EVALUATION OF AN ANIMAL EXCRETA DRYER

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ABSTRACT

EVALUATION OF AN ANIMAL EXCRETA DRYER

By

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Considerable research has been conducted on developing methods of animal excreta management, but little of this research has been concerned with finding means of drying the excreta on the farm. A poultry excreta dryer was developed for farm use, but a lack of data made it impossible to evaluate this dryer's performance while processing poultry and other animal excreta. This research was concerned with the production rate, fuel consumption, and thermal efficiency as well as a study of the drying process within the machine. Bulk densities and particle size distributions were determined for each dried excreta.

Based on a forty hour week, one dryer would process the excreta from 22 bovine weighing 1000 pounds, 184 hogs weighing 100 pounds, or 7800 laying hens. The dryer would also handle limited amounts of litter. Fuel oil consumption averaged 2.5 gallons per hour, and the electrical demand was 4.2 kilowatts. Bulk densities ranged from 10.9 pounds per cubic foot for bovine excreta, 3.9 per cent straw, to 23.4 pounds per cubic foot for poultry excreta. A very small percentage of dried

excreta particles were outside the size range of 0.01 to 0.1 inches. The high drying temperature caused a reduction in the nutrient content of the excreta in most cases.

Drying was accomplished with air temperatures as high as 1000° F in one area. Seventy-five per cent of the drying was found to result from a pneumatic process where the mass transfer coefficient for an idealized situation varied directly with absolute temperature and inversely with particle diameter.

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EVALUATION OF AN ANIMAL EXCRETA DRYER

By

Truman Carl Surbrook

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My special thanks go to my parents, Mr. and Mrs. Floyd G. Surbrook and Mr. and Mrs. W. Earl Holman. Their advice, council, encouragement and help proved invaluable to the completion of this research.

And to the one for whom appreciation cannot be expressed in words, my wife Mary. Her smile would have been enough, but with it she gave unboundless help and encouragement.

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LIST OF SYMBOLS

A	area, ft^2
a	as subscript, air
C	moisture concentration, lb_m H_2O/ft^3
D	mass diffusivity of H_2O into air, ft^2/hr
D	as subscript, diffusion
d	diameter of particle, ft
f	as subscript, final
G	mass flow of fluid, $lb_m/hr\text{-}ft^2$
h_D	mass transfer coefficient, ft/hr
M	moisture content, fraction
$\dot{m}$	mass flow rate of H_2O, lb_m/hr
N_p	number of particles per unit volume
o	as subscript, initial, time zero or before
p	as subscript, particle
s	as subscript, solid
T	temperature, °R
U	velocity, ft/hr
V	volume, ft^3
$\dot{v}$	volume flow rate, $ft^3/hr\text{-}ft^2$
W_d	oven dry weight, grams
W_w	wet weight, grams
ε	fraction void

μ viscosity of fluid, $lb_m/hr\text{-}ft^2$

ν kinematic viscosity μ/ρ , ft^2/hr

ρ density, lb_m/ft^3

ϕ fraction solid $(1 - \varepsilon)$

CHAPTER I

INTRODUCTION

In many areas of the United States, the problem of the utilization or disposal of animal excreta without creating a health hazard or public nuisance has become serious. As greater numbers of poultry and livestock are confined in smaller areas, the situation becomes increasingly crucial. "Farm Animals in the United States produce ten times as much waste as the human population."*

At present, the greatest portion of animal excreta is put on the land in an untreated form. With the rising rural non-farm population and increasing emphasis on reducing environmental pollution, this means of waste disposal is uncertain. Society is no longer willing to accept the odor, and questions have been raised as to the possible pollution of streams and underground water supplies by this material. In some localities, ordinances limiting the disposal of animal excreta on land have caused some poultrymen and livestock raisers much expense and inconvenience.

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*"Restoring the Quality of Our Environment," The White House (November, 1965), 170-171.

Considerable research has been conducted on developing methods of animal excreta management, but little has been concerned with drying excreta on the farm. A flow-through type rotating drum dryer was used on a poultry farm in England, but a report on the dryer was not complete enough to evaluate the process. A flash dryer using pneumatic conveying was also tested in England, but on a scale too large for the average farm.

Recently, however, a commercial poultry excreta dryer was developed for farm use in this country. A lack of data made it impossible to evaluate this new dryer's performance while processing poultry and other animal excreta. Late in 1967 a dryer was consigned to Michigan State University for testing and evaluation. Preliminary trials were started in January, 1968 and testing continued until March, 1969.

The aim of the research conducted on the new dryer was as follows: (1) evaluate the performance of the dryer while processing poultry and livestock excreta; (2) determine some of the physical characteristics of the dried product; and (3) study the drying process itself to determine the primary drying mechanism and parameters involved. The intent of this research is not to dwell upon the economics of drying with this machine, or to speculate as to the utilization of the dried product.

CHAPTER II

LITERATURE REVIEW

Few researchers have investigated the possibilities of drying animal excreta on the farm. Of the published reports, few specific details were given. From the standpoint of general appraisal of the processes themselves, these published reports are significant and worthy of consideration.

Two types of excreta dryers have been tested on poultry farms in England. The first is a flow-through type rotating drum dryer. A variable speed auger feeds the fresh excreta into the upper end of an inclined rotating drum. Hot air is circulated around the outside of the drum and then directed through it, entering at the upper end and leaving at the lower end. The flue gases are passed through an afterburner to reduce odor. The heated air is circulated around the lower end of the drum before it is released. The flow-through rotating drum dryer is diagrammed in Figure 1. Cross wires fitted in the drum prevent balls of material from forming.

A second type of system used to dry poultry excreta in England was a flash mixer dryer using pneumatic conveying of the solids. The flash type excreta dryer was not described in the literature, but a similar flash process has been used to dry potato granules.

Various types of flash dryers for producing potato granules are described in literature on food processing and technology. A slurry in the order of 70 per cent moisture is mixed with a large amount of dried granules of about 10 per cent moisture. The product from this mixture is a material of about 35 to 40 per cent moisture. In the Raymond Flash Drying System, a disintegrator is used to granulate the agglomerated mixture before it enters the vertical pneumatic drying and conveying tube. The granules are retained in the vertical tube in the order of 6 to 10 seconds after which time the moisture content has been reduced from near 40 per cent down to 10 per cent. Air and granules are separated in a cyclone, and a large portion of the dried granules are used as "add-back" for the mixer. A fan at the exhaust is used to induce air flow through the system. The Raymond Continuous Flash Dryer is diagrammed in Figure 2. Neel et al (1954) reported that up to 85 per cent of the dried product was used as "add-back" to the mixer in a slightly different flash dryer. Flash dryers using horizontal pneumatic conveying have been used, but higher air velocities were required to prevent the granules from settling in the drying tube.

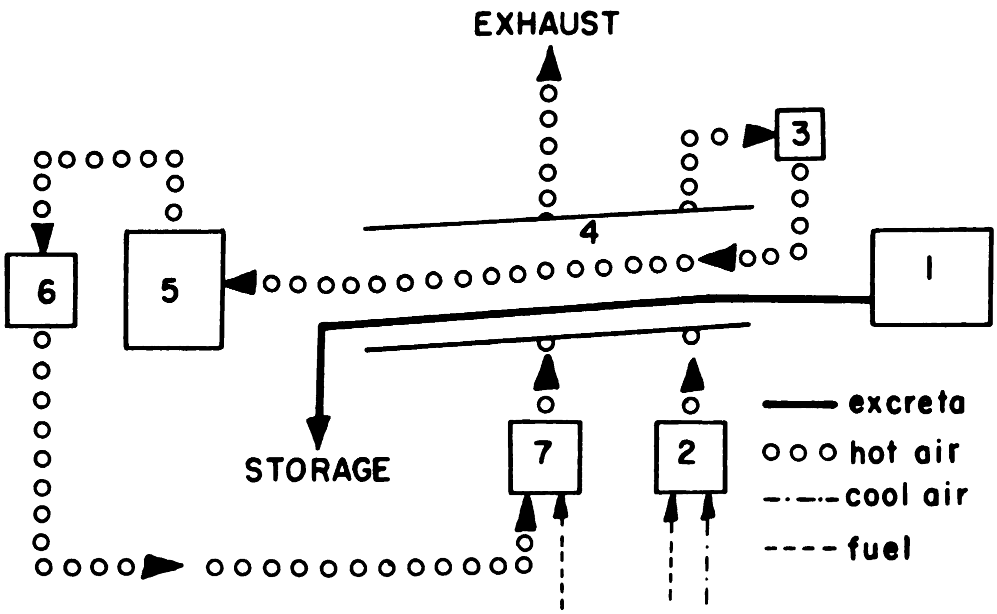

Figure 1. Flow-through rotating drum dryer. (1) fresh excreta hopper; (2) burner; (3) fan; (4) rotating drying drum; (5) dust precipitator; (6) fan; (7) deodorizing afterburner.

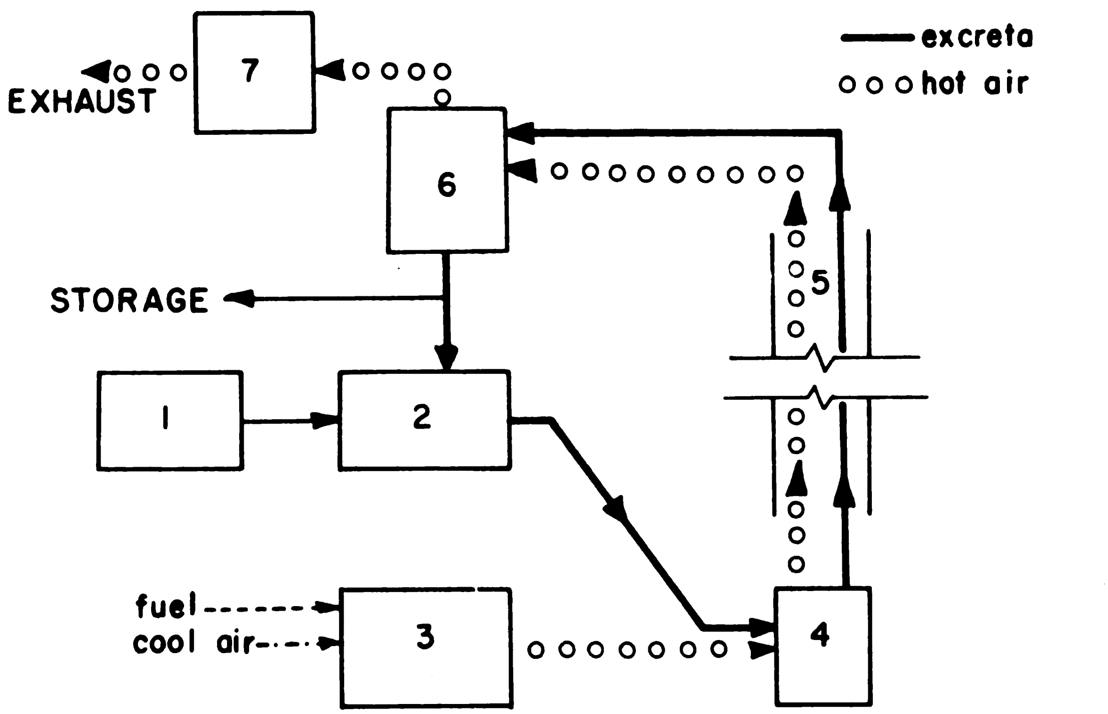

Figure 2. Raymond Flash Dryer with pneumatic drying and conveying. (1) fresh excreta hopper; (2) mixer; (3) burner; (4) disintegrator; (5) vertical drying tube; (6) cyclone separator; (7) fan.

Ryder (1967) discussed the various types of dryers and concluded that the flow-through rotating drum and flash dryers showed the greatest promise for processing poultry excreta. The thermal efficiency of the drum dryer was reported to be low as compared to the flash dryer. The uniformity of drying was questionable with the drum dryer especially if measures were not taken to prevent balling of the material. For the flash process uniformity of drying was reported to be good, especially if some means of particle attrition was included in the system. As far as capital investment is concerned, the drum dryer was most favorable for farm drying. The flash process became competitive only on a large scale such as a farm with 200,000 or more laying hens. High power requirements were necessary to operate the fan and particle disintegrator on the flash drying unit. Power requirements were comparatively low for the drum type dryer. Both dryers were reported to render the product sterile after drying.

Performance figures were given for two flow-through rotating drum dryers and a flash dryer, although precise measurements were not made during the trials. The estimated dryer production rates given in the literature were converted to a 40 hour work week and listed in Table 1. Physical dimensions were given only for the smallest flow-through drum dryer, however, investment cost estimates were given for all three. Therefore, capital investment was included in Table 1 as a crude means of comparing the size of the dryers.

TABLE 1. Comparison of three poultry excreta dryers. Two flow-through rotating drum dryers and a flash dryer. Dried product output is based on 40 hours of operation per week.

	Drum[1]	Drum[2]	Flash[2]
Estimated Capital Investment	$7,000	$17,000	$38,000
Estimated Fresh Excreta in 70% m.c. (w.b.)	8 tons/wk.	20 tons/wk.	57 tons/wk.
Estimated Dried Product Out 15% m.c. (w.b.)	3 tons/wk.	7 tons/wk.	20 tons/wk.

[1]"High Temperature Dryer for Poultry Manure," Farm Mechanization and Buildings (May, 1968), 27.

[2]C. Ryder, "Water Costs Money," English paper unpublished (December, 1967), 9-10.

CHAPTER III

THE ANIMAL EXCRETA DRYER

The object of this research was to evaluate a commercial animal excreta dryer. The dryer operated on a principle similar to the flash dryer. The main difference was that with this unit, granulated material was thrown into the air stream by a hammer mill, rather than being suspended by the air itself. The dryer also employed a different method of facilitating final drying.

The dryer consists of five internal inclined surfaces rigidly connected together (Figure 4). These drying surfaces and their side walls are constructed of 16 gauge stainless steel. One end of the internal drying chamber is connected to an eccentric which applies a horizontal shaking action. The shaking causes material to slide down the surfaces during drying. The hammer mill for mixing and pulverizing is located at the lower end of the top inclined drying surface. The hammer mill is eight inches in diameter and turns at 2250 revolutions per minute. A plate with either 1/4 inch or 3/8 inch holes acts as a screen to limit maximum particle size (E in Figure 4). The material must pass through holes in

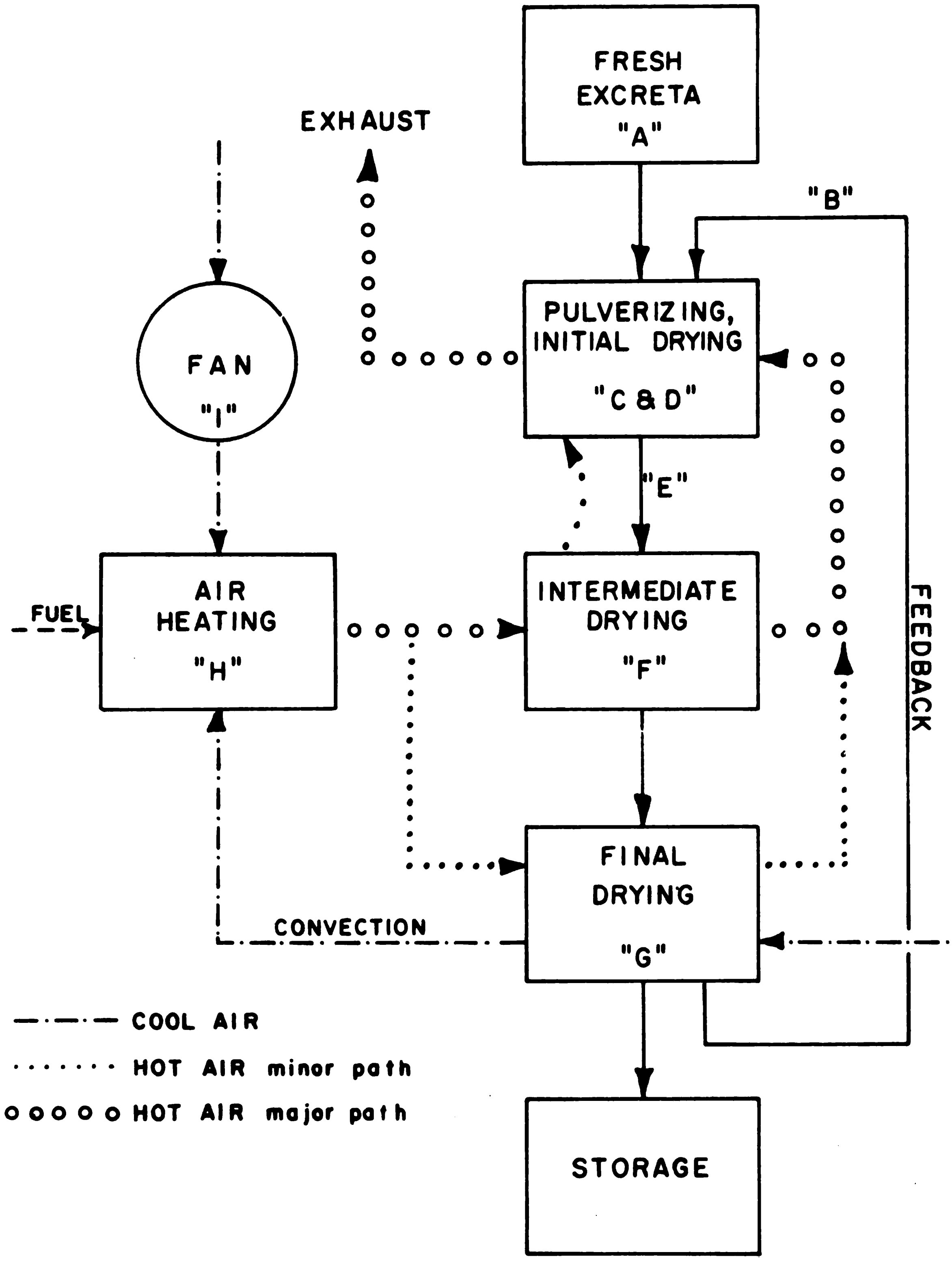

Figure 3. Air and material flow-through the animal excreta dryer. Legend: (A) excreta feed mechanism; (B) dried feedback mechanism; (C) initial drying area; (D) hammer mill; (E) screening plate with 1/4 or 3/8 inch holes; (F) intermediate drying area; (G) final drying area; (H) fire box; (I) fan.

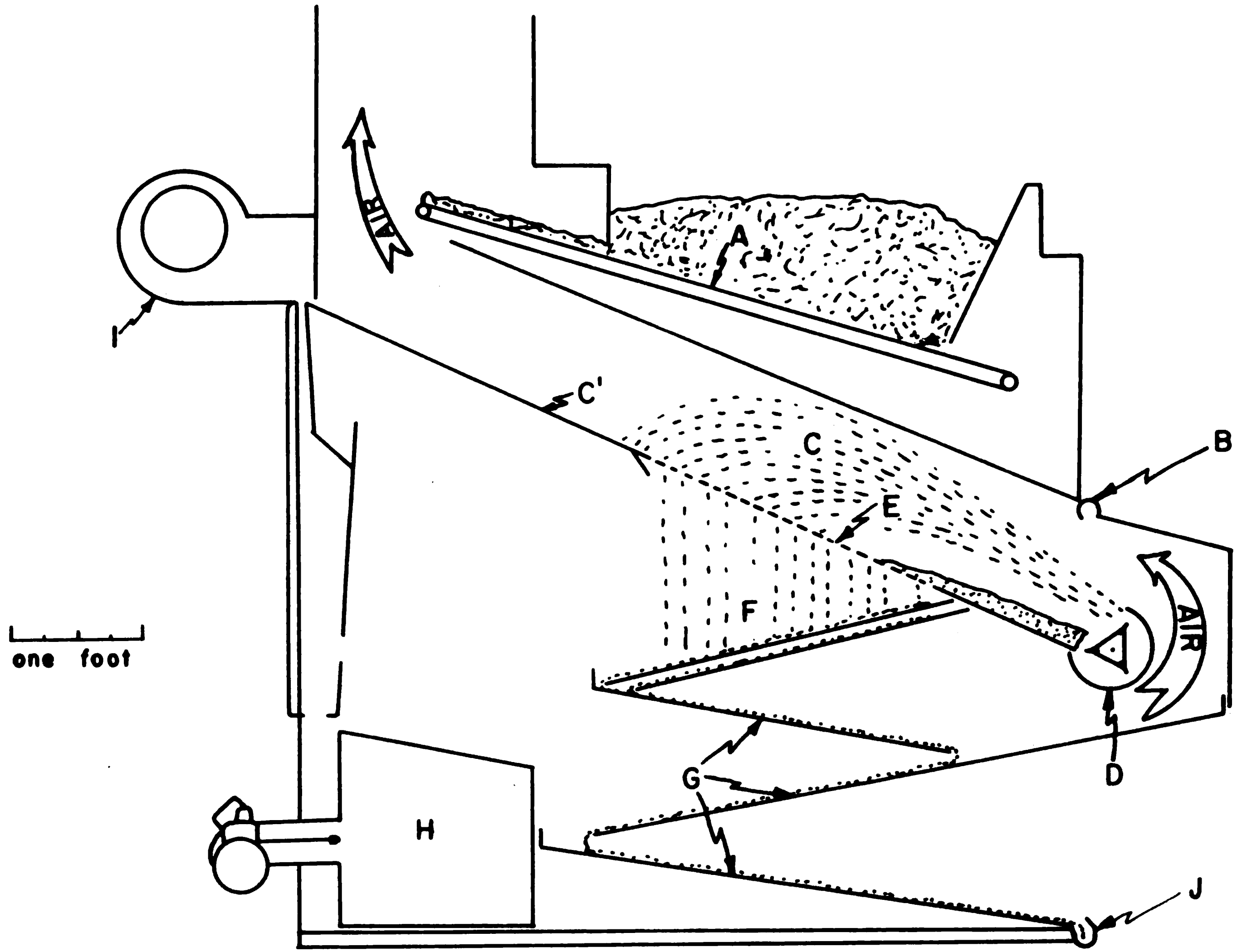

Figure 4. Interior of the excreta dryer. The inclined surfaces (C', E, F, G) are rigidly connected, and shake horizontally to cause material flow. Legend: (A) excreta feed mechanism; (B) dried feedback mechanism; (C and C') initial drying area; (D) hammer mill; (E) screening plant; (F) intermediate drying area; (G) final drying area; (H) fire box; (I) fan; (J) dry material auger.

this screening plate in order to get to the lower drying surfaces.

Hot dry air is produced by burning fuel oil in a fire box. Additional air is forced into the dryer by a blower (I in Figure 4) and enters from the lower side walls near the fire box. Air movement through the dryer results from the combination of back pressure of air entering, convection, and draft stimulated by outside air blowing across the top of the stack.

The walls consist of an inner drying chamber wall of stainless steel, a 1/2 inch air space, fiberglass insulation and the outer steel skin. An air duct pressurized by the blower (I in Figure 4) extends along both sides and one end of the dryer. Air passes downward from this duct through the 1/2 inch air space between the inner drying chamber wall and the insulation. An opening along the lower walls allows this air to enter the machine, and become part of the drying air. This air cools the surface of the dryer and, at the same time, is preheated before becoming part of the drying air. Some additional air enters by convection.

The hammer mill, shaking drying chamber, blower for conveying dry product, and elevator are powered by a three horsepower single phase electric motor. Additional 120 volt, single phase fractional horsepower electric motors are used to power the fresh excreta feed drag chain, air inlet fan, and burner pump and fan.

The burner is controlled by an adjustable thermostat. The sensing bulb for the thermostat is located on the side wall of the dryer near the hammer mill.

The exhaust stack of the dryer extends through the roof to the outside of the building. The stack opening is fourteen feet above the ground and about level with the peak of the roof. The stack is covered to prevent snow and rain from entering.

Fresh excreta is fed intermittently into the dryer when needed. An adjustible current sensing relay in the line to the main drive motor determines when more fresh excreta is needed. The fresh material drops onto the upper end of the top inclined drying surface (C' in Figure 4) and slides downward toward the hammer mill. At the same time fresh excreta is entering the machine, dried granules are fed back and dropped into the hammer mill (B in Figure 4). The dried feedback, fresh excreta, and partially dried residual are mixed by the action of the hammer mill and subjected to the drying air. The excreta circulates in this area until it finally drops through the holes in the screening plate.

The intermediate drying area consists of a series of two inch wide channels with a 1/2 inch slot between them through which air passes (Figure 8). The greatest amount of air and the hottest air is directed onto the excreta granules on these channels. The air then passes through the slots and on to the initial drying area. The temperature in this area is high enough to cause some sparking during normal drying.

Final drying is accomplished as the material moves down the last three inclined drying surfaces (G). Smaller quantities of lower temperature air are directed over these surfaces. Actually, the final surface acts more as a cooling area with very little additional drying taking place. After leaving this final surface, the material is moved horizontally by an auger and then elevated to a small storage hopper from which dried material is augered into the initial area as feedback with the remainder transferred to permanent storage by a blower.

Dryer controls consist of two sub-systems. One sub-system senses the current drawn by the three horsepower motor powering the dryer. When this current falls below a preset value, the feed mechanism is activated. When the current again surpasses this preset value, the feed mechanism is shut off. Both dried feedback and fresh excreta enter the dryer when the feed mechanism operates.

The second control sub-system operates an elevator that keeps the dryer hopper supplied with excreta. A pressure switch senses a nearly empty hopper and activates the control relays to start the elevator. This second control sub-system was not used during these tests.

When an elevator is used to keep the hopper supplied with excreta, the dryer operates automatically. Manual labor is not required during the drying operation. The unit will shut down automatically when the elevator no longer keeps the hopper supplied with material.

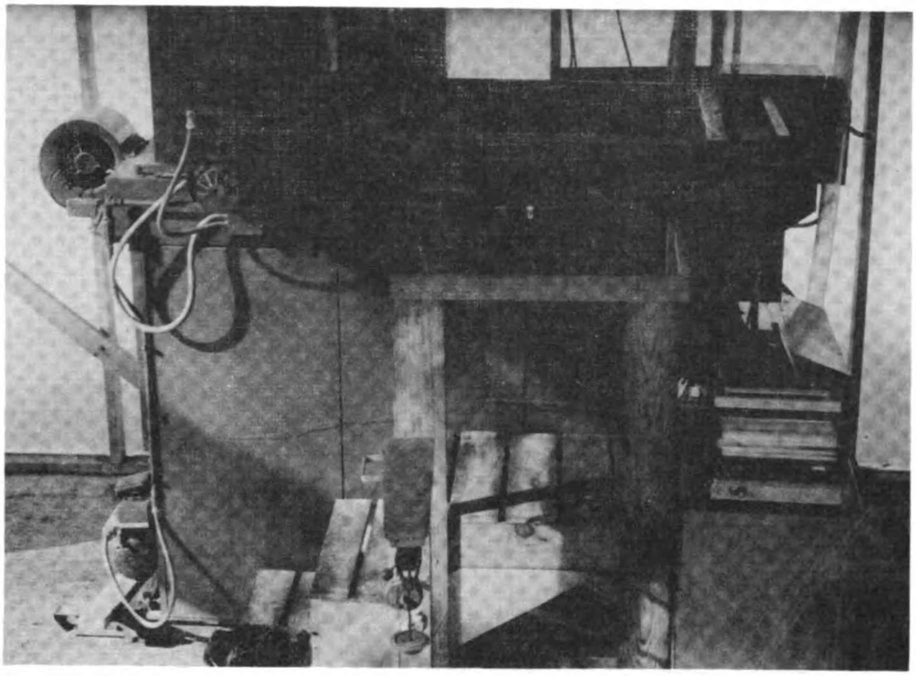

Figure 5. External view of the excreta dryer. Fresh excreta is loaded into the hopper at the top by a separate elevator.

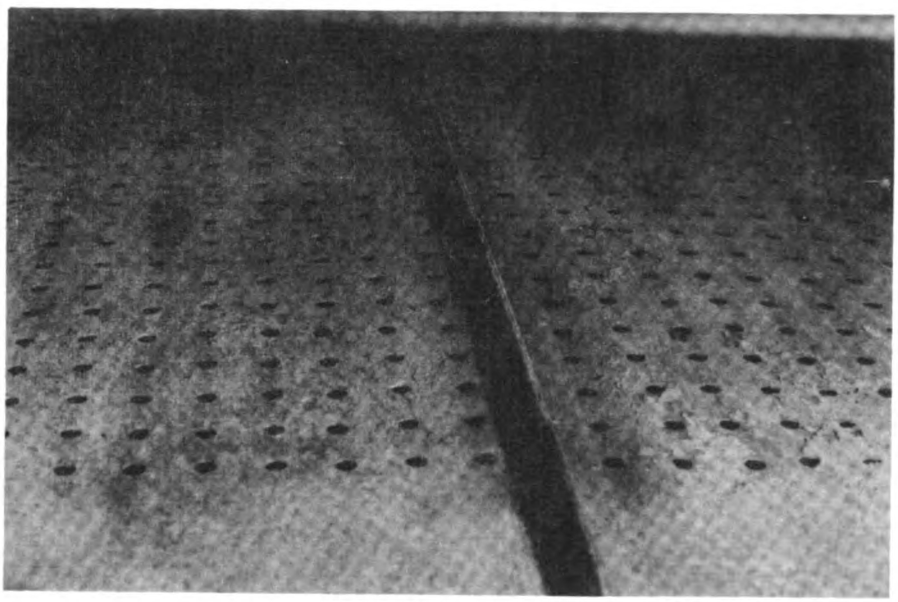

Figure 6. Dryer screening plate. The granulated material leaves the initial drying area by falling through the holes in the screen plate. This plate is marked (E) in Figure 4.

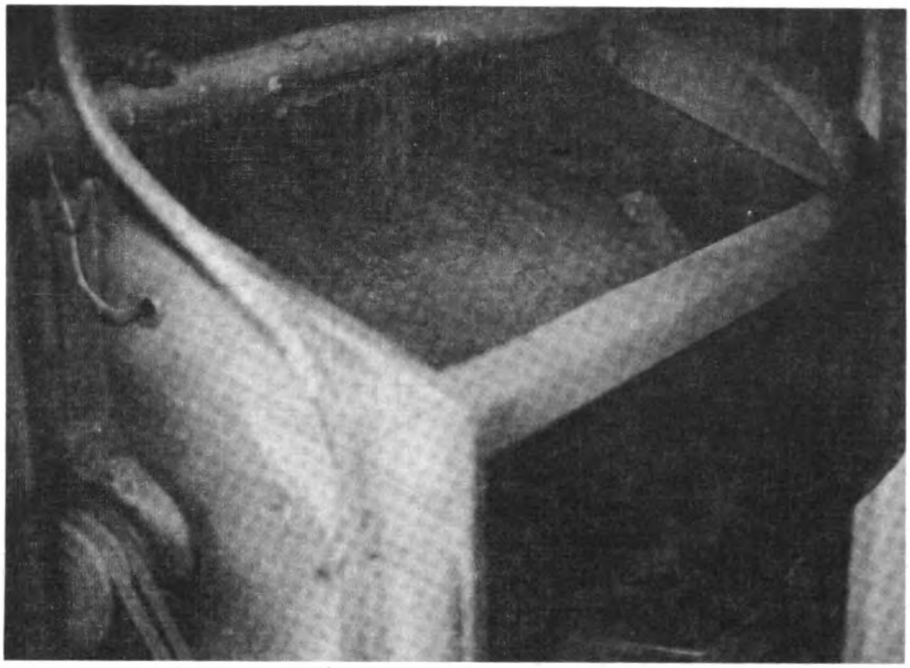

Figure 7. The hammer mill and feedback operating during drying. The hammer mill mixes and pulvarizes the excreta, and throws it into the drying air. The dried feedback is also visable coming from the auger above the hammer mill.

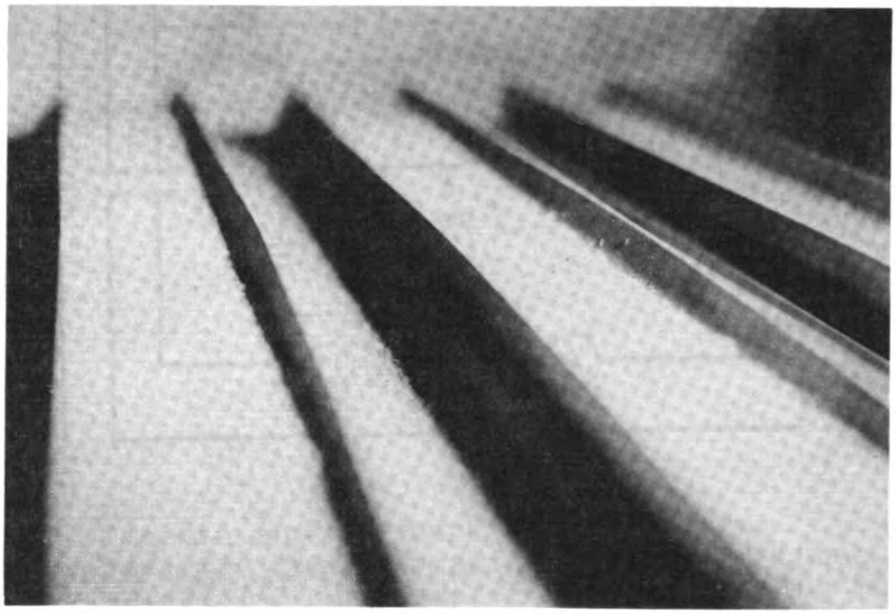

Figure 8. The intermediate drying area. The granular material moves down these two inch wide channels. Air passes through the 1/2 inch slots between the channels.

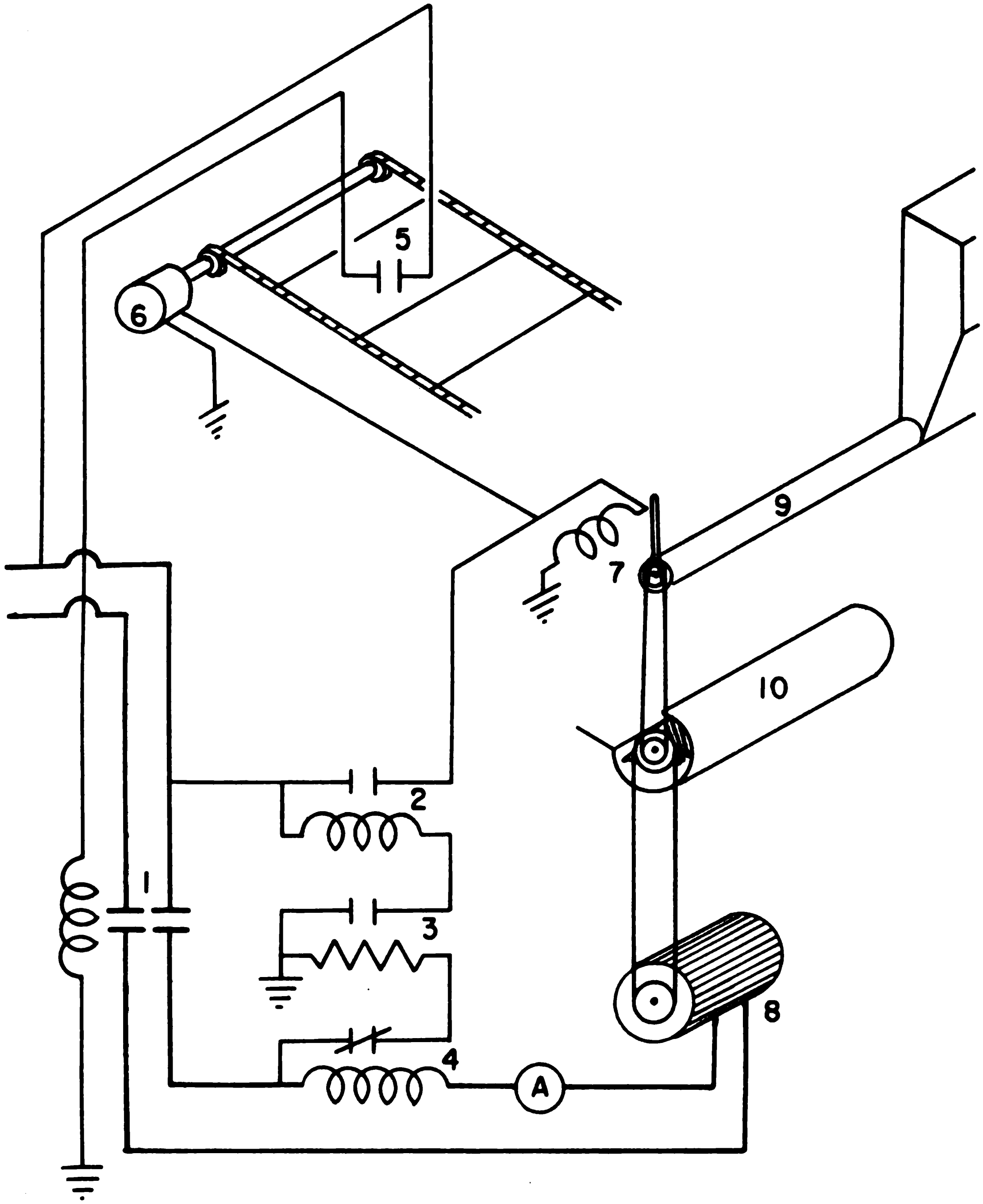

Figure 9. Excreta and feedback control system. Legend: (1) main relay; (2) feed mechanism relay; (3) three second time delay relay; (4) drive motor current sensing relay (closes when current drops below preset value); (5) pressure switch; (6) fresh excreta feed motor; (7) dried feedback solenoid operated clutch; (8) drive motor; (9) dried feedback auger; (10) hammer mill.

CHAPTER IV

OBJECTIVES OF THE RESEARCH

The work reported on previous dryers was incomplete with only rough estimates of the capabilities of these dryers. If an animal excreta dryer is to be fitted to a farm situation, the performance of the unit must be known exactly. The first major objective of this evaluation was to determine the overall performance of the dryer while processing animal excreta. The questions to be answered were as follows:

1. Can the dryer be used to process bovine and swine excreta?
2. Will the dryer handle poultry excreta containing wood chip litter and bovine excreta containing straw?
3. What are the production rates, fuel oil and electricity consumptions, and efficiencies while drying different animal excreta?
4. Is solid material released from the stack into the air?
5. Does the machine give off an odor during drying?

Animal excreta is obviously difficult to handle especially with a minimum of labor. If the ease of handling is to be evaluated, certain physical characteristics of the dried excreta must be known. The second major objective of this research, then, is to determine some physical characteristics of the dried excreta.

6. What are the bulk densities of the dried products collected during the production trials of various animal excreta?
7. What are the particle size distributions of the dried animal excreta?
8. Is there an odor to the dried excreta?
9. Is a change in the levels of nitrogen, phosphorus, potassium, and protein detected before and after drying?

Little was known about the actual drying process taking place within the machine itself when the evaluation began. A logical approach to dryer evaluation from a design standpoint would be an investigation to determine the key drying mechanism and possible parameters involved. Specific questions to be answered that would help accomplish this third major objective were as follows:

10. What is the temperature gradient through the dryer?
11. How does temperature vary with time at any one location within the dryer?

12. What is the temperature of the surface of the machine during drying?
13. What per cent of total drying takes place at the various areas within the dryer?
14. What parameters most significantly affect the drying rate?

CHAPTER V

EVALUATION PROCEDURES

The animal excreta was put into buckets and weighed on a platform scale before manually filling the dryer hopper. The weight of fresh excreta was determined to the nearest one half pound. The dried excreta out of the machine was also weighed on the platform scale.

A one gallon (U. S.) graduated cylinder was used to measure the fuel oil consumed by the dryer. A stop-watch recorded the time to consume the one gallon of fuel. When the cylinder was emptied, the time was recorded, the stop-watch reset, and the cylinder quickly refilled with fuel from a previously filled one gallon container. The amount of electricity was measured with a kilowatt-hour meter.

The solid material leaving the stack was collected in screened containers. The openings in the screen were larger than the average particle size collected, but the screen very quickly became coated with solid material thus improving the ability of the screen to catch the small solid material. Actually, little of the material was lost. The material collected was removed from the screen containers and weighed on a spring scale.

The air velocity profile was determined in the stack by a vane anemometer. The air in the stack directly above the initial drying chamber contained much floating material which interfered with other types of instruments. This floating solid material did not affect the vane anemometer. Average air velocity measurements were taken over a period of two minutes.

Temperatures in excess of 1000° F were anticipated, therefore, Chromel-Alumel (type K) thermocouple wire was selected. Chromel-Alumel thermocouples have a range of 0° to 2500° F. Glass insulation was chosen that would withstand a temperature of 1800° F. A two channel continuous potentiometric recorder with an internal temperature compensating reference junction was used. One channel recorded over the range 0° to 800° F while the second reccrded over the range 0° to 2500° F. A special thermocouple switch was used when temperature readings were taken for many different locations.

Moisture content was determined by weighing several samples of material before and after drying in a laboratory oven at 220° F, for twenty four hours. All moisture contents in this work are expressed on a wet basis.

$$\text{Moisture Content (per cent, w.b.)} = \frac{W_w - W_d}{W_w} \times 100$$

CHAPTER VI

RESULTS AND DISCUSSION

6.1 Performance of the Dryer

The dryer had been used to process poultry excreta on several farms in the Mid-west before this research began. It was known that the machine would do a satisfactory job of drying poultry excreta, but would the dryer satisfactorily process other animal excreta?

Bovine excreta, both dairy and beef, containing no straw was dried successfully. Tests were conducted with 1/4 inch and 3/8 inch screening plates. Dried excreta particle size was somewhat larger when the 3/8 inch screen was used. The production rate was higher with the 3/8 inch screen, but the difference was not determined. Complete drying can be accomplished when the 3/8 inch screening plate is used with a resulting higher production rate, therefore, this size is recommended over the 1/4 inch screen.

Swine excreta was tested successfully, but with some difficulty. The partially dried excreta granules were quite coarse and rough, causing a great deal of friction. As a result, the excreta did not slide down the floor of the initial drying area easily. A slight build up of excreta at the leading edge of the hammer mill was often enough to restrict the flow of material into the hammer mill. Even then, the hammer mill did not throw the material very far up into the initial drying area limiting granule exposure to the drying air.

This sluggishness of flow resulted in a concentration of material at the lower end of the initial drying area near the hammer mill, and the upper end of the screening plate was not covered with excreta granules. Under these conditions, some of the hot air short circuited through these holes and did not come in contact with excreta. Short circuiting of hot air was greatest when the 3/8 inch screening plate was used, but was not satisfactorily reduced when the 1/4 inch screen was put in place. This short circuiting effect also occurred, to some extent, when the 3/8 inch screen was used during the drying of bovine excreta. Simply eliminating the top few rows of holes in the screening plate would probably correct this problem.

The control system was over ridden during trials with swine excreta to increase the amount of dry excreta feedback. This extra amount of feedback increased the fluidity of the material in the initial drying areas. The feedback, however, dropped into the center of the hammer mill in a narrow stream. Therefore, distribution across the dryer was poor. This did not cause any complication with poultry or bovine excreta, but did cause trouble when processing swine excreta. The material flowed well in the center of the dryer where feedback was applied, but did not flow well along the edges. A more even distribution of feedback across the dryer should eliminate this lack of uniform flow.

Some sticking occurred as the highly fluidized swine excreta slurry moved down the first inclined surface towards the hammer mill, although it did not pose much of a problem. Drying rate probably could be maintained and sticking eliminated if the plate temperature could be reduced.

Dryer performance while processing swine excreta seemed questionable, but the machine performed quite well under these difficult circumstances. By using a 3/8 inch screening plate with the top few rows of holes eliminated, and a greater amount of more evenly distributed dried excreta feedback, the dryer would probably do a good job of processing swine excreta.

During one trial, the swine excreta entered the dryer in frozen chunks as much as three inches across. No difficulty occurred during the drying, but extra heat was needed to thaw out the frozen excreta.

Mink excreta was dried successfully, and no difficulty resulted when the 1/4 inch screening plate was used. Only one trial was conducted with mink excreta, and the dryer temperature setting was a little too low. A drier final product and a higher production rate could have been achieved if the machine had been operated at the same settings as used for poultry excreta. The mink excreta did, however, contain some litter which tended to lower the production rate of the dryer.

The first dryer test with litter in the excreta was conducted with straw in bovine excreta. The mixture was mainly wet soggy straw. The dryer could not handle this excessive amount of straw. Later the dryer was tested with bovine excreta containing lesser amounts of straw. Under these new conditions, the dryer operated smoothly. One test was run with bovine excreta of which 2.0 per cent of the dry matter was straw, and another with 3.9 per cent straw. As the amount of straw increased, the production rate and efficiency decreased. Tests were made with a 3/8 inch screening plate in the dryer. These percentages of straw in the excreta may seem insignificant, but straw is largely void, and a large quantity has very little weight.

Poultry excreta containing litter of wood chips was tested. The dry matter in the mixture consisted of 18.3 per cent litter. There was some difficulty with this high concentration of litter. Some of the larger pieces of wood (as large as 5 1/2 inches long, 1/2 inch wide, 1/4 inch thick) did not break down sufficiently to pass through the 3/8 inch holes in the screening plate.

Figure 10. Poultry excreta mixture containing 18.3 per cent wood chip litter.

Figure 11. Bovine excreta mixture containing 3.9 per cent straw.

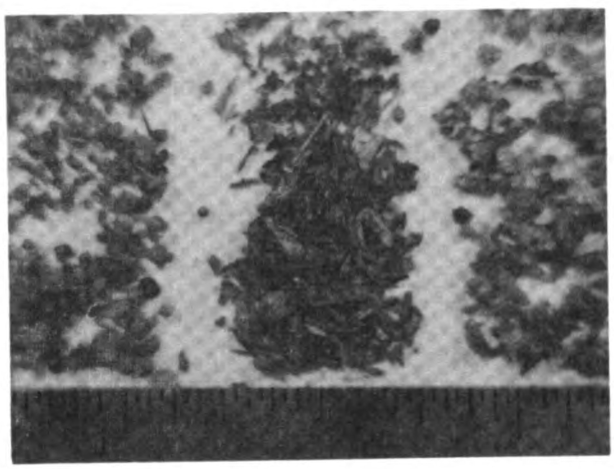

Figure 12. Granules of dried poultry (left), bovine (center), and swine (right) excreta. Each small division on the scale is 1/32 inch.

As a result, an accumulation occurred in time (roughly 30 minutes) after which the bulk of the unpulverized wood chips had to be removed by hand. Other than the problem of repeated accumulation of larger chips, the wood litter passed through the dryer quite well.

Turkey excreta containing feathers was tested. The feathers were quite brittle and the hammer mill effectively pulverized them. There was no noticeable accumulation of feather material above the 1/4 inch screening plate.

A higher individual production rate on poultry excreta was obtained with the 1/4 inch screening plate, but higher overall production could be obtained by using a 3/8 inch screen. Complete production figures are listed in Tables 2 and 3.

The production and efficiency of the dryer were greatly reduced as the amount of litter was increased. If bovine excreta without any straw was processed in the dryer using a 3/8 inch screening plate with the upper few rows of holes eliminated, the production rate and efficiency should be higher.

Although higher production was indicated for swine excreta when the 1/4 inch screening plate was used, this most likely would not have been the case if a 3/8 inch screening plate was used with the top few rows of holes eliminated.

TABLE 2. Production figures for the dryer while processing different kinds of animal excreta. Electricity consumption averaged 4.2 kilowatt-hours per hour in all trials.

Material	Screen size	Wet excreta Production Rate lb/hr	Initial Moisture % w.b.	Final Moisture % w.b.	Water Removed lb/hr	Fuel Consumption gal/hr	Efficiency %
Poultry excreta	1/4"	428	73.6	4.7	309	3.7	57.8
		387	80.3	9.8	303	3.6	58.2
		337	78.1	8.8	256	3.0	59.0
		237	75.6	5.1	176	2.0	60.9
		215	74.4	10.7	153	2.2	48.1
avg.		321	76.4	7.8	239	2.9	57.0
Poultry excreta	3/8"	340	76.3	11.1	249	2.4	71.8
Poultry excreta 18.3% litter	3/8"	252	69.4	8.7	168	2.6	44.7
Bovine excreta 2.0% straw	3/8"	243	82.4	12.0	194	2.6	51.6
Bovine excreta 3.9% straw	3/8"	178	82.4	17.2	140	2.0	48.4
Swine excreta	1/4"	225	72.2	12.5	153	2.4	44.1
Swine excreta	3/8"	215	72.2	16.9	143	2.4	41.2
Mink excreta	1/4"	185	64.8	16.7	107	1.8	41.1

TABLE 3. Production figures for the animal excreta dryer expressed in terms of one ton of wet excreta.

Material	Screen size	Time/Ton (hr)	Fuel/Ton (gal)	Elect./Ton (KWH)	Dried Excreta per ton of Wet Excreta (Tons)	Final Moisture (% w.b.)
Poultry excreta	1/4"	6.2	18.0	26	.22	7.8
Poultry excreta	3/8"	5.9	14.2	25	.25	11.1
Poultry excreta 18.3% litter	3/8"	8.0	20.8	33	.28	8.7
Bovine excreta 2.0% straw	3/8"	8.3	21.5	35	.17	12.0
Bovine excreta 3.9% straw	3/8"	11.0	22.0	46	.22	17.2
Swine excreta	1/4"	8.9	21.3	38	---	12.5
Swine excreta	3/8"	9.3	22.3	39	---	16.9
Mink excreta	1/4"	10.8	19.4	45	.31	16.7

In Table 2, pounds of water removed from the excreta per hour was determined by the following expression:

Pounds H_2O Removed per hour

$$= (\text{Production Rate}) \left[M_0 - \frac{(1 - M_0)\, M_f}{(1 - M_f)} \right]$$

And, overall thermal efficiency of the dryer was determined from the following:

Overall Thermal Efficiency, per cent

$$= \frac{(\text{lb. water evaporated})(\text{latent heat, Btu/lb})(100\%)}{(\text{gal. fuel used})(\text{net heating value of fuel, Btu/gal})}$$

The net heat value of the fuel oil was taken as 140,000 Btu per gallon, and the latent heat of vaporization of water taken as 970 Btu per pound.

A variation in final moisture content of from five per cent to about twenty five per cent could be obtained by changing the dryer thermostat setting. The proper setting for a particular output moisture content was determined easily in a few minutes of experimentation.

The wet excreta production rates of the dryer take on real meaning when compared with the amounts of excreta voided by poultry and livestock.

TABLE 4. Excreta voided by poultry and livestock, Maddex (1965).

Animal	Weight of Animal (lb)	Weight of excreta/day (lb)	Per cent Feces-Urine (per cent)	Moisture Content (per cent)
Hens	4 to 5	1/4	100 - 0	76
Bovine	1400	90	70 - 30	84
	1000	64		
	750	48		
Swine	175	12.5	73 - 27	84
	100	7.0		

From the figures in Table 5, the dryer has potential for processing excreta produced by poultry and swine, but the amount of excreta voided by bovine seems too great for the capacity of this dryer.

TABLE 5.--Projected number of animals that can be served with the excreta dryer operating forty hours per week.

Animal	Weight of Animal (lb)	Weight of excreta/wk. (lb)	40 hour capacity of dryer (lb)	Animals served by dryer
Hens	4 to 5	1.75	13,600	7,800
Bovine	1,400	630	9,720	15
	1,000	448	9,720	22
	750	336	9,720	29
Swine	175	88	9,000	102
	100	49	9,000	184

Exhaust analysis revealed that solid material was released from the stack during drying. Up to six per cent of the dry matter entering the dryer escaped from the stack. This solid material was very light and fine. It consisted of fines and hair from feathers in the case of poultry excreta, and animal hair and fines in the case of bovine excreta. This material could be removed by drawing the exhaust air through a cyclone separator, or eliminating it with an afterburner.

A slight odor was released form the stack, but it did not resemble the fresh excreta odor. A more thorough evaluation of the level of odor from the stack should be conducted using impartial observers. Ostrander (1969) described the odor from an animal dehydrator as less offensive than fresh excreta. He stated that these odors are not serious because there are means of eliminating them at the dehydrator.

Even though the exhaust air was released to the outside of the building, there was considerable dust in the air around the dryer. The operator used a face mask to reduce intake of dust. Dust accumulation in nasal passages became offensive if the face mask was not used.

6.2 Properties of the Dried Excreta

Bulk density is an important factor to consider where handling and storing of materials is concerned. Sobel (1966) reported a bulk density of 66 pounds per

TABLE 6. Solid material released from the dryer stack.

Material	Screen size (in)	Fresh Excreta Dry Matter (lb)	Stack Material Dry Matter (lb)	Moisture Content of Stack Mat. (per cent)	Stack Loss Per cent of Total Dry Matter
Poultry	1/4	137	8.2	37.9	6.0
		120	4.7	20.5	3.9
avg.				29.2	4.9
Poultry	3/8	169	2.5	22.7	1.5
Bovine	3/8	120	3.6	34.7	3.0

TABLE 7.--Particle size distribution of solid material released from the dryer stack. The material larger than 0.0930 inches was primarily clumps of fines matted together during storage.

Particle size (in)	Poultry 1/4" Screen %	Poultry 3/8" Screen %	Bovine 3/8" Screen %
.0000			
	41.0	36.6	29.3
.0165			
	23.4	25.3	27.7
.0232			
	15.2	21.3	22.0
.0328			
	7.9	11.2	12.1
.0550			
	2.7	1.8	2.6
.0930			
	9.8	3.8	6.3
--			

cubic foot for bovine excreta. Comparing these values with the ones in Table 8, the bulk density of the dried granular excreta is about one-third the value for the fresh excreta. Also, as would be expected, the bulk density increases as granule size decreases.

TABLE 8. Bulk density of dried animal excreta at 10 per cent moisture content, wet basis.

Dried Material	Screen Size	Bulk Density lb/ft^3
Poultry excreta	1/4"	23.4
Poultry excreta	3/8"	16.8
Poultry excreta 18.3 % litter	3/8"	17.4
Bovine excreta	1/4"	19.0
Bovine excreta 2.0% straw	3/8"	12.3
Bovine excreta 3.9% straw	3/8"	10.9
Swine excreta	1/4"	20.9
Swine excreta	3/8"	19.4
Mink excreta	1/4"	22.7

The dried excreta in all cases was a fine granular material. The degree of fineness is illustrated in Figures 13 to 15. It is interesting to note that particle size distribution remained relatively constant for

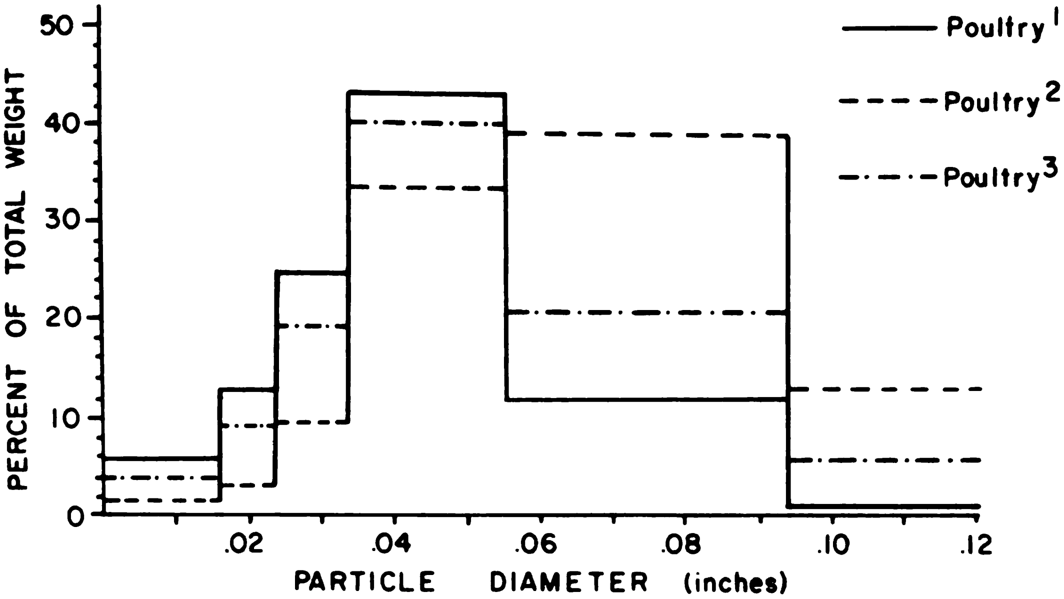

Figure 13. Particle size distribution of poultry excreta. (1) 1/4 inch screen; (2) 3/8 inch screen; (3) 3/8 inch screen, 18.3 per cent wood chip litter.

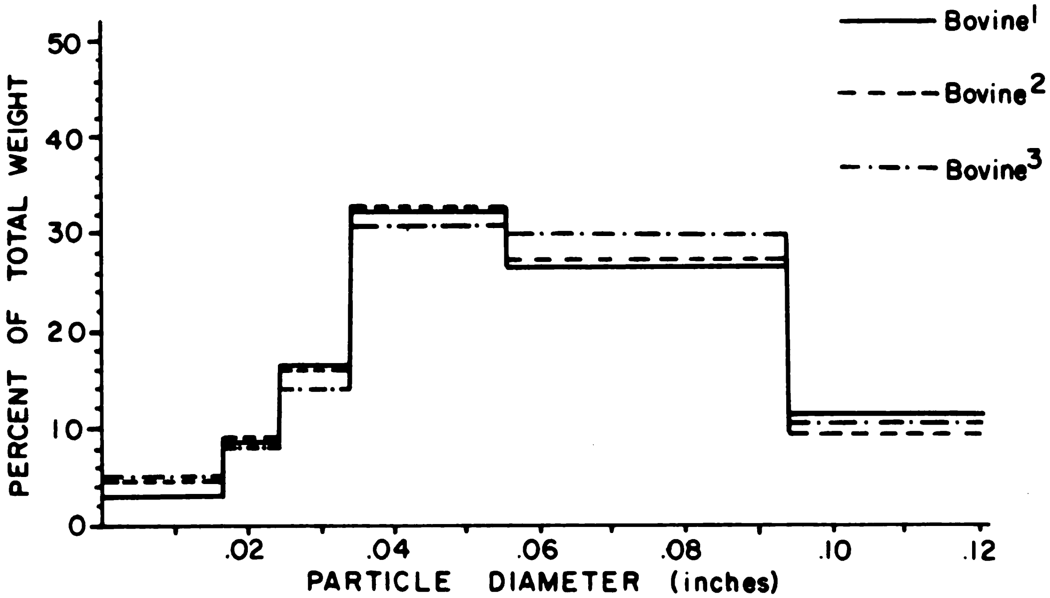

Figure 14. Particle size distribution of bovine excreta. (1) 1/4 inch screen; (2) 3/8 inch screen, 2.0 per cent straw; (3) 3/8 inch screen, 3.9 per cent straw.

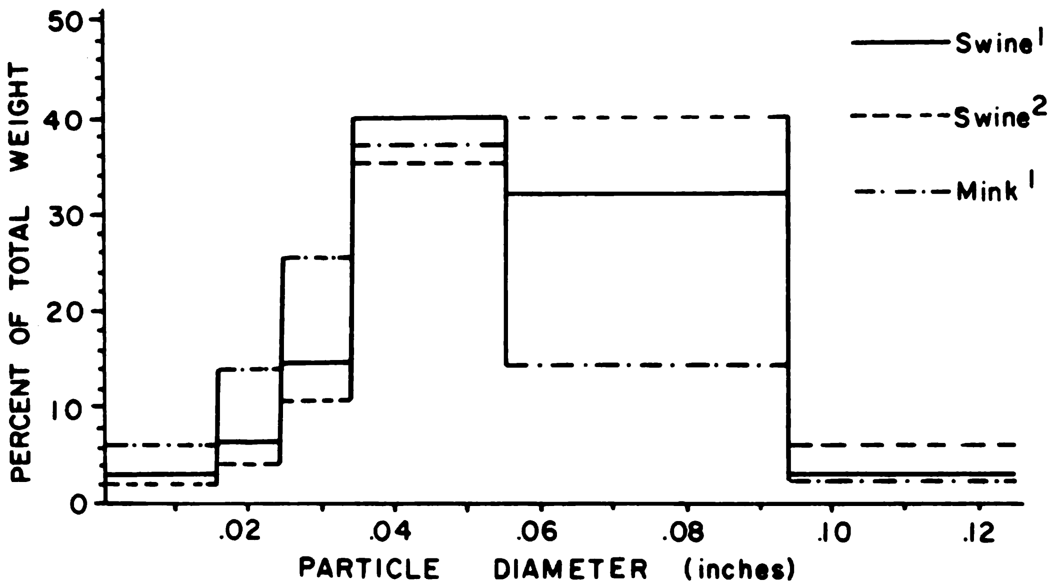

Figure 15. Particle size distribution of swine and mink excreta. (1) 1/4 inch screen; (2) 3/8 inch screen.

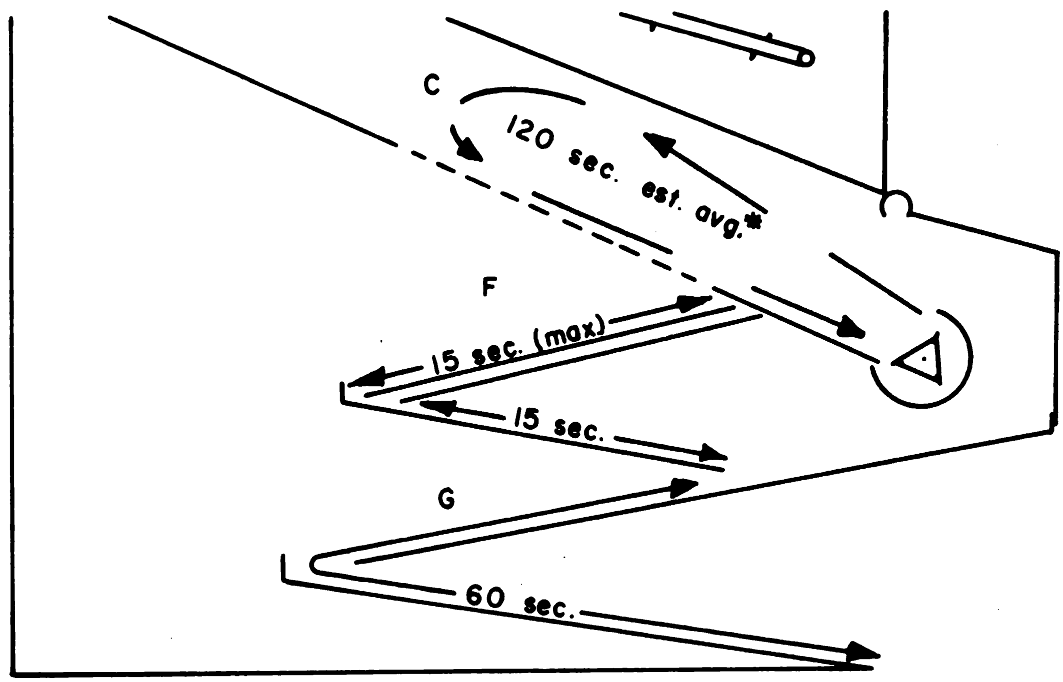

Figure 16. Time required for excreta to travel through the dryer. The total estimated average exposure time for poultry excreta was 3.5 minutes. Legend: (C) initial drying area; (F) intermediate drying area; (G) final drying area; (*) for poultry excreta, 1/4 inch screen.

a particular animal excreta regardless of the amount of litter or size screening plate used except in the case of poultry excreta where the 3/8 inch screen was used. Table 9 compares the particle size distribution for all of the animal excreta tested.

A Ro-Tap machine and Tayler sieves were used to determine the particle size distribution of the dried excreta. A standard test was conducted where 100 ± 1 gram of excreta was sifted for three minutes.

The odor of the dried poultry and mink excreta did not resemble the fresh excreta. There was resemblance between the odor of the dried as compared to the fresh bovine and swine excreta, however, much of the odor was removed. When dried poultry excreta was applied on the surface of flower beds in a residential area, the odor was offensive for a few days although it did not resemble the fresh poultry excreta. The odor was, however, confined to the area of the flower beds and could not be detected a short distance away. After a few days the dried excreta became odorless. Also, when the dried excreta was rewetted, the odor increased.

The fresh and dried excreta was analyzed to determine whether the nutrient levels were altered by the high temperatures near 1000° F for up to 15 seconds. The fresh and dried analysis were expressed on an oven dry basis so they could be compared directly.

TABLE 9. Animal excreta particle size distribution expressed in per cent of total weight.

Material	Screen size	Sieve size (in)						
		.0000	.0165	.0232	.0328	.0550	.0930	.1500
Poultry excreta	1/4"	5.9	12.9	24.9	43.3	12.2	0.8	
Poultry excreta	3/8"	1.4	3.0	9.3	33.6	39.4	13.3	
Poultry excreta 18.3% litter	3/8"	4.0	9.2	19.7	40.4	20.8	5.9	
Bovine excreta	1/4"	3.4	8.7	16.5	32.6	27.0	11.8	
Bovine excreta 2.0% straw	3/8"	4.9	9.1	16.5	32.8	27.8	9.8	
Bovine excreta 3.9% straw	3/8"	5.2	8.6	14.4	31.0	30.1	10.7	
Swine excreta	1/4"	3.1	6.4	14.8	40.7	32.0	2.9	
Swine excreta	3/8"	2.1	4.1	10.6	35.7	40.7	6.8	
Mink excreta	1/4"	6.2	13.9	25.7	37.1	14.4	2.7	

Only one set of the bovine and swine excreta were analyzed. Therefore, the figures serve only as indicators of possible trends and cannot be cited as the rule. Notice for poultry excreta in Table 10 the level of phosphorus decreased slightly (3.6%), and nitrogen decreased a much greater amount (26%). This apparent reduction in nitrogen may render the dried poultry excreta more suitable as a lawn and garden fertilizer. Potassium was also found to decrease (17%) and protein (26%). Three additional sets of data in Table 11 further support these trends. These figures show that for poultry excreta high temperature appears to decrease nutrient level. Tables 12 and 13 give nutrient levels for bovine and swine excreta.

TABLE 10. Poultry excreta nutrient levels before and after drying.

	N	P	K	Crude fiber	H_2O	Protein
% as received						
FRESH	1.22	.623	.570	4.31	74.89	7.63
DRIED	3.48	2.30	1.81	15.81	3.60	21.75
% oven dry basis						
FRESH	4.86	2.48	2.27	17.16	--	30.39
DRIED	3.61	2.39	1.88	16.40	--	22.56

TABLE 11. Feed value of poultry excreta before and after drying. Expressed in per cent on an oven dry basis.

		Calcium	Phosphorus	Non-Protein Nitrogen	Crude fiber	Protein
FRESH	(1)	5.85	2.86	2.74	19.57	12.03
	(2)	7.49	2.85	2.57	24.72	15.04
	(3)	8.35	3.19	4.75	14.96	12.71
avg.		7.23	2.97	3.35	19.75	13.26
DRIED	(1)	6.16	2.77	1.54	18.15	11.21
	(2)	8.17	2.89	1.55	21.87	10.97
	(3)	7.31	2.97	2.49	16.75	12.46
avg.		7.21	2.88	1.86	18.92	11.55

TABLE 12. Bovine excreta nutrient levels before and after drying.

	N	P	K	Crude fiber	H_2O	Protein
% as received						
FRESH	.489	.136	.012	5.21	81.56	3.06
DRIED	2.56	1.12	.79	27.61	3.02	16.00
% oven dry basis						
FRESH	2.65	.738	.65	28.25	--	16.59
DRIED	2.64	1.15	.81	28.47	--	16.50

TABLE 13.--Swine excreta nutrient levels before and after drying.

	N	P	K	Crude Fiber	H_2O	Protein
% as received						
FRESH	1.05	.515	.426	3.14	75.21	6.56
DRIED	3.34	2.12	1.31	13.12	6.49	20.88
% over dry basis						
FRESH	4.24	2.08	1.72	12.67	--	26.46
DRIED	3.57	2.27	1.40	14.03	--	22.33

The excreta used for these drying trials was obtained from the university farm and undoubtedly some of the animals were on special feed rations. This may have resulted in abnormal levels of some of the nutrients. Table 14 was included as a comparison with levels of nutrients obtained by Benne et al (1961).

6.3 Study of the Drying Process

Temperature measurements at different locations within the dryer revealed the extremes of the stress conditions applied to the machine and showed where heat was being applied and to what intensity. Air, sometimes at a temperature exceeding 1000° F, made contact with the partially dried material falling through the holes in the screening plate. This same high temperature air was directed onto the granules of excreta on the channeled tray. Sparks were always present in the air leaving this intermediate drying area during normal drying. When a 3/8 inch screening plate was used in the dryer, sparking was reduced but not eliminated. A lower temperature was applied to the bottom two drying surfaces. Therefore, the excreta granules were allowed to cool before leaving the dryer.

TABLE 14. Nutrient levels of animal excreta converted to per cent oven dry basis from Benne *et al* (1961).

Excreta	Nitrogen	Phosphorus	Potassium
Poultry	3.48	0.87	0.76
Dairy cattle	2.67	0.48	2.38
Fattening cattle	3.50	1.00	2.25
Swine	2.00	0.57	1.52
Horse	1.72	0.25	1.50
Sheep	4.00	0.60	2.85

The temperature gradient can be used as a rough approximation of the drying taking place. For example, a temperature drop of about 250° F occurred across the lower drying area and 600° F across the initial drying area.

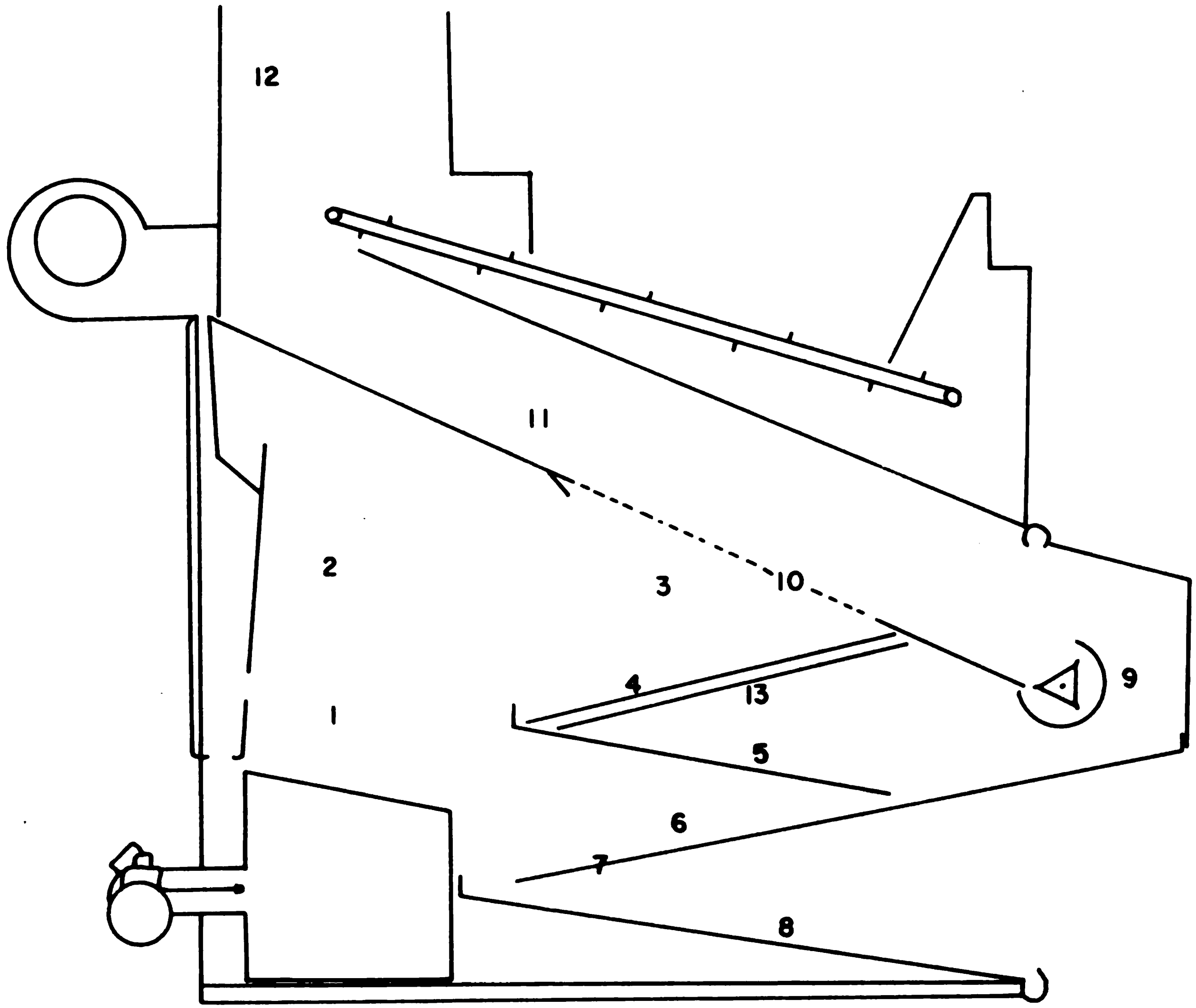

Figure 17. Average peak temperatures measured while processing poultry excreta. Thermocouples were connected directly to the recorder, and not through a switch. The air temperature was 61° F. Temperatures: (1) 1625°; (2) 1250°; (3) 1060°; (4) 850°; (5) 850°; (6) 645°; (7) 350°; (9) 780°; (10) 625°; (11) 210°; (12) 183°; (8 and 13) readings not taken.

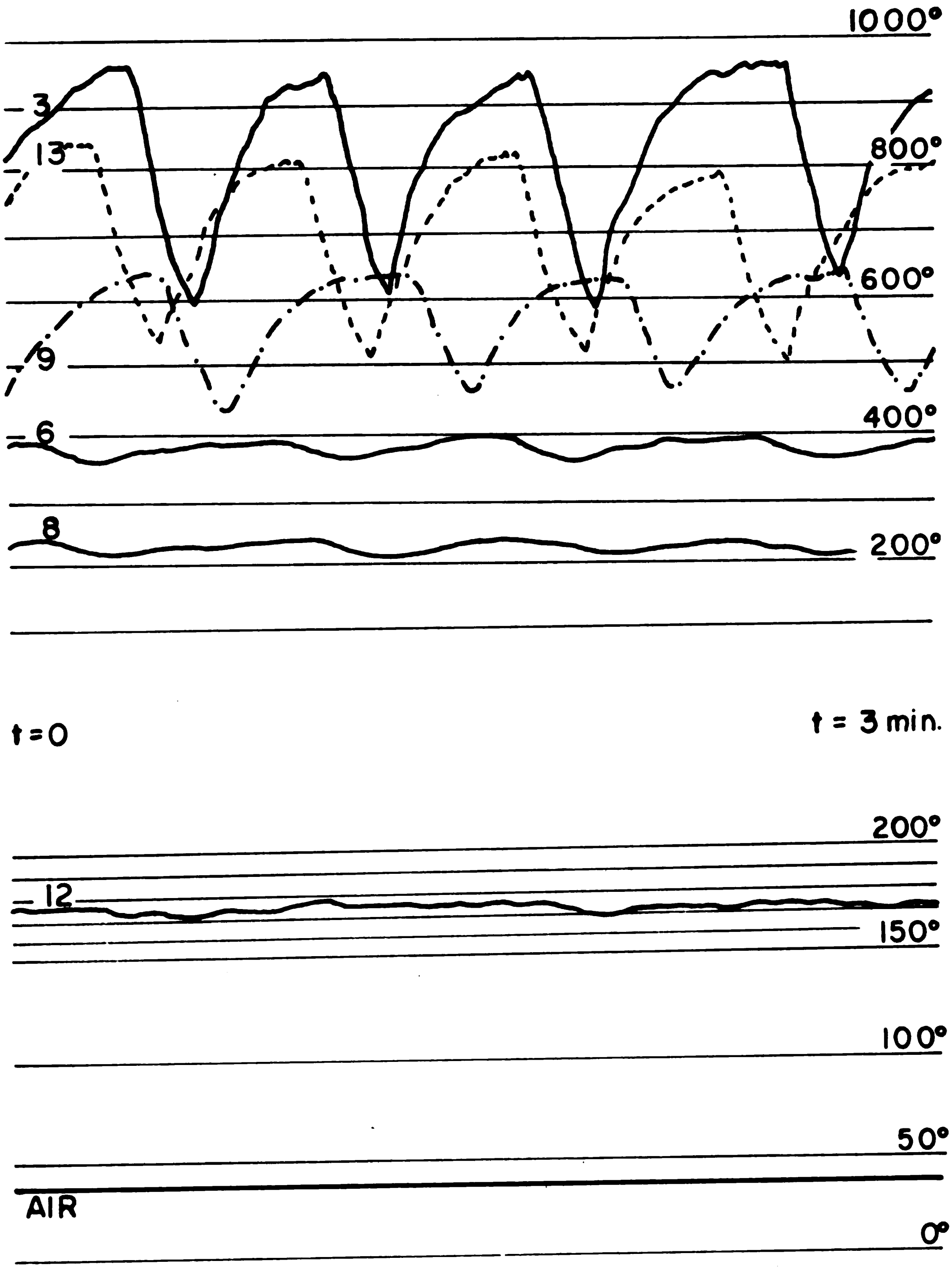

Figure 18. Temperature variation with time within the dryer. Each curve is representative of temperature at the point, but the curves were not obtained simultaneously.

One double nozzel oil burner was used as the heat source for the dryer. When the thermostate tripped the burner off, a dramatic temperature drop in the drying area resulted. In the lower portion of the dryer, vapor could be seen rising from the surface of the excreta granules when the burner was off. Vapor was not visible when heat was applied. A two burner system, where one remains on continuously and a second is operated by a thermostat, would probably result in a higher and more even drying rate. When the air temperature drops, the water holding capacity of the air also drops. This is evidenced by the visible vapors.

In most areas, the surface of the dryer did not get hot enough to cause discomfort if a person touched it. The two main exceptions were the area on the end near the burner, and the area near the hammer mill. In neither of these areas was there air circulated in the wall to carry away the heat as was the case in the side walls. The distribution of heat over the surface of the dryer is shown in Figure 19.

The quantity flow of air in the dryer stack about three feet above the initial drying area was determined from average air velocity measured with a vane anemometer. The air flow was found to vary between 1200 and 1500 cubic feet per minute. The flow rate was to some extent

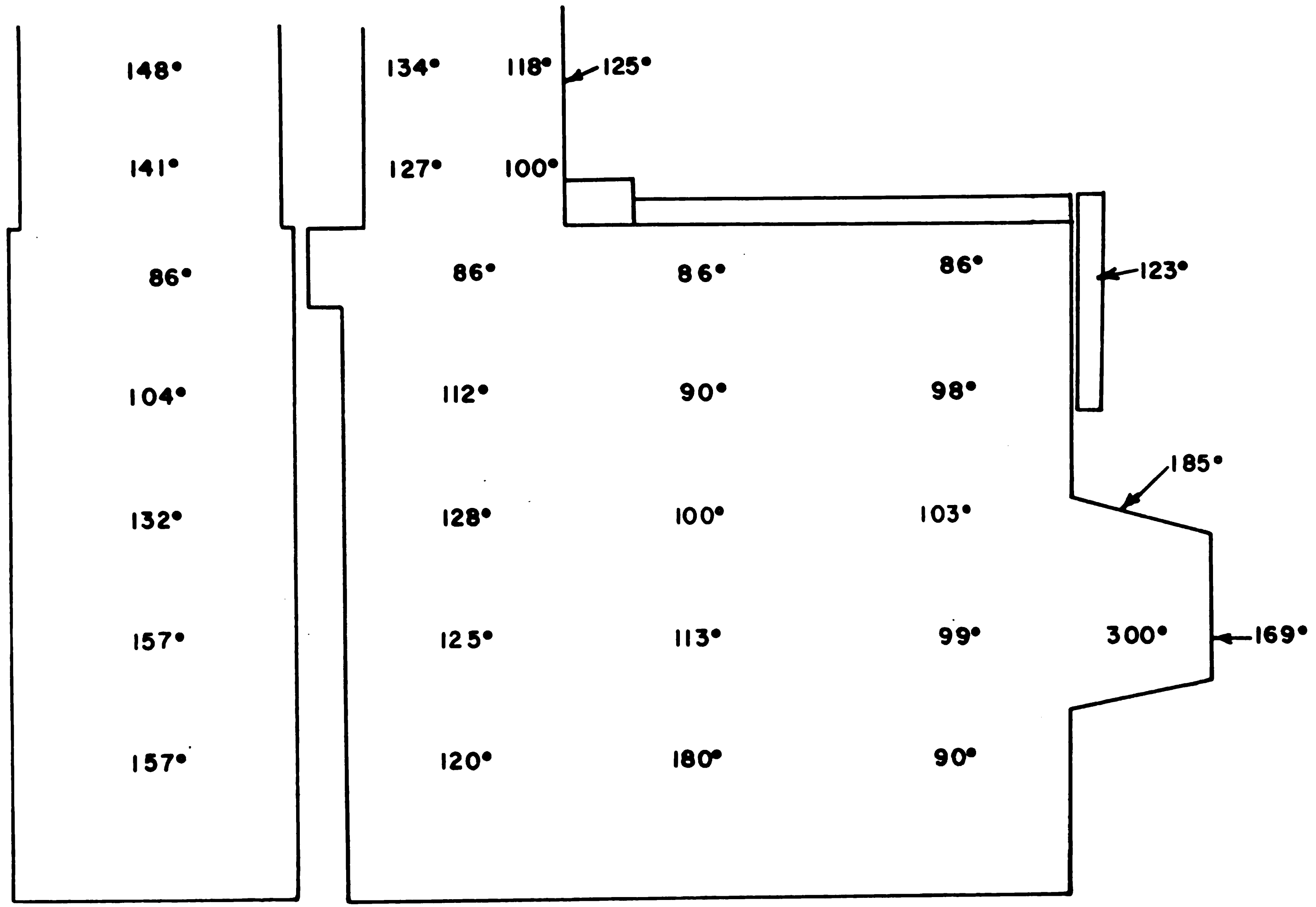

Figure 19. Temperature variation over the surface of the dryer. The air temperature was 61° F. These surface temperatures resulted under the conditions shown in Figure 17. Temperatures were taken with a thermocouple attached to the end of an insulated probe.

dependent on the outside air speed across the top of the stack.

There was actually three modes of drying. Fresh excreta and dried granules were fed into the initial area and mixed with about thirty pounds of 35 to 40 per cent moisture residual already in this area. The dried poultry excreta feedback rate was 3.3 pounds of dry matter per minute for 14.8 minutes out of each hour. Pneumatic drying was the primary mode in the initial area.

The second mode consisting of a combination of pneumatic and tray drying occurred in the intermediate area. Air at about 1000° F was blown directly onto the granular material which remained in this area for approximately 15 seconds.

Tray drying was the final mode which occurred on the last three inclined surfaces. A lesser amount of lower temperature air passed over the surface of the granules on these trays. The material remained in this area for about 75 seconds.

A schematic flow diagram of the material during the drying process is shown in Figure 20. Table 15 shows the amount of moisture removed during each step of drying poultry excreta where a 1/4 inch screening plate was used in the dryer. Table 16 gives the breakdown in per cent of total drying that took place in each area of the dryer. It is interesting to note that pneumatic drying

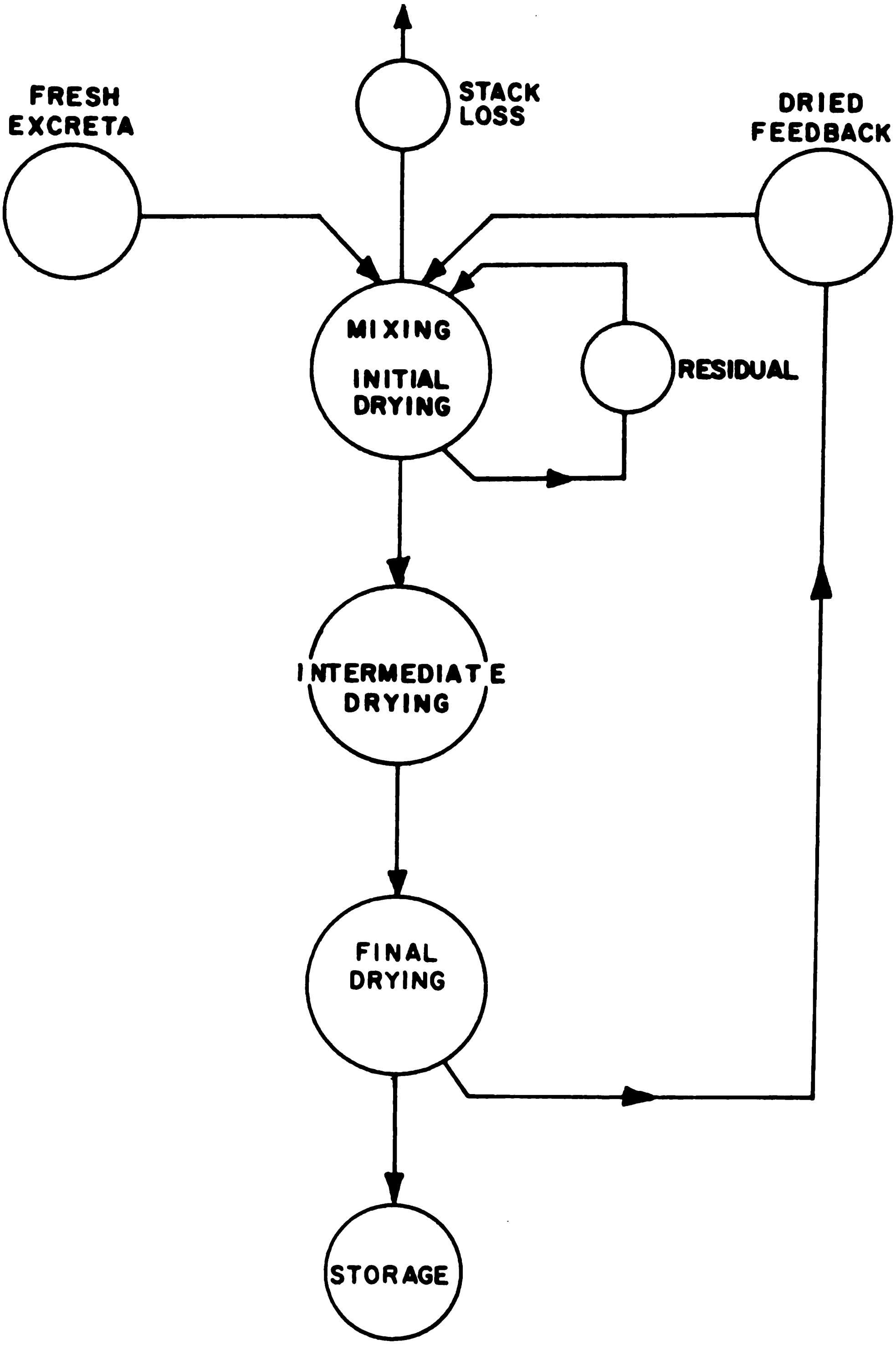

Figure 20. Diagram of excreta flow through the dryer. For poultry excreta and 1/4 inch screening plate, feedback was 3.3 pounds of dry matter per minute for 14.8 minutes out of each hour.

TABLE 15. Water removed during each phase of drying poultry excreta (1/4 inch screening plate).

Drying Process	Total Weight (lb)	Moisture (% w.b.)	Water (lb)	Dry Matter (lb)
Mixing				
Fresh excreta	237	75.6	179	58
Dried feedback	52	5.1	3	49
Stack loss (4.9% m.c.)	- 4	29.2	- 1	- 3
Residual	30	32.7	10	20
Before initial drying	315	60.6	191	124
After initial drying	184	32.7	60	124
Before intermediate drying	154	32.7	50	104
After intermediate drying	117	10.9	13	104
After final drying	112	6.9	8	104
After elevating	110	5.1	6	104
Storage	58	5.1	3	55

TABLE 16. Per cent of total drying that occurred during each phase of drying poultry excreta (1/4 inch screening plate).

Drying Process		Total Weight (lb)	Water (lb)	Per cent of Total Drying
Initial Drying (120 sec.)	before	315	191	
			(131)	75%
	after	184	60	
Intermediate Drying (15 sec.)	before	154	50	
			(37)	21%
	after	117	13	
Final Drying (75 sec.)	before	117	13	
			(5)	3%
	after	112	8	
Elevating	before	112	8	
			(2)	1%
	after	110	6	
Total Water Removed			175	

accounted for 75 per cent of the total, and 21 per cent occurred in an area where exposure time was no greater than 15 seconds. Similar results were obtained in additional trials.

From these results, most of the water was removed by pneumatic drying. The parameters controlling pneumatic drying would be the parameters controlling drying in this machine.

In the initial area of the dryer, fresh excreta was attached to dried and partially dried granules as these ingredients were mixed by the hammer mill. Drying took place as the material passed through the hot air after leaving the hammer mill.

Olson (1953) and Neel (1954) in studies on drying of potato granules did not attempt to analyze the process from a theoretical standpoint. Without such an analysis, it is difficult to determine the most significant parameters controlling drying. In an attempt to determine the effect of temeprature, air flow, particle diameters, and particle cloud density on pneumatic drying in the excreta dryer, the following idealized theoretical analysis was made.

Assumptions

1. steady state.
2. random distribution of particles in cloud.
3. spherical particles.

4. uniform moisture content throughout particle.
5. negligible moisture gradient within particle.
6. heat and mass transfer between particles and between particles and walls can be neglected.

$$\dot{m} = h_D\, A\, (C_p - C_a) \qquad (1)$$

holds true if:

$$\frac{D}{h_D\, d} > 10 \qquad (2)$$

(neglect internal moisture gradient)

$$h_D = \frac{D}{d}\, Sh \qquad \text{(Sherwood number)} \qquad (3)$$

$$D = 0.779 \times 10^{-4}\, T^{3/2} \qquad (4)$$

for general equation Rohsenaw & Choi, p. 382.

$$Sh = j_D\, (Re\, Sc)^{1/3} \qquad (5)$$

$$Re = \frac{U\, d}{\nu} \qquad \text{(Reynolds number)} \qquad (6)$$

$$Sc = \frac{\nu}{D} \qquad \text{(Schmidt number)} \qquad (7)$$

The following are values of the Colburn j_D factor expressed for fluid flow through a cloud of spherical particles as reported by Soo (1967).

$$\frac{d\, G_o}{\mu(1 - \varepsilon)} > 30 \qquad j_D = 1.77 \left[\frac{d\, G_o}{\mu(1 - \varepsilon)}\right]^{-.44} \qquad (8a)$$

$$\frac{d\, G_o}{\mu(1 - \varepsilon)} < 30 \qquad j_D = 5.7 \left[\frac{d\, G_o}{\mu(1 - \varepsilon)}\right]^{-.78} \qquad (8b)$$

The mass flow of the fluid is based on the unobstructed flow area.

$$G_o = \dot{v}\ \rho_a = U\ \rho_a \tag{9}$$

$$\varepsilon = 1 - \phi \tag{10}$$

The number of particles per unit volume (N_p) must be determined experimentally.

$$V_s = \frac{\pi}{6} N_p\ d^3 \tag{11}$$

$$\phi = \frac{V_s}{V} \tag{12}$$

Combining the above equations and neglecting the dependence of the kinematic viscosity ν on the temperature, the result is the following expression for the mass transfer coefficient.

$$h_D = \frac{3.22 \times 10^{-3}\ (\nu\phi)^{.44}\ T}{U^{.11}\ d^{1.11}} \tag{13}$$

In the temperature range (600° to 1200° R) during initial drying, the following linear expression closely approximates the dependence of kinematic viscosity on temperature.

$$\nu = -1.058 - 0.00284\ T \tag{14}$$

Substituting equation (14) into equation (13):

$$h_d = \frac{2.42 \times 10^{-4}\ \phi^{.44}\ (T^{1.44} - 13.7\ T)}{U^{.11}\ d^{1.11}} \tag{15}$$

It appears that the two primary parameters controlling mass transfer are temperature of the air and particle diameter. The fraction solid is also a significant parameter but to a lesser extent. Air speed is relatively unimportant unless a large change is initiated.

$$h_D \approx \frac{T}{d}\sqrt{\phi} \tag{16}$$

It is important to keep in mind that the preceding analysis of pneumatic drying is set forth for a highly idealized case. It does, however, give some indication of the importance each parameter plays in the actual drying process.

Conditions vary considerably in the initial drying area, where a form of pneumatic drying takes place. Particle cloud density is not uniform. The fraction void ε is different for each location in the initial area, and at any one location, ε varies with time in a cyclic manner with a period of about two minutes for poultry excreta with a one-quarter inch screening plate. The granules were only approximately spherical with rough surfaces, and a wide range of diameters. As the granules dried, average size was reduced by hammer mill action. Average granule size changed in a cyclic manner with a period of about two minutes for poultry excreta. The moisture content of the granules was not uniform. High moisture material was attached to the surface of partially dried granules. The granules themselves attained an initial velocity of approximately seventy feet per second at the hammer mill, while the air speed was in the range of 10 to 15 feet per second. Temperature gradient through the dryer was great due to rapid mass transfer taking place. Other parameters such as particle shape, surface roughness and porosity can be linked to the drying rate.

Even under these varied conditions, one can assume that the temperature and particle size are key parameters controlling the drying rate in the initial area. Analysis of conditions in the intermediate area were not made, but it is safe to assume that temperature and particle diameter are also key parameters controlling drying in that area.

To give an idea of the approximate magnitude of the mass transfer coefficient, equation (15) is evaluated for the extreme high and low temperatures in the initial drying area. The granular excreta is exposed to the highest temperature as it leaves the hammer mill. The approximate conditions are as follows:

$T = 1200\ ^{\circ}\ R$

$U = 150{,}000$ ft/hr

$\phi = 0.5$

d - 0.004 ft

Mass Transfer Coefficient, $h_D = 240$ ft/hr

$$\frac{D}{h_D\ d} = 3.4$$

About three feet into the initial area from the hammer mill, the conditions have changed greatly. The following are approximate values:

$T = 700^{\circ}\ R$

$U = 36{,}000$ ft/hr

$\phi = 0.5$

$d = 0.004$ ft

Mass Transfer Coefficient, $h_D = 74$ ft/hr

$$\frac{D}{h_D\ d} = 4.9$$

If equation (1) is to be used to determine the rate of mass transfer, $\frac{D}{h_D\ h}$ must be greater than ten. The values estimated above do not quite meet these conditions, however, for a first approximation equation (1) can be assumed valid.

CHAPTER VII

SUMMARY

The animal excreta dryer was tested with poultry, bovine, swine and mink excreta to determine whether these materials could be dried satisfactorily with this machine. Poultry excreta containing wood chip litter and bovine excreta containing straw were also tested. For each of these materials, the production rate, fuel oil and electricity consumption, and overall thermal efficiency were determined.

Some attention was focused on the properties of the dried excreta. The bulk density and particle size distribution were determined for each of the materials tested. The effect of high temperature on nutrient content of poultry, bovine and swine excreta was also determined.

Temperature gradient through the dryer and temperature variation with time at several key locations were determined. For poultry excreta, the per cent of total drying in each of the three major areas was determined. An idealized theoretical analysis of the primary drying mechanism was undertaken to determine key parameters controlling drying.

Conclusions

1. The dryer successfully processed poultry, bovine and swine excreta, although some difficulty was incurred during trials with swine excreta (p. 23).

2. Poultry excreta of which 18.3 per cent of the dry matter consisted of wood chip litter, and bovine excreta with 2.0 and 3.9 per cent straw were dried successfully (p. 26).

3. Production rates for the dryer ranged form 178 pounds per hour for bovine excreta consisting of 3.9 per cent straw up to 340 pounds per hour for poultry excreta. Efficiencies ranged form 41.1 to 71.8 per cent (p. 29).

4. Up to 6 per cent of the dry matter entering the dryer escaped from the stack (p. 33).

5. An odor was released during drying, but it was different than the fresh excreta (p. 33). There also was an odor in the dried product, but it was less intense than the fresh excreta (p. 38).

6. Bulk densities ranged from 10.9 pounds per cubic foot for bovine excreta consisting of 3.9 per cent straw up to 23.4 pounds per cubic foot for poultry excreta (p. 35).

7. A very small percentage of the dried excreta particles were outside the size range of 0.01 to 0.1 inches (p. 39).

8. In most cases nitrogen, phosphorus, potassium and protein levels decreased as a reuslt of drying (p. 40).

9. The temperature gradient through the drying area varied from 1100° F to 200° F (p. 44).

10. Temperature varied widely with time at distinct locations within the dryer (p. 45).

11. In most areas the temperature on the surface of the dryer was not high enough to cause personal injury (p. 47).

12. About 75 per cent of drying occurred in the initial area by a pneumatic process (p. 50).

13. The most significant parameters controlling drying were temperature and particle diameter. The mass transfer coefficient for idealized pneumatic drying varied directly with absolute temperature and inversely with particle diameter (p. 54).

Suggestions for Further Research

1. The time required for combustion to occur for various temperatures and moisture contents is needed to establish the upper bounds on drying conditions.

2. A thorough study of pneumatic drying is needed to investigate the full potential of this process.

3. Air flow through the excreta dryer was not studied. Undoubtedly an improved air flow pattern would aid drying. Perhaps an exahust fan should be used to induce air flow.

4. The highest temperatures were applied to partially dried excreta, and on occasion combustion resulted. A study could be made to determine the effect of applying the hottest air to the initial drying area.

5. The composition of the exhaust gases from the dryer should be determined to see if undesirable levels of air pollutents are being released.

6. Determine the comparative economics of this and other methods of animal waste management.

7. A thorough study of drying with a flow-through rotating drum dryer would be desirable for comparison.

8. The consumer market should be tested to determine whether dried excreta would be accepted as lawn and garden fertilizer.

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