MECHANISMS OF POTATO CELL RUPTURE RESULTING FROM DEHYDRATION PROCESSING

by

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TABLE OF CONTENTS

INTRODUCTION

The removal of water from potatoes to form a product known as instant potato granules, which may be rehydrated to form a mashed potato suitable for table serving has been under study for several years. This work has attracted the attention of the armed services and, if perfected, should find wide domestic acceptance.

One of numerous problems associated with the dehydration processing is that of prevention of cell rupture. When a cell wall breaks the intra cellular fluid-like substance, containing starch particles, is liberated. It has been estimated that if about 10 to 20 percent of cells are ruptured, a pasty, unpalatable table serving will result. Various investigators have found prevention of excessive cell rupture a difficult problem (1; 2, p. 11; 3; 4, p. 1; 5; 6).

This study was undertaken to determine the mechanism of and the cause of potato cell rupture during the dehydration and the rehydration process and, if possible, to find means of preventing the rupture.

METHODS AND MATERIALS

In general, the method used in this work followed the general pattern of:

1. Making observations.
2. From the observations establishing a hypothesis.
3. Devising experiments to test the hypothesis.
4. Analyzing experimental results for confirmation of the hypothesis.

This work was divided into several sections, each section of which follows the same general pattern outlined above. Since the observations made, the materials used, and the method of attack followed on each section varied considerably, each section was treated individually and is so presented in this work.

Incidental to various studies it was found necessary to standardize such items as the cell rupture count technique and to develop new measuring techniques such as the pressure release test. These items are described in the Appendix.

HYPOTHESIS I

CELL RUPTURE IN DUCT TYPE DEHYDRATOR IS A RESULT OF ABRASIVE ACTION AND RUPTURE DOES NOT OCCUR UNTIL THE CELL WALL BECOMES BRITTLE AT ABOUT TWENTY TO TEN PERCENT MOISTURE

Conclusion

The experimental evidence did not indicate that cell rupture occurred at any given moisture content.

From the work of earlier investigators (5, p. 8; 6, p. 549) it appeared that no cell rupture occurred in duct driers until the moisture content of the granules reached about 15 percent. Apparently these workers thought that the cells retained a resillient surface characteristic and would rebound (like a rubber ball) when they struck the walls of the duct. At about 15 percent moisture, however, the surface of the cell became brittle and would fracture (like an egg shell). Based upon these thoughts, hypothesis I was presented.

As a test of this hypothesis, it was proposed that the plot of percent rupture as a function of percent moisture through the drying process should show a low level line until about 15 percent moisture was reached, and that the line should then break to rise rapidly as moisture content continued to decrease.

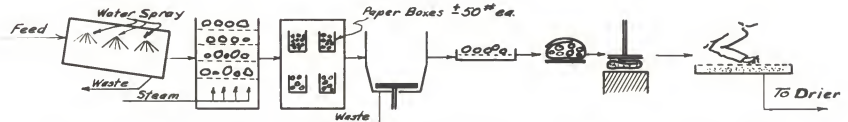
In order to obtain data for this plot, the duct and cyclonedrying equipment as assembled in the Chemical Engineering laboratories was used. Olson (7) had studied and described duct and cyclone drying as applied to potato granules. Erskine (4, Plate II) had described the procedure for drying in the cyclone. Haney (8, Plate I) had described a unit for alfalfa dehydration consisting of a duct and cyclone. For potato granule drying the Haney equipment was modified by substituting 8" duct for the tower E (see Plate III). Preliminary processing of potatoes was as outlined in Plate I.

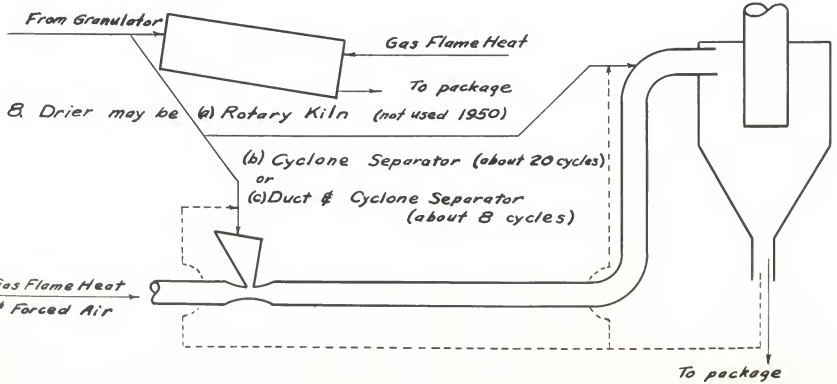
With the Erskine dryer it was necessary to feed the outlet product back into the cyclone about twenty times in order to bring the moisture content to about 10 percent. Each feed through was termed a cycle or a pass. With the modified Haney dryer about ten passes brought the moisture content to about 10 percent.

EXPLANATION OF PLATE I

Flow sheet of potato processing to produce the Instant Potato Granules. Processing followed July, 1950 to March, 1951.

PLATE I


Feed
Water Spray
Waste
Steam
Paper Boxes ±50# ea.
Waste
To Drier
1 Wash
Rotary Unit
2 Cook
Potatoes on trays
Use live steam
atm. pressure
3 Freeze & Store
4 Peel
Abrasive
unit - about
15% loss
5 Thaw
Hand trim
Place on Screen
at room cond.
6 Press
Immediate, after
thawing, wrap in
canvas sheet
7 Granulate
Immediately
after press. Do
not extrude.


From Granulator
Gas Flame Heat
To package
8 Drier may be (a) Rotary Kiln (not used 1950)
(b) Cyclone Separator (about 20 cycles)
or
(c) Duct & Cyclone Separator
(about 8 cycles)
Gas Flame Heat
& Forced Air
To package

EXPLANATION OF PLATE II

Fig. 1. Cooking Unit.

a. Ten quart aluminum pressure cooker with false bottom.

b. Condenser, used to return escaping water vapors to cooker.

c. Thermometer.

d. Vacuum buffer chamber (pump not shown).

e. Manometer.

f. Timer.

g. Fisher burner.

h. Pressure regulator valve for pressure cooking (not shown).

Fig. 2. Processing Equipment.

a. Potatoes on glass plate in process of thawing.

b. Fan.

c. Filter cloth in which freshly thawed potatoes were wrapped before placing into press.

d. Perforated wooden press plates.

e. Hydraulic press unit.

f. Granulator.

g. Granulator screen, 14 mesh, stainless steel.

h. Recepticle for granules.

PLATE II

Fig. 1.

Fig. 2.

EXPLANATION OF PLATE III

Pneumatic Potato Granule Dehydrators

Fig. 1. Modified from Haney alfalfa dehydrator

A. Furnace

B. Blower

C. Feed Hopper

E. 8" duct drying section

F. Cyclone separator

Fig. 2. Cyclone dehydrator

a. Feed entrance to Erskine cyclone dehydrator

PLATE III

Fig. 2

Fig. 1

At the end of each pass or group of passes a sample was taken and moisture and rupture analyses were made. The results as shown on Plate IV were obtained.

As another approach to the same type of analysis the influence of the number of passes on the percent rupture was plotted in Plate V. Again, if rupture was absent or negligible until a given moisture content was reached the plots should show a low, nearly level line until a given point and should then break to rise rapidly. No clear cut break, to substantiate hypothesis I, was observed.

EXPLANATION OF PLATE IV

Plots of rupture as a function of water content of granules through the drying process.

Fig. 1. Data of 24 August 1950

●——● modified Haney dryer, 7-7/8" orifice

○——○ modified Haney dryer, no orifice

◠——◠ Erskine dryer

Fig. 2. Data of 28 August 1950

●——● modified Haney dryer, 7-7/8" orifice

○——○ modified Haney dryer, no orifice

◠——◠ Erskine dryer

Fig. 3. Data of 6 September 1950

All through modified Haney dryer, no orifice

○ drying temp. 80° F.

● drying temp. 100° F.

◠ drying temp. 120° F.

◠ drying temp. 150° F.

◡ drying temp. 175° F.

Fig. 4. Data of 11 September 1950

All through modified Haney dryer

○ 10" orifice for all passes

● 10" orifice for first pass, decrease orifice size with each five passes to 3-7/8" orifice on final pass.

Most points represent arithmatic average of at least three rupture counts on 100 cells on each count.

PLATE IV

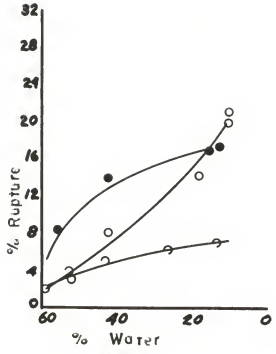


Fig. 1

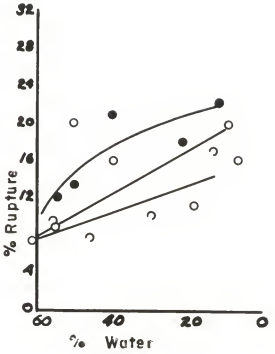


Fig. 2

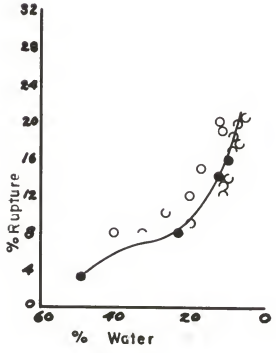


Fig. 3

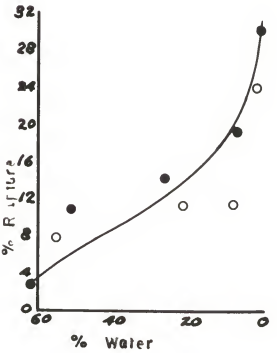


Fig. 4

EXPLANATION OF PLATE V

Plots of rupture as a function of number of passes through the indicated dehydrator.

Fig. 1. Data of 24 August 1950

●——● modified Haney dryer, 7-7/8" orifice

○——○ modified Haney dryer, no orifice

◠——◠ Erskine dryer

Fig. 2. Data of 28 August 1950

●——● modified Haney dryer, 7-7/8" orifice

○——○ modified Haney dryer, no orifice

◠——◠ Erskine dryer

Fig. 3. Data of 6 September 1950

All through modified Haney dryer, no orifice

○ drying temp. 80° F.

● drying temp. 100° F.

◠ drying temp. 120° F.

◠ drying temp. 150° F.

◡ drying temp. 175° F.

Fig. 4. Data of 11 September 1950

All through modified Haney dryer

○ 10" orifice for all passes

● 10" orifice for first pass, decrease orifice size with each five passes to 3-7/8" orifice on final pass.

Most points represent arithmatic average of at least three rupture counts of 100 cells on each count.

PLATE V

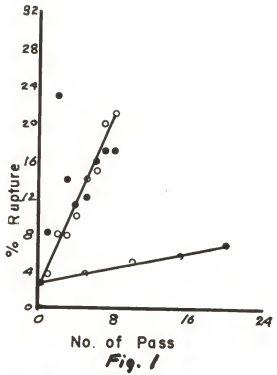


Fig. 1

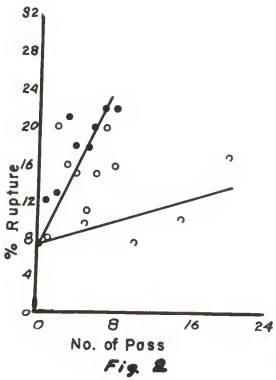


Fig. 2

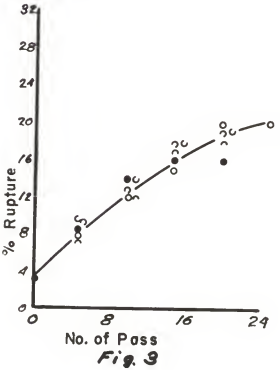


Fig. 3

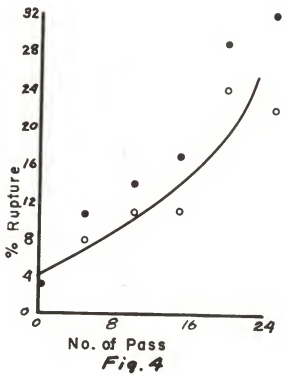


Fig. 4

HYPOTHESIS II

CELL RUPTURE RESULTS FROM ABRASION OF POTATO GRANULES AS THEY STRIKE AND RUB ALONG THE WALLS OF THE DUCT AND AS THEY STRIKE ONE ANOTHER IN THE TURBULENT AIR STREAM

Conclusion

The experimental evidence indicated that rupture in duct and cyclone type dehydrators was not due to abrasive action.

As a result of study of hypothesis I it was questioned whether or not rupture did occur as a result of abrasive action. Based upon the work of previous investigators hypothesis II was stated in a positive manner.

It was observed that the product from the duct and cyclone type dehydrator could be separated into size fractions by use of standard sieves. Individual particles retained on the sieve were termed granules. The granules were visualized as popcorn balls; the cells representing the individual pieces of popcorn. It was assumed that only the cells on the periphery of the granules could make the necessary contact with a foreign object to result in abrasive rupture. Since, for a given number of cells the percent on the periphery would increase with decrease in granule size, it was realized that if hypothesis II were correct, the rupture count on the various size fractions should increase in the same manner as the increase in surface area (9, p. 11).

Direct measurement of rehydrated cells (for the cell rupture count) with a calibrated microscope (10, p. 41) gave diameters ranging from about 40 to 100 microns or about 0.1 mm as a maximum. It was estimated that the cells swell about 2x upon rehydrating. This would place the size of the dehydrated cells at about 0.05 mm maximum diameter.

Based on indicated assumptions the curves of Plate VI were prepared, the size fractions of granules were separated with standard sieves and rupture counts made on each size fraction. Results were tabulated in Table 2. The expected increase in cell rupture with decrease in granule size was not observed.

EXPLANATION OF PLATE VI

Curve (a). For total volume = 1 cubic mm. Curve (a) was drawn to show how surface area increased as particle size (remaining in cube form) decreased with sieve opening size.

Curve (b). Based on the assumption that a cell was a 0.05 mm cube and that granules were larger cubes composed of the cell cubes, curve (b) was drawn to show how the number of cells in a granule increased with the granules retained on various sized standard sieves.

Curve (c). Based on the assumptions that percent rupture varies directly with surface area, that all granules are cubes, that the cells are infinitely small, and that the +20 sieve contains 10 percent ruptured cells, curve (c) was drawn to show the increase in cell rupture as size of granules decreased.

PLATE VI

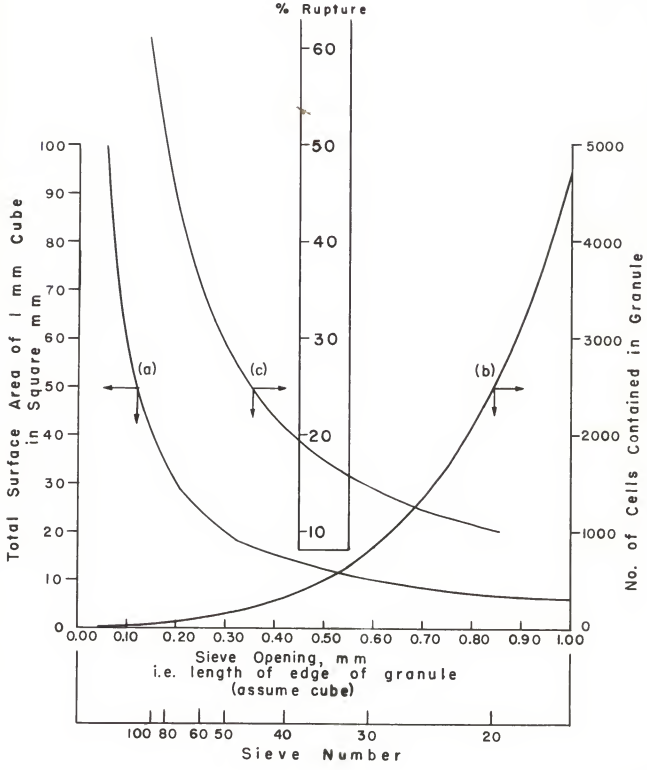

% Rupture
60
50
40
30
20
10
Total Surface Area of 1 mm Cube in Square mm
100
90
80
70
60
50
40
30
20
10
0
No. of Cells Contained in Granule
5000
4000
3000
2000
1000
0
(a)
(c)
(b)
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 1.00
Sieve Opening, mm
i.e. length of edge of granule
(assume cube)
100 80 60 50 40 30 20
Sieve Number

Table 1. Data of Plate VI.

Sieve opening : mm = granule dimension	Sieve No. (11, p. 963)	Volume of particle	No. of particles	No. of cells contained in granule	Total surface area sq. mm
1.00	—	1	1	4550	6
0.84	20	0.540	1.85	2460	—
0.59	30	—	—	—	—
0.50	—	0.125	8	570	12
0.42	40	—	—	—	—
0.40	—	0.064	15.7	290	15
0.30	50	0.0270	37.1	122.5	20
0.25	60	—	—	—	—
0.20	—	0.0080	125	36.4	30
0.18	80	—	—	—	—
0.15	1000	—	—	—	—
0.10	—	0.0010	1000	4.6	60
0.08	—	0.00053	1890	2.4	72.5
0.06	—	0.00022	4550	1	98.5

Table 2. Observed rupture percent on indicated granule sizes.

Granules retained on sieve:		36-11-E-1	36-34	36-20-1	36-20-2	36-20-3	36-20-4	36-20-5
		Sample number						
		Percent rupture						
no.	counts	av.	av.	av.	av.	av.	av.	av.
20	6 - 5	6	5	16	19	14	18	11
30	5 6 8	6	7	20	16	16	17	10
40	3 4 6	4	7	21	11	13	15	11
50	7 7 7	7	7	20	19	16	16	15
60	9 6 7	7	6	19	19	18	19	18
80	7 5 8	7	7	24	22	11	17	16
100	7 6 8	7	7	22	15	14	14	16
past 100	7 8 9	8	10	21	25	18	15	20
before sieving	6 8 7	7	4	19	16	18	19	19

Sample no.	Drying procedure
36-11-E-1	Dried in Erskine cyclone to 12 percent moisture
36-34	Dried in cone type dryer to about 1 percent moisture
36-20-1	Dried in modified Haney dehydrator at 80° F., full throat to 11 percent moisture
36-20-2	Same at 100° F. to 11 percent moisture
36-20-3	Same at 120° F. to 9 percent moisture
36-20-4	Same at 150° F. to 8 percent moisture
36-20-5	Same at 175° F. to 6 percent moisture

HYPOTHESIS III

CELL RUPTURE IS DUE TO THE SUDDEN INCREASE OF VAPOR PRESSURE INSIDE THE CELL WALL AS THE TEMPERATURE OF THE CELL RISES WHEN SUBJECTED TO A FLOW OF HOT GAS

Conclusion

No definite conclusion was drawn. However, it appeared that the hypothesis could be true. Further investigation needed.

While making cell rupture counts it was noted that many cells, after rupture, had shapes which were suggestive of a volcano mouth. This observation led to the speculation that rupture occurred as a result of increase of pressure within the cell wall. The volcano appearance was demonstrated by Plate VII, Fig. 1 and 2. Figure 1 may be drawn:

Before Rupture

After Rupture

While Fig. 2 may be drawn:

Before Rupture

After Rupture

In order to test the possibility of rupturing in this manner it was realized that a sudden decrease in external pressure should give the same result as an equivalent increase of internal pressure. Accordingly the apparatus described in Plate VIII was assembled.

EXPLANATION OF PLATE VII

Photographs of various types of cell rupture.

Fig. 1 and 2 "volcano" type rupture

Fig. 3 "push out" type rupture

Fig. 1 and 2 (a) vs. (b) different photography lighting effect

Fig. 3 (a) vs. (b) demonstration of influence of microscopic adjustment

PLATE VII

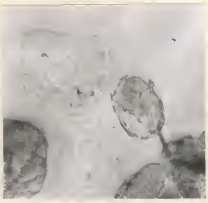


Fig. 1. (a)

Fig. 1. (b)

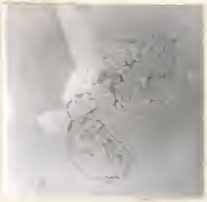


Fig. 2. (a)

Fig. 2. (b)

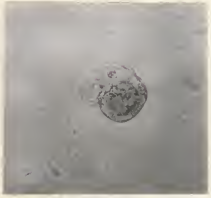


Fig. 3. (a)

Fig. 3. (b)

EXPLANATION OF PLATE VIII

Equipment used to exert pressure or vacuum change on potato cells.

To operate close pinch clamp, remove pyrex test tube from rubber stopper, place pinch of potato granule into sample well of cork float, assemble pressure cell, adjust Hg. well to desired position, open pinch clamp, and keep open for specified time, close pinch clamp, adjust Hg. well to new desired position, snap pinch clamp open, repeat desired number of cycles, close pinch clamp, disassemble pressure cell, remove potato granules, run standard microscopic count.

A clamp device was found necessary to keep pyres test tube properly assembled to rubber stopper while under appreciable positive pressure.

The cork float was found necessary to keep the potato granules separated from the mercury.

The "I" notch was found necessary to prevent the cork float from acting as a stopper when pressure was released suddenly.

Pressure or vacuum rubber tubing was found to be somewhat cumbersom to use. It was necessary to wrap light weight rubber tubing with friction tape to prevent bursting while under pressure.

PLATE VIII

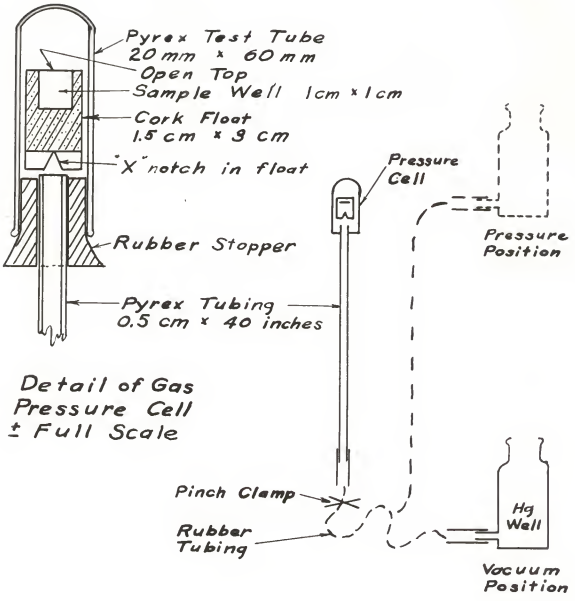

Pyrex Test Tube
20 mm x 60 mm
Open Top
Sample Well 1cm x 1cm
Cork Float
1.5 cm x 3 cm
"X" notch in float
Rubber Stopper
Pyrex Tubing
0.5 cm x 40 inches
Detail of Gas
Pressure Cell
± Full Scale
Pressure Cell
Pressure Position
Pinch Clamp
Rubber Tubing
Hg Well
Vacuum Position

Table 3. Results of pressure release test using apparatus described on Plate VIII, September 22, 1950.[1]

Moisture content granules: 66%				
Sample no.	cm Hg vacuum	Number of cycles	Rupture % Counts	Av.
0	control	none	1 3 5 2	3
1	25	1	2 3	3
2	25	2	3 2	3
3	25	3	3 3 4 4	4
4	25	4	6 6	6
5	25	5	6 6 5 7	6
6	25	6	5 7	6
7	25	7	4 6 7 6	6
8	25	8	7 9 6 5	7
9	25	9	5 7 7	7
10	25	10	6 4 6	6

[1]Initial pressure: atmospheric.

From this observation it was decided that a sudden change of pressure inside the cell could result in rupture.

The mechanism of pressure change inside the cell was visualized as follows:

Assume atmospheric pressure = 760 mm Hg.

and temperature of granules = 70° F.

assume fluid inside cells has vapor pressure characteristic of pure water, then the vapor pressure of this fluid will = 18.8 mm Hg. or 19 mm Hg.

Total pressure inside cell = vapor pressure water + other unknown

(x) pressures = 760 mm Hg.

Then other (x) pressures = 760 - 19 = 741 mm Hg.

Now suppose that the cell is suddenly hit with hot air, that the temperature of the intracellular fluid increases to 160° F. and that the vapor pressure accordingly increased to 191 mm Hg. If the other pressures (x) have remained unchanged at 741 mm Hg., the new internal pressure will = 741 + 191 = 932 mm Hg. Or the increase of internal pressure = 932 - 76 = 172 = 17.2 cm Hg. From the observations of Table 3 it appeared that this increase in pressure could result in cell rupture.

Several assumptions were necessary. It was assumed that the cell was a membrane which was impermeable, or nearly impermeable, to the water vapors (12, p. 128). Actually the intracellular solution, or portions of it, were thought to travel through the cell wall by such processes as liquid diffusion, gas diffusion, and capillarity. However, it was thought, that the rate of pressure release by such means was so slow that the effect of rate of temperature rise would be much greater.

The assumption that the intracellular fluids would possess the same vapor pressure as free water was obviously in error. However, for lack of more specific data this assumption served as a basis for estimation.

The other unknown (x) pressures were difficult to explain. If such did not exist the cell would surely collapse. It was thought that it could, in part, be due to vapor pressure of other liquids or to compression of the intracellular liquids (12, p. 60 to 63).

The assumption that the temperature of the intracellular fluid would reach that of the air stream was recognized as being questionable. It was

pointed out that this was a problem of heat and mass transfer relationships. Heat would be transferred to the cell through various films and would be lost from the cell through the heat content of resulting vapors. However, it was recognized that a temperature rise of the intracellular fluids could result and that the actual temperature involved need not be known for initial studies. It was further recognized that use of saturated steam, instead of partially dry air, would result in no material transfer from the cell; in which case the temperature of the intracellular fluids would rise to the temperature of the surrounding atmosphere.

Table 3. Influence of temperature change (using equipment of Plate IX) on rupture.

Sample no.	Room temp. °F.	Air blast temp. °F.	% rupture
A	80	control (no treatment)	2
B	80	200	1
C	80	200	0

The equipment was next modified by inserting a heat exchanger made of 1 1/2 inch x 1½ inch long standard pipe filled with metal shavings. (See Plate X, Fig. 2, item C.) Results using this equipment were tabulated in Table 4.

EXPLANATION OF PLATE IX

Diagram of equipment used to hit granules with sudden temperature change (also see Plate X).

To operate, remove screen basket from glass tubing, turn on air at desired rate (slow enough so granules are not blown out of the basket as predetermined experimentally), light enough burners to raise air temperature to desired figure, hold thermometer in hand and adjust flame so that exit air is at desired constant temperature, introduce a pinch of granules to basket, set (as rapidly as possible) the charged basket into glass tube holder (as illustrated in Plate IX), remove basket after a few minutes drying time, run standard microscopic rupture count.

Insert, upper left hand corner, pencil outlines of cell shapes after temperature change = 80° F. to 200° F.

PLATE IX

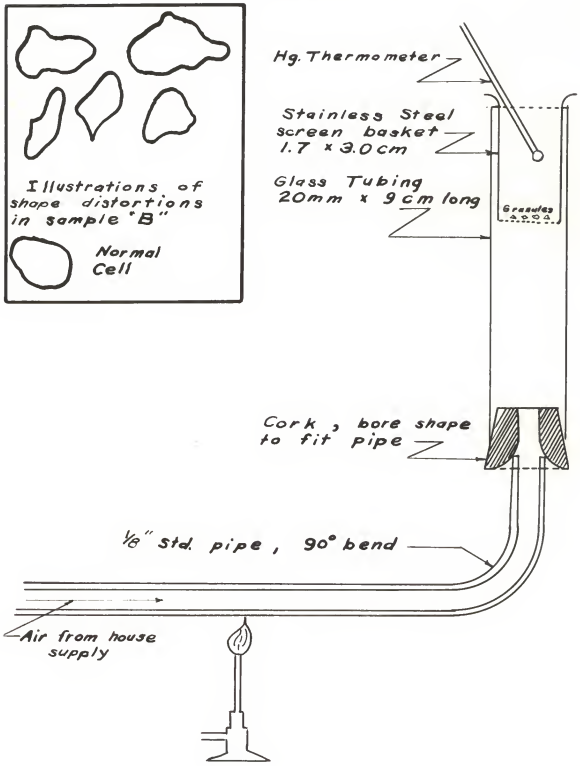

Illustrations of shape distortions in sample "B"
Normal Cell
Hg. Thermometer
Stainless Steel screen basket 1.7 x 3.0 cm
Glass Tubing 20mm x 9 cm long
Granules
Cork, bore shape to fit pipe
1/8" Std. pipe, 90° bend
Air from house supply

Table 4. Influence of temperature change (using equipment of Plate II with modified heat exchanger) on rupture.

Sample no.	Room temp. °F.	Air blast temp. °F.	% rupture
32-A	80	control (no treatment)	3
32-B	80	350	1
32-C	80	350	2

Because of the small quantity of granules involved with this procedure it was impractical to run moisture contents on the dehydrated product. It could be observed, by full and visual inspection, that the granules were "quite dry". The equipment was also limited in air velocity. As the granules became dry they would float out with the air stream.

The equipment was next modified by replacing the glass tube and wire basket with an adjustable cone which measured about 26 inches in length, (See Plate I, Fig. 2). With this equipment it was possible to use much higher air velocities, variations in air velocity were not so critical and it was possible to use larger quantities of granules so that the moisture content could be observed. The gas velocity to which particles were subjected in the adjustable cone drier was their normal settling velocity in the given gas at the given conditions. This is true because the particles would rise or fall in the cone until they reached the vertical level where the velocity of the gas was that of the settling velocity of the granule. Results using this equipment were tabulated in Table 5.

EXPLANATION OF PLATE X

Fig. 1. (a). Tensiometer used to demonstrate bound water in potato granules.

F. Porous clay cup

G. Mercury column

H. Sample of wet granules

Fig. 1. (b). Equipment used to hit granules with hot, water saturated atmosphere to gather data for Table 6.

A. Fisher burner

B. Liter wash bottle, half full of boiling water

C. Calcium chloride tube of water saturated atmosphere

D. Stainless steel screen basket used as container for granules

E. Adjustable wire hook used to suspend basket in tube

Fig. 2. Cone dehydrator and equipment used to hit granules with hot, dry atmosphere.

A. Inlet pipe, either compressed air or live steam

B. Water entrainer, to dry steam

C. Superheater, 1 1/4 inch pipe filled with metal shavings

D. Fisher burners

E. Aspirator pump, used (if desired) to introduce thin potato slury into dehydrator gas stream

F. Flask of potato slury as feed

G. Adjustable cone, made of light weight tin sheet, 24 x 18 inches, roll into cone.

H. Ring, used to hold shape of adjustable cone.

I. Low velocity separator

J. Funnel shaped top feeder

K. Product delivery spout

L. Recepticle for product

PLATE X

Fig. 1. (a)

Fig. 1. (b)

Fig. 2.

Table 5. Influence of temperature change (using equipment of Plate II with modified heat exchanger of Table 5 and adjustable cone dryer unit) on rupture.

Sample no.	% Moisture	% Rupture	
34-1	31	5	
34-2	2	4	temperatures were not recorded
control	wet	3	

As previously noted it was recognized that the transfer of water of the cell to water vapor in the surrounding atmosphere could result in lowering of temperature; i.e., a retarding of rate of temperature rise in the cell. In order to decrease, or perhaps eliminate this effect the equipment of Plate X, Fig. 1 (a) was used. Granules were placed into the screen bag and instantaneously lowered into the calcium chloride tube. Results were tabulated in Table 6.

Table 6. Influence of temperature change (in nearly saturated drying stream) on rupture.

Sample no.	Room temp. °F.	Steam temp. °F.	Length of time exposed to steam	Rupture % counts	av.
66 control	80	210	none	3 2 3 4 0 4 2	2.6
66-5	80	210	5 sec	5 0 4 3 5	3.5
66-10	80	210	10 sec	4 5 7 1 5 4 6	6.0
66-30	80	210	30 sec	3 6 7 2 3 1 2	3.5

This was considered to give substantial evidence that the hypothesis III was correct. It was pointed out, however, that the cool granules served as a cool body on which the hot vapors would condense and that this was, in effect, much like plunging the granules in hot water. Also, the velocity of atmosphere past the granules was very slow in this system as compared to the velocity in other parallel experiments.

No definite conclusion could be drawn but it was believed that the hypothesis could be true. Further investigation needed.

HYPOTHESIS IV

CELL RUPTURE OCCURS DURING THE REHYDRATION PROCESS
WATER FIRST WETS THE ENTIRE PERIPHERY OF THE CELL
CAPILLARY ACTION FORCES THE WATER FROM THE PERIPHERY TOWARD THE CENTER,
INTRACELLULAR GASES ARE COMPRESSED AND THIS COMPRESSION INCREASES UNTIL AN
EXPLOSION RESULTS

Conclusion

No definite evidence was obtained to substantiate hypothesis IV as stated. However, cells were observed in rupture during the rehydration process. Such observation did not preclude the possibility of rupture occurring during the dehydration processing.

After the study of hypothesis III indicated that an increase in internal pressure could be responsible for cell rupture, thought was given to other possible mechanisms of increasing intracellular pressure. It has been shown that soil aggregates (small clods) can be made to explode by wetting action (13, 14). This action has been demonstrated by filling a test tube about half full with a clay soil and adding water to a depth of three or four centimeters. As the soil wets downward it compresses the air below the layer of wet soil and air pressure builds up to a point where it raises the wet soil layer (15).

Several assumptions were necessary before this same type of action could be applied to cell rupture.

(a). It was assumed that cell rupture did not occur during the drying process. Upon consideration it was realized that it was not definitely known that rupture did occur during the drying process. Earlier workers (6, p. 551, col. 1) who had made this assumption gave no basis for it. Burton (16) was able to up-grade the dehydrated granules by sieving out the very fine material which could be assumed to be material from inside the cell. In this case it is probable that rupture can occur during the dehydration processing.

(b). It was assumed that the cell wall had become inflexible and had reached a low degree of elasticity (12, p. 32; 38; 72; 73; 74) as a result of the processing through the dehydration. It was apparent that sugars could be present on the surface of the cells (17) and it was thought that such action as carmelization on the surface of the cell wall could create the inelastic condition. Previous workers apparently attributed the formation of "* * * thin film or crust * * *" on sliced potato surfaces to

humidity and temperature conditions during the thawing step (18).

(c). It was assumed that the cell is dried such that air (or other gas) is contained in the cell body, perhaps in capillary cavities. Actually there was little to support this assumption. It was, however, thought rather improbable that all pores of the intracellular body were completely void of air. Even though air was absent the wedging effect of water being "dragged" in by capillary or osmotic action could result in enough expansion to cause the case-hardened (19, p. 307) surface to split open.

Since the nature of rehydration to make the cell rupture count is that of a very rapid process it was thought that slow rehydration or partial rehydration preceding the addition of water for the rupture count would result in a reduction of ruptured cells. It was thought that very slow rehydration would result in a wetting of the surface of the cell wall and restore this membrane to an elastic state before added water and subsequent cell enlargement took place.

In order to make experimental observations a quantity of dry cells was placed in a container and air was passed first through a packed tower filled with water where it was assumed to reach a nearly saturated condition and was then passed through the container of cells. Results of this exercise were recorded in Table 7.

Table 7. Influence of slow rehydration in water saturated atmosphere on cell wall rupture.

Sample no.	Date	% Moisture	Rupture % Counts			Av.
41-1	15 Nov.	6.7	14	13	-	14
41-2	17 Nov.	13.6	18	-	-	18
41-3	20 Nov.	36.5	16	17	-	17
41-4	1 Dec.	41.0	13	-	-	13

Molds (or some such forms of life) were observed to be growing on the cells after a few days. These foreign bodies, added to the debris, increased the confusion of making rupture counts and produced a possible unknown influence on the strength of the cell walls.

In an attempt to increase the rate of rehydration over that of Table 7, strips of blotter paper were arranged with one end in water and the other end lying on a flat surface and several inches above the water level. The dry granules were then placed in a pile of the elevated portion of the blotter paper. Several of these were used. However, a great deal of mold growth occurred and only one sample was analyzed.. Results were recorded in Table 8.

Table 8. Influence of slow rehydration using blotter wick on cell wall rupture.

Sample no.	Date	% Moisture	Rupture % Counts			Av.
42-1	17 Nov.	6.7	14	15	-	14
42-2	20 Nov.	77.0	12	10	-	11

In order to make direct observation of cell action a slide was prepared in the normal manner and placed in focus under the microscope micrometer. About six cells were in the microscopic field with one cell showing a diameter of 22 x 14 = 318 microns. This assembly was left undisturbed for 24 hours in the low humidity room atmosphere. At the end of this period the diameter of this same cell was observed to be 20 x 14 = 280 microns. The cells were rehydrated by placing a drop of water on the slide. Instantly intracellular material began to flow from a given point on the surface of the cells. The diameter of the one observed cell remained constant at 280 microns even though it did take on water and did extrude material from its interior. Greene et al (6, p. 551) apparently observed a similar action on cells before dehydration. They attributed the diffusion of water to difference in osmotic pressures and apparently were able to prevent the rupture by use of a salt solution. In my observation the shape of the cell did not change as the Greene workers reported. It is possible that the glycerine in the staining solution served to cement the cell to the glass slide, at least temporarily, in such a manner that as the cell expanded, the line along the cell periphery and next to the glass was subjected to severe and abnormal stress.

It was proposed that, if cell rupture did result from case hardening, washing of the cells could possibly remove the substance responsible for this effect from the outer surface of the cell wall.

The process outlined in flowsheet of Plate XI was used to study the influence of washing on cell rupture. Washing was carried out by placing the granules in a large crockery basin, adding about four volumes of tap water and stirring with the hand for about ten minutes. (It may be noted that this procedure apparently closely parallels the Greene process of

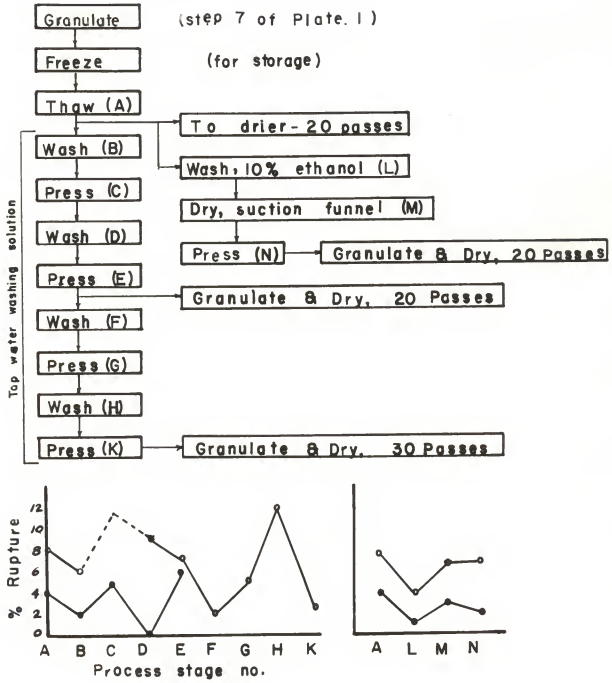
EXPLANATION OF PLATE XI

Block flowsheet of washing procedure used before drying to give results plotted on Plate XII. (After each washing step the granules were dewatered with a suction funnel before pressing).

Lower part:

Observed rupture percentages at indicated stages of processing in top flowsheet.

PLATE XI


Granulate
(step 7 of Plate. I)
Freeze
(for storage)
Thaw (A)
To drier - 20 passes
Wash (B)
Wash, 10% ethanol (L)
Press (C)
Dry, suction funnel (M)
Wash (D)
Press (N)
Granulate & Dry, 20 Passes
Press (E)
Granulate & Dry, 20 Passes
Wash (F)
Press (G)
Wash (H)
Press (K)
Granulate & Dry, 30 Passes
Top water washing solution
% Rupture
0
2
4
6
8
10
12
A B C D E F G H K
Process stage no.
A L M N

slurrying). The slurry was then filtered through a Buchner funnel and the granules pressed and granulated in the normal manner. It was noted that granulation was greatly facilitated by this process.

In view of the findings of Green et al. (6, p. 551) who, under apparently the same treatment, reported extensive cell rupture to occur when the potatoes were slurried, it was interesting to note that the rupture count nearly always dropped after each washing.

Results of the drying were plotted in Plate XII. Although the first trial gave definite indication that washing did result in lesser cell rupture through the drying process a second, apparently exact duplication of the processes failed to confirm the initial findings. It should be pointed out that the rupture counts were made at an early stage of the standardization of the cell rupture count procedure and may well be in considerable error. Additional study is needed on this subject. The use of such substances as ethanol as a washing agent could be of value.

While no definite evidence was gained to substantiate hypothesis IV several interesting observations were made.

(a). Cell rupture was observed to occur during the rehydration process. This did not preclude the possibility of rupture during dehydration.

(b). Indications were that very slow rehydration did not increase the rupture percent.

(c). It appeared that the removal of undesired substances from the cell surface by washing could possibly reduce cell rupture during the duct drying processing.

EXPLANATION OF PLATE XII

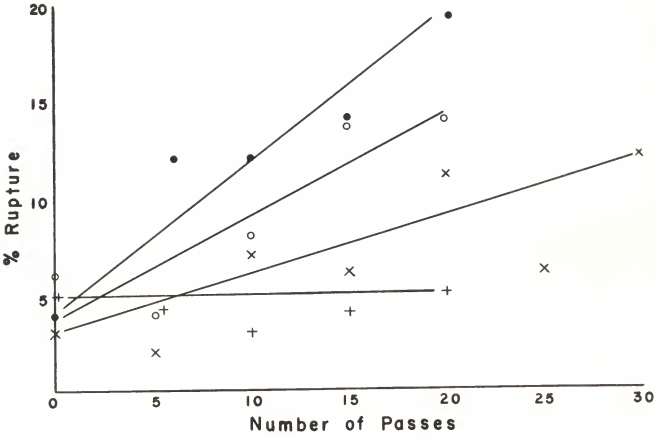
Influence of washing of cells on the rupture during dehydration process.

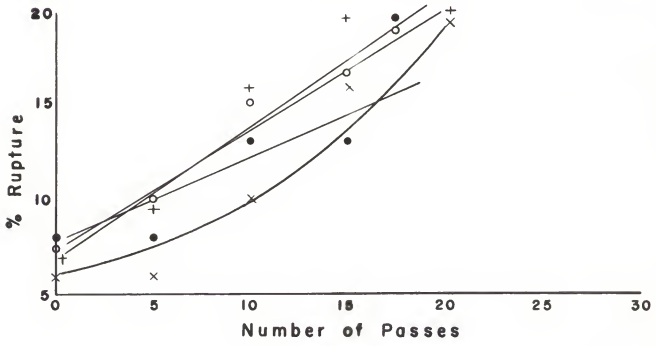
- ● no washing.
- o two water washings.
- × four water washings.
- + one 10 percent ethanol washing.

Upper graph, first trial.

Lower graph, second trial.

PLATE XII


20
15
10
5
% Rupture
0
5
10
15
20
25
30
Number of Passes


20
15
10
5
% Rupture
0
5
10
15
20
25
30
Number of Passes

HYPOTHESIS V

CELL RUPTURE RESULTS FROM TOO RAPID DRYING. WHEN A CELL IS DEHYDRATED IT SHRINKS IN VOLUME. IF THE SKIN OF THE CELL IS DRIED AT A RATE GREATER THAN THE RATE AT WHICH WATER CAN MIGRATE FROM THE INTERIOR OF THE CELL TO REPLACE THAT WHICH HAS BEEN REMOVED, THE SURFACE WILL SHRINK IN AREA, THE VOLUME OF THE CELL WILL REMAIN NEARLY CONSTANT, EXTREME STRETCHING OF THE CELL WALL WILL RESULT, AND RUPTURE WILL FOLLOW.

Conclusion

Tray drying in order that there was no possibility of abrasive or mechanical injury, at room temperature in order that there was no possibility of explosion due to change in vapor pressure, and at slow rates produced much less rupture than drying at high rates. Further, the percent rupture was shown to be directly proportional to the air velocity raised to the 0.8 power; i.e., to the rate of drying. This was considered as strong experimental evidence to substantiate the hypothesis.

At this stage of the work two simple observations were made. First, it was noted that the amount of cell rupture did not increase on the samples which were oven dried for the moisture content determinations. The test for this was simple, counts were made on a given sample before and after oven drying. The results were recorded in Table 9.

Table 9. Rupture percents before and after oven drying.

Sample no.	Before oven drying Counts			Av.	After oven drying Counts			Av.
21-80-5	9	9	-	9	8	7	-	7
21-80-10	12	14	-	13	12	10	-	11
21-80-15	16	14	-	15	14	16	-	15
21-80-25	23	19	-	21	18	18	-	18
21-100-10	13	12	-	13	19	11	-	15
21-100-15	14	13	-	14	20	16	-	18
21-100-20	13	15	-	14	20	16	-	18
21-120-10	13	20	-	17	23	14	-	19
21-150-10	15	11	-	13	13	11	-	12
21-175-5	9	12	-	11	10	3	-	9
21-175-10	16	16	-	16	10	14	-	12
21-175-15	18	20	-	19	15	18	-	17
21-175-20	21	19	-	20	19	20	-	20
Average				15.0				14.7

As a second observation it was noted that freshly granulated potatoes which were stored in the cold, dry outside November atmosphere to prevent

fermentation were dried, after a few days to white, tasty, fluffy granules with no increase in rupture. Apparatus was assembled outside the building so that air was slowly drawn through $CaCl_2$ and then through a three-inch deep bed of the granules. Outside temperatures ranged from about 25° F. to about 40° F. during the run. Results of the run were recorded in Table 10. No rupture counts were made on the samples before dehydration.

Table 10. Rupture percent on slowly dried granules.

Sample no.	Year 1950	Moisture %	Rupture percent Count				Av.
45-control	28 Nov.	about 60	2	0	-	-	1
45-1	1 Dec.	5.2	3	1	2	-	2
45-2	4 Dec.	6.5	6	5	6	9	6

The apparatus used for this exercise was of extremely small scale. The small quantity of sample available for moisture determination was responsible for the apparent increase in moisture content on 4 Dec. after the 1 Dec. determination. In order to obtain larger samples the unit described in Plate XIII was built and used. Initial results with this unit were recorded in Table 11.

Table 11. Rupture percents on slowly dried granules.

Sample no.	Approx temp.	Drying time	Moisture %	Rupture percent Count	Av.
58-A	65° F.	2 days	8.4	9 8 8 8 5 8 8 6 8	7
58-B	65° F.	3 days	8.0	5 5 3 2 4 3 5 9 3	4
58-B-C	same as "B" except crush			28 (to high to count)	

EXPLANATION OF PLATE XIII

Dynamic drum desiccator, detail

Nomenclature of detail

A. Drum with removable top and bottom.

B. Three-compartment drying tray.

C. Flow rate control valve.

D. Centrifugal air pump.

E. Fisher burners.

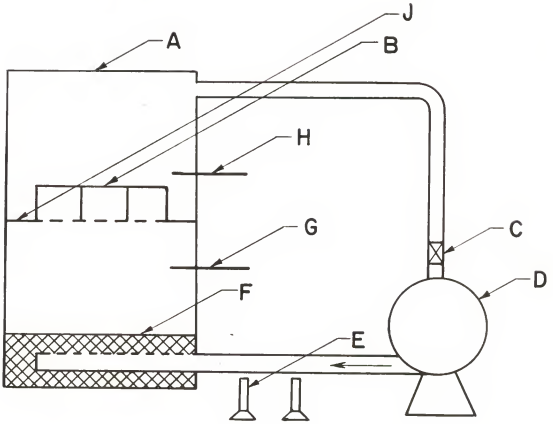
F. Calcium chloride drying media.

G. Thermometer, T_1

H. Thermometer, T_2

J. False bottom.

PLATE XIII



Although the dynamic dessicator type of dehydrator apparently produced a product very low in rupture the granules were much larger than those which may be desired for maximum bulk density. It was thought that gently grinding might result in increasing the density to that of potatoes produced by the duct type of dehydrator. Some of sample B, Table 11 was gently crushed between the thumb and finger. Rupture count, as shown in Table 11, indicated that this type of grinding would result in excessive cell rupture.

The rate of drying with this unit was gradually increased by increasing the temperature inside the double drum dynamic dessicator until drying time reached two hours which was the maximum rate possible with the equipment as assembled. In order to bring the rate of drying into minutes and seconds it was found necessary to increase the velocity of air past the particle to values greater than the normal settling velocity value. This was accomplished by use of the equipment described in Plate XIV. Results of this exercise were recorded in Table 12.

Table 12. Influence of rate of drying on rupture percent.

Sample no.	Drying time (Approx. air velocity = 1100 ft./min.)	Rupture % Before drying (av. of 10 counts)	Rupture % After drying (av. of 10 counts)	Rupture % Due to drying
63-J-5	2 min.	2.2	3.8	1.6
63-J-3	60 sec.	2.2	4.9	2.7
63-J-4	30 sec.	8.6	13.0	4.4

This procedure produced a product having an undesirable taste. Efforts to eliminate this off taste by repeated cleaning of all surfaces with soap

EXPLANATION OF PLATE XIV

Equipment used to obtain rapid flow of air past potato granules.

A. Glass drying conduit, 1.89 inches in diameter.

B. Granule retainer screen.

C. Centrifugal air pump, variable speed motor.

D. Exhaust tube, 2.0 inches inside diameter.

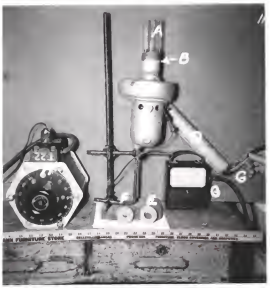
E. Super-velocity drying conduit, 1.0 inches inside diameter, with retainer screen. (Placed in top of 1.89 inch conduit when in use).

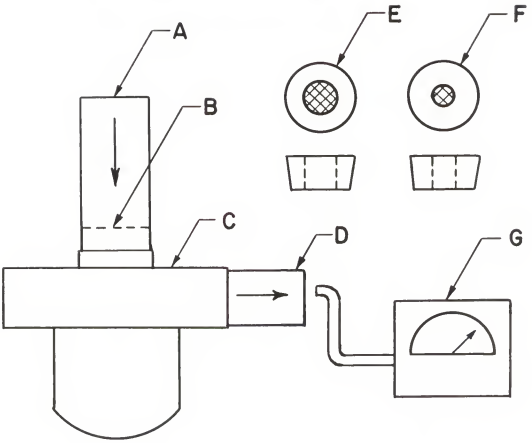
F. Super-velocity drying conduit, 1.5 centimeter inside diameter, with retainer screen. (Placed in top of 1.89 inch conduit when in use).

G. Velometer.

H. Variable transformer, power to variable speed motor of "C".

PLATE XIV





and water failed. The taste seemed to be as bad on the two hour runs as on the two day runs. Samples produced by the two minute process were too small to make test observations. Equipment was not available to lower the temperature of the dehydrating equipment below tap water temperature (about 65° F.). Increasing the temperature to around 150° F. did not appreciably improve the taste.

It was noticed that the volume of the granules in the dynamic dessicator decreased considerably as the granules became drier. In order to evaluate this effect moisture tins (volume = 45.1 cm^3) were filled to overflowing with granules at increments of moisture content and, exercising care that no packing occurred, were struck off level with the top of tin. Standard oven procedure was used to evaluate the moisture content. In order to make the volume measurement at zero moisture, granules from the oven dry determination were placed into a graduated cylinder and actual volume measured. Since it was desired to know the volume change of a single cell and since, it was assumed, one gram of oven dry material would always contain the same number of cells, the abscissa of Plate XV was recorded in volume of wet sample per gram of dry sample. Data were recorded in Table 13.

EXPLANATION OF PLATE XV

Volume of a given number of wet potato cells (the number contained in one gram of oven dry material) as a function of their moisture content, (see Table 13).

PLATE XV

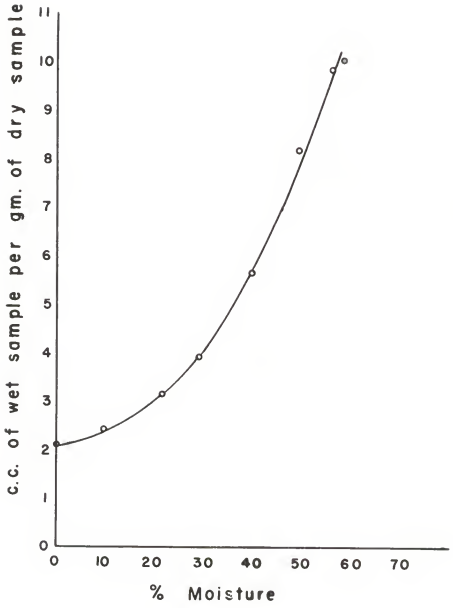

c.c. of wet sample per gm. of dry sample
0
1
2
3
4
5
6
7
8
9
10
11
0
10
20
30
40
50
60
70
% Moisture

Table 13. Volume change of potato granules with change in moisture content.

Sample no.	Moisture % (wet basis)	Weight of sample, gm	Volume of wet sample, cc	cc wet sample / gm dry sample
1	57.8	4.324	45.1	10.4
2	55.6	4.678	45.1	9.85
3	48.8	5.540	45.1	8.15
4	39.5	8.000	45.1	5.65
5	29.0	11.340	45.1	3.98
6	21.3	14.296	45.1	3.16
7	8.7	19.223	45.1	2.34

The average dry volume of all of the samples was 2.05 cc dry sample per gram of dry sample.

It was pointed out that the resulting curve probably did not represent the true volume change of a single cell. The void space between cells within a granule and the void space between granules was expected to contribute materially to the volume of a bulk of granules. Plate XV can only be used to demonstrate that there is probably a change in cell size with moisture content.

It was reasoned that if dehydrated cells were placed in a graduated cylinder and shaken or vibrated for a few moments so that they became oriented to a maximum degree, one with the other, then the influence of void space would be reduced to a minimum as the cells were rehydrated. Results of this exercise were recorded in Table 14.

Table 14. Volume change of potato granules upon rehydration.

Sample no.	Dry volume, cc	Volume after adding water: after 5 min.	after 20 min.	after 24 hr.	wet volume / dry volume
65-1	1.5	3.6 cc	—	3.8 cc	2.5
65-2	1.0	2.4	2.5	—	2.5

The procedure, used in Table 12, of observing the drying time appeared to be impractical for accurate laboratory observations. The quantities used were too small to accurately evaluate the final moisture contents and equipment necessary to vary temperature, humidity, etc., were not immediately available.

It has been stated (20) that "The film thickness at the boundary of a turbulent fluid has usually been found to vary inversely with the 0.8 power of the velocity past this boundary. - ***" Since the rate of mass transfer through a film is inversely proportional to the thickness of the film it followed that the rate of drying of potato granules could probably be found to vary with the 0.8 power of the velocity of drying air past the boundary of the stagnant diffusion layer surrounding the potato granule or cell. It then became apparent that if the percent of rupture increased with the rate of drying, it should increase with the 0.8 power of the velocity of the drying air. If this were true a plot of percent rupture vs air velocity raised to the 0.8 power should give a straight line.

The apparatus of Plate XIV was used for the experiment. Velocity of air was measured at the exit and corrected to conduit diameter at the point at which the granules were located. No correction was made for the influence

of the screen on velocity. Only a few granules were spread over the screen support in order that their influence on air velocity (which would have been extremely difficult to estimate) would be negligible. Observed data were recorded in Table 15 and results plotted on Plate XVI.

The fact that straight lines were obtained in Plate XVI was considered extremely strong evidence that the rate of drying had great influence upon the percent rupture. Since no abrasion was possible, and since the air was at room temperature so that no build up of internal pressure could occur these two possible mechanisms of rupture were ruled out. This left only two suggested mechanisms; that as suggested by hypothesis V and that of rupture upon rehydration as suggested by Table 9.

Time did not allow a study of influence of slow rehydration upon rupture percent of samples dried at various rates in the manner described in Table 15. If slow rehydration would have shown a decrease in rupture percent the mechanism suggested by Table 9 would have been confirmed. If slow rehydration would have shown no change in rupture percent it could still be possible that rupture did occur during rehydration or during dehydration. Rupture during rehydration could result from a cell skin condition, which was inelastic after dehydration. To test the elasticity of the cell wall after rehydration, use could be made of the two slide demonstrations of Appendix I. If the cells, after slow rehydration showed no change in rupture as compared with rapid rehydration and if the cells, after test of Appendix I gave indication of having an elastic wall, then the mechanism of hypothesis V could be accepted.

Table 15. Influence of drying air velocity on rupture.

Sample no.	Percent initial moisture	Humidity of drying air, percent	Rupture percent (count 1000)	(Drying air velocity$^{0.8}$ in feet per second) minute
68	55	—	2.4	none
68A	55	44	4.8	310
68B	55	44	7.1	426
68C	55	44	9.2	525
68D	55	44	16.8	1000
68K	55	44	8.2	240
68L	55	44	5.1	112
69A	70	44	7.6	891
69B	70	44	9.8	522
69C	70	44	5.9	377
69D	70	44	5.5	355
69E	70	44	5.1	257
69F	70	44	4.4	214
69G	70	44	3.6	166
69H	70	--	1.0	none
70A	68	—	3.1 4.0	none
70B	68	30	8.1 7.9	892
70C	68	30	6.7 9.1	725
70D	68	30	5.7 7.3	536
70E	68	30	6.3 5.8	457
70F	68	30	8.3 7.4	331
70G	68	30	3.9 5.7	246
70H	68	30	5.9 5.7	95

EXPLANATION OF PLATE XVI

Plots of percent rupture as a function of drying air velocity to the 0.8 power.

Sample 69. McClure potatoes, initial moisture 70 percent.

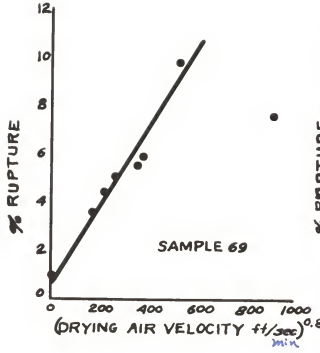
Sample 68. Idaho Russet potatoes, initial moisture 55 percent.

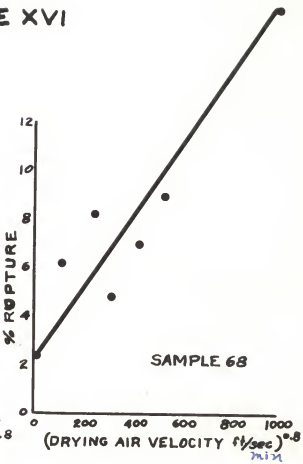
Sample 70. Idaho Russet potatoes, initial moisture 68 percent.

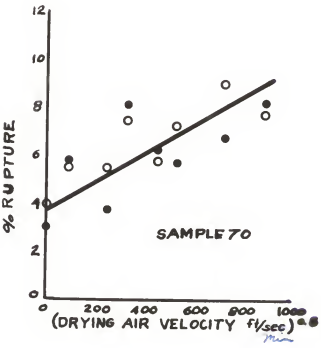
●——● Independent rupture counts by Hall.

○——○ Independent rupture counts by Stimpson.

PLATE XVI


% RUPTURE
0
2
4
6
8
10
12
0
200
400
600
800
1000
SAMPLE 69
(DRYING AIR VELOCITY ft/sec)^0.8
min


% RUPTURE
0
2
4
6
8
10
12
0
200
400
600
800
1000
SAMPLE 68
(DRYING AIR VELOCITY ft/sec)^0.8
min


% RUPTURE
0
2
4
6
8
10
12
0
200
400
600
800
1000
SAMPLE 70
(DRYING AIR VELOCITY ft/sec)^0.8
min

ACKNOWLEDGMENT

The author wishes to express appreciation to Dr. H. T. Ward, major instructor and Head of the Department of Chemical Engineering, who has made this work possible; to Dr. R. G. Taecker and Dr. R. V. Olson whose valuable encouragement and suggestions have contributed materially to the carrying through of the work and to Dr. John Frazier for valued guidance on subjects pertaining to cell wall compositions.

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APPENDIX

APPENDIX I

Cells in Rupture

It has been noted that it is possible to observe potato cells in the process of rupturing. The procedure for making this observation consists of preparing a slide in the same manner as for the cell rupture count. Another slide is placed on the top of the mounted cells, and the assembly placed under the microscope. Pressure is then gradually applied to the top of the upper plate while focus is maintained on the cell with the microscope. As pressure is increased the plates squeeze together and compress the potato cells; the cells flatten out and stretch, and the cell wall finally breaks allowing the intercellulose fluids to rush out.

Figure 1 of Plate XVII shows cells prepared as described above but with no pressure applied. Figure 2 to 5 show these same cells under increasing increments of pressure. Figure 6 shows the cells after pressure was released. In Fig. 2 note that cell "C" has just ruptured. In Fig. 3 it appears that cell "F" has ruptured at point marked by arrow "a". Figure 4 however shows that cell "F" ruptured at arrow "b" and cell "E" to be rupturing at arrow "a". This point serves to illustrate one of the difficulties which were encountered in personal evaluation of cell rupture. In Fig. 3 cell "E" did not appear to be ruptured. Probably this is because the point of rupture actually lies on the underside of the cell. As additional pressure was applied, going from Fig. 3 to Fig. 4, the rupture point spread until it is visible as an actual break in the darkened outside line of Fig. 4.

Note cell "H" in Fig. 2. Arrow "h" indicates an apparent weak spot in the cell wall. This point looks like an actual rupture. In making cell

rupture counts this point could easily be considered as a rupture. Figure 4, however, clearly shows that the cell ruptured at another point and that the apparently weak point was still intact.

It is interesting to note that the cell walls possessed a definite elastic property. As added pressure was applied the cells tended to approach spherical shape. When pressure was released, Fig. 6, the cells all exhibit a tendency to revert to the original shape.

In Fig. 6 all of the cells have been ruptured. Note the confusion which the intracellular material has added to the picture and how complicated and difficult it is to distinguish between the ruptured and the not ruptured cells. This shows why it is difficult to obtain an accurate count when a relatively large number of cells have been ruptured.

PLATE XVII

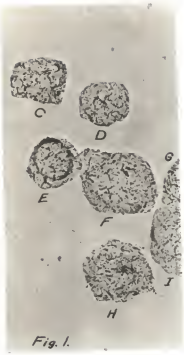

Fig. 1.

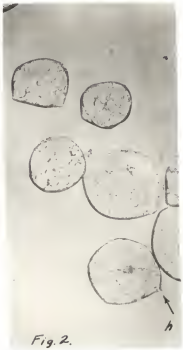

Fig. 2.

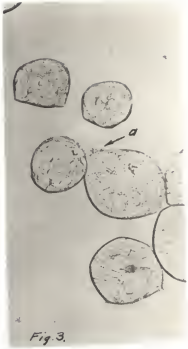

Fig. 3.

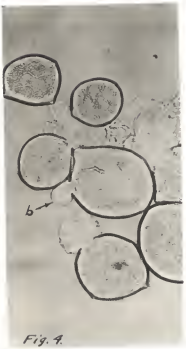

Fig. 4.


Fig. 5.


Fig. 6.

APPENDIX II

Standardization of Cell Rupture Count

Greene et al. (6) recognized the need for a method of quality evaluation of the dehydrated granules and outlined a microscopic technique of visually counting ruptured and not ruptured cells in the dehydrated granules as a means of quality evaluation. However, he did not include specific directions for carrying out the count. This work was undertaken to standardize the rupture count procedure. It represents the results of largely trial and error procedures which have been worked out over a six month period of use.

Sampling

Since the very nature of granulation with subsequent mixing in the usual rotary or air dust dryer normally results in extensive mixing, hand grab samples should be adequately representative. A pinch of this sample is placed in a pyrex 20 x 150 mm test tube. (With dry material, enough to fill the hemisphere of the test tube bottom will normally be adequate, while wet material will require more). After water is added to the sample, swelling will result. Normally the depth of the rehydrated sample in the bottom of the tube should not exceed 1.5 cm. As experience is gained the technician will be able to judge the size of sample to be placed in the tube.

Rehydrating

Boiling water from a suitable flask or beaker is poured into the test tube which contains the pinch of sample until the tube is half full. Keep the container of boiling water over the flame while pouring into the test tube.[1] Allow the test tube to stand until cool. If refrigeration facilities are available the prepared sample may be allowed to stand several days before the rupture count is made.

Preparation of Slide

The standard glass slides should be freshly cleaned.[2] The test tube, containing water and rehydrated granules is vigorously shaken (stopper with thumb). It appears that shaking in this manner results in a breakdown of the granules into single cells. After shaking, allow to stand for a few seconds while the larger granules settle to the bottom. The optimum time of this standing varies with individual samples and can be evaluated by the technician as experience is gained. Insert the dropper[3] into the upper

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[1]The scanty data presented below indicates that percent of cell rupture may be a function of water temperature at time of rehydration.

(From file "Potato Project - Data Sheets" dated Feb. 15 - May 21, 1946)

Sample A	Rehyd. with boiling water	17.8% rupture
Sample A	Rehyd. with room temp. water	2.0
Sample B	Rehyd. with boiling water	6.0
Sample B	Rehyd. with room temp. water	0.0

[2]Excellent results may be obtained by washing the slides in soap and water, rinsing, and dipping them into a solution of Bon Ami. The slides are then placed in a rack and wiped clean with a soft, lint free cloth immediately before use.

[3]A satisfactory dropper may be made from 8 mm pyrex tubing by drawing one end to about 4 mm outside diameter and cutting to length of about 20 cm. Insert the small end about 3 cm into the suspension and close the open end with the index finger.

portion of the suspension of water and cells, and withdraw the dropper containing the suspension. Hold the dropper in a verticle position with small end down while the larger granules are allowed to settle to the bottom. Again, the technician will learn to time this properly as experience is gained. Wipe the first drop onto a discarded glass slide. Allow a second drop to form (this time the drop should contain nearly all single cells) and touch it to the center of the clean slide. Add two drops of staining solution[1] on top of the first drop of cell suspension. Rock the slide back and forth and from side to side in such a manner as to cause uniform dispersion of individual cells over the glass slide.[2]

Making the Count

A microscope with a movable stage is needed. A 10x objective and a 7.5x occular give adequate magnification. Each cell must be studied individually. Count cells from one to 100 and record the ruptured cells. Repeat four times on the first slide. Prepare two more slides and repeat the count three times on each of these slides. (This will give a thousand cells counted. To find percent of rupture add the ten individual rupture counts together and divide by ten).

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[1]Staining solution prepared as follows:

Soln. 1. 20% glycerine (20 ml glycerine + 80 ml distilled water).
Soln. 2. Iodine soln., 0.05 gm Iodine plus 0.02 gm KI plus 15 ml water.
Soln. 2 should be placed in a smoked bottle and covered with dark paper. The staining solution is made by adding 5 drops of solution 2 to about 4 ml of solution 1. Vary this strength as desired for intensity of cell stain.

[2]It is desirable to get the specimen spread as thin as possible in order to minimize the need for excessive focusing when going from one cell to another. This is difficult to accomplish if the slide is not clean.

Distinction Between Ruptured and not Ruptured Cells

It is necessary to exercise judgment and care and to be patient in deciding whether or not a cell is ruptured. Comments from previous writings help to illustrate this point; "Cells show a little more strain", "Cells appear more rounded", "A few look to be on verge of rupture", "Cells crushed and starch appears to be gone". Some cells will be clearly ruptured, such may appear as  or as  . In other cases it may be more difficult to decide.  illustrates one cell covering another.  illustrates corners which may or may not be broken. (For additional illustrations see Fig. 1 to 6 "Cells in Rupture", Appendix I. It is recommended that the prospective technician run through the exercise of this illustration several times in order to familiarize himself with actual rupture.) After the prospective technician begins to recognize the ruptured cells he may gain additional experience by preparing a special slide. For this, an unclean slide, such that water will not wet the glass, is used. Prepare according to the standard procedure except do not introduce as many cells onto the slide. The surface of the water on the unclean slide will be in constant motion and will roll the cells about. Under these conditions one can see all sides of the cell and, occasionally, one can see inside the cell wall void from which all the inside material has been removed. Needles made by drawing out glass rods and forming points or hooks on the ends may be used to push the cells around as an aid in this type of study.

Size of Cell Count

In general it will be found that four counts of one hundred each will pretty well cover the average slide prepared according to the preceding directions. As a general rule it is therefore probably desirable to count no more than four or five hundred on any one slide.

The number of cells to be counted will depend upon the accuracy desired, the actual number of ruptures which occur, the difficulty of distinction between ruptured and not ruptured cells, and upon the unknown personal factor.

Table 16 will be of value in estimating necessary sample size; i.e., the actual number of cells to be counted.

Explanation of the Use of Table 16

(Reference is made to: Snedecor, George W. Statistical Methods, Iowa State College Press, Published in 1946, Fourth Edition).

1. 95% confidence means that the count will be right within indicated range in 19 out of 20 trials.

2. If size of sample; i.e., number of cells counted equals 100, and if the ruptured cells counted equals 10, then the number of ruptured cells will actually lie between 5 and 18.

3. If the size of sample equals 1000 and if the fraction of ruptured cells equals 0.10, then the number of ruptured cells will lie between 8 and 12 percent.

4. If desired accuracy equals $\pm$ 5 percent and if preliminary counts show the rupture to be in the neighborhood of 15 percent then the actual count may lie between the values of 10 percent and 20 percent (15 - 5 equals 10 percent and 15 + 5 equals 20 percent). From the table, along line (number observed equals 15) one finds that it is necessary to count 250 cells.

The above notes are on the assumption that the cells will be either clearly ruptured or not ruptured. Since the decision as to whether or not the cell is ruptured is up to the individual making the count, an unknown and uncontrollable factor is introduced. The influence of this personal factor can be reduced by using an experienced technician who has no interest in results obtained.

Table 16. Ninety-five percent confidence interval (percent) for binomial distribution.

No. observed	Size of sample								Fraction observed	Size of sample			
x	20		30		50		100		x/n	250		1000	
0	0	17	0	12	0	07	0	4	.00	0	1	0	0
1	0	25	0	17	0	11	0	5	.01	0	4	0	2
2	1	31	1	22	0	14	0	7	.02	1	5	1	3
3	3	38	2	27	1	17	1	8	.03	1	6	2	4
4	6	44	4	31	2	19	1	10	.04	2	7	3	5
5	9	49	6	35	3	22	2	11	.05	3	9	4	7
6	12	54	8	39	5	24	2	12	.06	3	10	5	8
7	15	59	10	43	6	27	3	14	.07	4	11	6	9
8	19	64	12	46	7	29	4	15	.08	5	12	6	10
9	23	68	15	50	9	31	4	16	.09	6	13	7	11
10	27	73	17	53	10	34	5	18	.10	7	14	8	12
11	32	77	20	56	12	36	5	19	.11	7	16	9	13
12	36	81	23	60	13	38	6	20	.12	8	17	10	14
13	41	85	25	63	15	41	7	21	.13	9	18	11	15
14	46	88	28	66	16	43	8	22	.14	10	19	12	16
15	51	91	31	69	18	44	9	24	.15	10	20	13	17
16	56	94	34	72	20	46	9	25	.16	11	21	14	18
17	62	97	37	75	21	48	10	26	.17	12	22	15	19
18	69	99	40	77	23	50	11	27	.18	13	23	16	21
19	75	100	44	80	25	53	12	28	.19	14	24	17	22
20	83	100	47	83	27	55	12	29	.20	15	26	18	23
21			50	85	28	57	14	30	.21	16	27	19	24
22			54	88	30	59	14	31	.22	17	28	19	25
23			57	90	32	61	15	32	.23	18	29	20	26
24			61	92	34	63	16	33	.24	19	30	21	27
25			65	94	36	64	17	35	.25	20	31	22	28
26			69	96	37	66	18	36	.26	20	32	23	29
27			73	98	39	68	19	37	.27	21	33	24	30
28			78	99	41	70	19	38	.28	22	34	25	31
29			83	100	43	72	20	39	.29	23	35	26	32
30			88	100	45	73	21	40	.30	24	36	27	33
31					47	75	22	41	.31	25	37	28	34
32					50	77	23	42	.32	26	38	29	35
33					52	79	24	43	.33	27	39	30	36
34					54	80	25	44	.34	28	40	31	37
35					56	82	26	45	.35	29	41	32	38
36					57	84	27	46	.36	30	42	33	39
37					59	85	28	47	.37	31	43	34	40
38					62	87	28	48	.38	32	44	35	41
39					64	88	29	49	.39	33	45	36	42
40					66	90	30	50	.40	34	46	37	43

APPENDIX III

Equipment used for making cell rupture counts

A. Rehydrated samples in test tubes.

B. Slides.

C. Cloth to clean slides.

D. Clean slide on stand.

E. Dropper.

F. Flask of water for washing dropper immediately after each use.

H. Staining solution with dropper.

I. Microscope with mechanical stage.

J. Microscope lamp.

K. Xylene.

L. Camel hair brush.

M. Pad for making count notations.

N. High quality, 2 inch paint brush for general clean up.

P. Forcepts.

R. Pad of lense paper.

S. Recording sheet.

MECHANISMS OF POTATO CELL RUPTURE RESULTING FROM DEHYDRATION PROCESSING

by

RAYMOND CLARENCE HALL

B. S., Iowa State College
of Agriculture and Mechanical Arts, 1941

An Abstract of

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Chemical Engineering

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1951

A study was made of the mechanism(s) of cell rupture.

HYPOTHESIS I

Based upon conclusions of earlier investigators, hypothesis I was stated: "Cell rupture in a duct type dehydrator is a result of abrasive action and rupture does not occur until the cell wall becomes brittle at about twenty to ten percent moisture." Experimental consideration of this hypothesis consisted of removing samples from the duct at increments of dryness and running rupture counts on these samples. If the hypothesis were true the plot of percent rupture as a function of moisture percent should have shown a low, nearly level line until a certain moisture content (approximately 20 to 10 percent) were reached and should have risen rapidly at this point. The expected break in the curve was not found.

It was concluded that rupture was not a function of moisture content in the ranges studied.

HYPOTHESIS II

Based upon the results of hypothesis I, it was questioned whether or not rupture occurred by mechanical abrasion and hypothesis II was formulated to state: "Cell rupture results from abrasion of potato granules as they strike and rub along the walls of the duct and as they strike one another in the turbulent air stream." It was assumed that this type of rupture could occur only on those cells contained on the periphery of the granule and that the smaller size fractions (separated by standard sieves) should then contain a greater percent of ruptured cells than the larger size fractions. Rupture counts on the various size fractions gave no indication that

rupture was a function of granule size.

This was considered as strong evidence that rupture was not due to abrasive action.

HYPOTHESIS III

While making the microscopic rupture examinations of the preceding studies, it was repeatedly noted that the "volcano mouth" shape of the ruptured cells suggested a release of pressure from within the cell wall; accordingly, hypothesis III was stated: "Cell rupture is due to the sudden increase of vapor pressure inside the cell wall as the temperature of the cell wall rises when subjected to a flow of hot gas." It was noted that the vapor pressure of water at 70° F. (the approximate temperature of wet granules at room conditions before drying) was about 19 mm Hg. and at 160° F. (the possible temperature of granules in a stream of hot drying gas) was about 190 mm Hg. It was postulated that if this increase in pressure did occur it would be great enough to result in an explosion of the cell. To test this possibility, cells were subjected to the pressure of a column of mercury and the pressure was suddenly released. Microscopic analysis indicated that rupture could result from this type of sudden pressure release. Various mechanical devices were arranged in an attempt to subject the cells to a sudden temperature change. None of these attempts was considered satisfactory.

No definite conclusion was drawn. However, it appeared that the hypothesis could be true.

HYPOTHESIS IV

In an attempt to consider all possible mechanisms of rupture it was recalled that clods of soil had been observed to explode when wetted. Based upon this observation hypothesis IV was stated: "Cell rupture occurs during the rehydration process. Water first wets the entire periphery of the cell, capillary action forces the water from the periphery toward the center, intracellular gasses are compressed and this compression increases until an explosion results." It was assumed that if this type of action were to occur, a form of hardness or inelastic characteristic of the cell wall was necessary. Efforts to remove this postulated hardness by washing in water and in an ethanol solution gave erratic rupture percents through the dehydration processing. It was suggested that very slow rehydration would restore the postulated case hardening of the cell wall to an elastic state. Difficulties of manipulation were encountered but no positive change in rupture percent was observed with rate of rehydration. The procedure of evacuating air from the cells before rehydrating was not studied but should be investigated. Cells were rehydrated while in focus under the microscope and were observed to rupture.

No definite evidence was obtained to substantiate hypothesis IV as stated. However, cells were observed in rupture during the rehydration process. Such observation did not preclude the possibility of rupture occurring during the dehydration processing.

HYPOTHESIS V

Based upon several observations, including the fact that cells slowly dried in the oven for moisture content analysis did not rupture, hypothesis V was stated: "Cell rupture results from too rapid drying. When a cell is dehydrated it shrinks in volume. If the skin of the cell is dried at a rate greater than the rate at which water can migrate from the interior of the cell to replace that which has been removed the surface will shrink in area, the volume of the cell will remain nearly constant, extreme stretching of the cell wall will result, and rupture will follow." It was recalled that the thickness of the stagnant diffusing layer around a drop of water in a turbulent air stream had been shown to be a direct function of the drying air velocity raised to the 0.8 power, and that the rate of mass transfer was inversely proportional to the film thickness. It was then realized that the rate of drying should be directly proportional to the velocity of the air past the granule raised to the 0.8 power or that, if the hypothesis were true, a plot of percent rupture as a function of drying air velocity raised to the 0.8 power should result in a straight line. The relationship was found to hold.

This was considered as strong experimental evidence to substantiate the hypothesis.

APPENDIX

Illustrations of cells in artificial rupture were presented. A standardization of the microscopic cell rupture count procedure was presented.