>4"Dia.</u>
Max. Power Density (watts/in ³)	1.3	3.7	8.4
Minimum Power Density (watts/in ³)	0.07	0.2	0.4

FIG. 1. CONTROL PANEL

0-40 TUBE 109 MASS 240
FISHES SCIENTIST

NE MA 12
SINGLE DOOR ENCLOSURE
72" x 20 1/2" x 16"

BOSTON ATTORNEY
MODEL VE 25 14
MOTOR SPEED CONTROL UNIT

- TO PLUMBING HOSE
SERIES WITH
MOTOR POWER
- TO MICROWAVE
POWER SUPPLY &
EXTERNAL INTERLOCK
TERMINALS
- TO MICROWAVE
POWER SUPPLY &
EXTERNAL INTERLOCK
TERMINALS
- TO ROCKET FEEDER CONTROL
SERIES WITH CONTROL POWER
- IN SERIES WITH
POWER TO AEROLINE
VALVE
- IN SERIES WITH
POWER TO
AEROLINE VENT VALVE

[illegible]

SCHEMATICS

- (A) 90° H PLANE BEND - 4014 (1 REQ'D)
- (B) FLEXIBLE WAVEGUIDE - 4017 - 24.00 IN (1 REQ'D)
- (C) 90° E PLANE BEND - 4013 (1 REQ'D)
- (D) FLEXIBLE WAVEGUIDE - 4017 - 12.00 IN (10° BEND) (1 REQ'D)
- (E) STRAIGHT WAVEGUIDE - 4016 - 40.75 IN (DE FMS) (1 REQ'D)
- (F) STRAIGHT WAVEGUIDE - 4016 - 80.50 IN (DE FMS) (1 REQ'D)
- (G) WAVEGUIDE CLAMPS - 4018 (7 REQ'D)

NOTE: THE SHOWN ARRANGEMENT IS NOT FINAL. IT IS PRESENTED FOR CONSIDERATION ONLY. IT IS ANTICIPATED THAT MINOR REARRANGEMENTS WILL BE REQUIRED.

- (H) 90° H PLANE BEND - 4014 (1 REQ'D)
- (I) FLEXIBLE WAVEGUIDE - 4017 - 24.00 IN (1 REQ'D)
- (J) STRAIGHT WAVEGUIDE - 4016 - 36.5 IN (DE FMS) (1 REQ'D)
- (K) 90° E PLANE BEND - 4013 (1 REQ'D)
- (L) STRAIGHT WAVEGUIDE - 4016 - 40.75 IN (1 REQ'D)
- (M) FLEXIBLE WAVEGUIDE - 4017 - 12.00 IN (10° BEND) (1 REQ'D)
- (N) STRAIGHT WAVEGUIDE - 4016 - 80.0 (DE FMS) (1 REQ'D)
- (O) WAVEGUIDE CLAMPS - 4018 (7 REQ'D)

REV	QTY	CODE	PART OR IDENTIFYING NO	DESCRIPTION OR IDENTIFYING NO	STOCK	MATERIAL OR MATERIAL CODE	DRAWING OR SPECIFICATION NO	NOTE	DATE
1	1			1/8 INCH NOZZLE					
2	1			PLATE					
3	1			WAVEGUIDE CONNECTOR ASSY					
4	1			PLATE					
5	1			WAVEGUIDE CLAMP					
6	1			WAVEGUIDE					
7	1			WAVEGUIDE					
8	1			WAVEGUIDE					
9	1			WAVEGUIDE					
10	1			WAVEGUIDE					
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99	1			WAVEGUIDE					
100	1			WAVEGUIDE					

U 7-055718 15

VACUUM PUMP, POWER SUPPLIES, WAVEGUIDE

DATE	FILE NO.	TEST NO.	TEST DATE	USED ON	POWER SPEC	TEST NO.	SCALE	CODE	TEST NO.	TEST NO.
	QTY REQD	APPLICATION			COUNT	76301		T-053718		
										LB (WEIGHT IN OUNCES)

E.O. EXTENSION #1
U-055710

E.O. EXTENSION #1
U-055710

REV	REV	CODE	PART OR IDENTIFYING NO	DESCRIPTION	STOCK	MATERIAL OR MATERIAL CODE	DRAWING OR SPECIFICATION NO	NOTE
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18	18	18	18	18	18	18	18	18
19	19	19	19	19	19	19	19	19
20	20	20	20	20	20	20	20	20

E.O. EXTENSION #1
U-055710

-57 PLATE
APPROX. 1/2 SCALE

-195 WINDOW
1/2 SCALE

-197 CLAMP RING
1/2 SCALE

A-A SECTION
O-RING GROOVE DETAIL
SCALE = 4X

-193 NOZZLE PLATE
1/2 SCALE

-193 NOZZLE PLATE
1/2 SCALE

-55 WAVEGUIDE CONNECTOR ASSEMBLY
FULL SCALE

ED. EXTENSION DWG. #1

SECURITY CLASSIFICATION	1-055718	REV	1
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REV	REV	CODE	PART OR IDENTIFYING NO.	INCHES/FEET OR DESCRIPTION	STOCK	MATERIAL OR MATERIAL CODE	DRAWING OR SPECIFICATION NO.	NOTE	ZONE
1	1								
MCDONNELL AIRCRAFT COMPANY MCDONNELL DOUGLAS CORPORATION E.O. EXTENSION DRAWING NO. 1 REF. ED. 069151 SCALE 1:1 10 SHEET 7 OF 8 10/22/58					1-055718 10/22/58				

1002218 2K1063 E0 EXT 1

MCDONNELL AIRCRAFT COMPANY Saint Louis, Missouri						CHANGE FORM								SHEET 1 OF 3	NO.						
TITLE MIVAC DEMONSTRATION DRYER						CONTRACT NO.				A	M	E	O	DD	DCN	DWG NO. T-055718	SEQ NO. 1	DCN	TYPE	A 069151	
REASON TO REVISE ACCESS PORT ON LOWER COMPARTMENT, REVISE MICROWAVE INJECTION PORTS AND CORRECT MINOR ERRORS.						EJS	CAR	RFI	REC	ECF	ACN	B/P DIST Δ	FSCM NO. 76301	• REISSUE							
												LTR	APPROVAL/DATE	REL DATE							
REMARKS VENDOR						PURCHASING	PRODUCT SUPPORT				DWG CONFORMS										
						DEPTS AFFECTED			CHG COORD	WRITER FC WENIE	CH LIA ENGR	YES									
						FIRM PLANNING INCORP	DATE.				CHK	APVD	REC	PRIORITY	VEN SEQ						
						NCI	B/P DIST				STR	APVD	MCAIR DEPT/VENDOR	WRITER							
						MFG ACTION					PROD ENGR	CUST	APVD	APVD							
										UNIT CH ENGR	DATE ISSUED 1-26-78	APVD	APVD								
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SHEET 1 - (CONTINUED) (BILL OF MATERIALS CHANGES)

ADD 1 -185 4" CONE ADAPTER (SEE SHEET OF THIS E.O.)

ADD 1 -187 NOZZLE DETAIL
1 -189 " " TO EACH -55 WAVEGUIDE
1 -191 " " CONNECTOR ASSEMBLY.

ADD 1 -193 NOZZLE PLATE (SEE E.O. EXTENSION DRAWING
1 -195 WINDOW NO.1, SHEET 1 FOR DETAILS
1 -197 CLAMP RING OF REVISIONS TO -55
ASSEMBLY.)

ADD 1 -201 FLANGE
1 -203 SAMPLER FLANGE (SEE E.O. EXTENSION DRAWING
1 -205 SAMPLER SIDE NO.1, SHEET 2 FOR
1 -207 SAMPLER END DETAILS OF SAMPLE COLLECTOR
1 -209 GASKET CHANGES.)

H	CHG CODE	P T A Y R P M T E			CODE IDENT.	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	S P A R I	E F F. CODE	R E U S E	L /	STOCK OR MAKE FROM PART NUMBER	FIND NO.	NOTE	ZONE	-ED -ING SUPERSED	MATERIAL CODE	L/T	U/I	S/L	QU
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CHANGE FORM

NO. 069151

E	EFF CODE	U S A G E	I A B O L E	MODEL SERIES	EFFECTIVITY	G	CHG CODE	P T Y M	NEXT ASSEMBLY	ASSY DASH NO.	QTY FIN ART	CREATE SAME AS NO.	SUPERSED -ED -ING	NOTE	E F F C O D E	R E U S E	X	EO	DD	DCN	DWG. NO.	SEQ.	DCN	SHT OF
																					T-055718	1		3

SHEET 5, ZONES 27 A-F, 28 A-F AND 29 A-F.

WAS - SEE DRAWINGNOW - SEE E.O. EXTENSION DRAWING NO.1, SHEET 1.

SHEET 6, ZONES 41 A-F, 42 A-F, 43 A-F, 44 A-F, 45 A-F AND 46 A-F.

WAS - SEE DRAWING

NOW - SEE E.O. EXTENSION DRAWING NO.1, SHEET 2.
(GRAIN SAMPLING MECHANISM REVISED
AS SHOWN)

H	CHG CODE	P T Y M	I A B O L E	CODE IDENT.	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	S P A R T I / R	EFF. CODE	R E U S E	M I S	STOCK OR MAKE FROM PART NUMBER	FIND NO.	NOTE	ZONE	-ED SUPERSED	-ING	MATERIAL CODE	L/T	U/I	S/L	OUT
											MATERIAL	MATERIAL SPECIFICATION									