THESIS

on

THE PHYSICAL BASES OF SEED SEPARATION

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THE PHYSICAL BASES OF SEED SEPARATION

Introduction

Modern seed separators and graders are the results of constant and continuous improvement during many years, and have for some purposes reached practical perfection. In certain cases however, the separation by existing machines, of seeds from chaff, of seeds from weed seeds, or of the more viable from the less viable can be made either not at all or only at prohibitive cost.

The existing machines provide means for tearing or crushing the husks or pods so as to free the seeds, and then of separating them from chaff by the use of air blasts or screens. This type of machinery, when provided with suitable means for sensitive adjustments, will satisfactorily separate two kinds of seeds that are large and that differ considerably in density. It is not, however, adequate to the task of separating mixtures of very small seeds having equal or nearly equal densities and surface areas.

It was decided, therefore, to take several such mixtures, study their physical differences and attack the problem of their separation by applying physical principles.
The first step is to list the characteristic physical properties in which seeds differ:

2. Area.
3. Density.
4. Shape.
5. Ability to become electrically charged.
7. Resilience. (Bounce).
8. Ability to roll.
9. Friction (with and without beards)

All of these with the possible exception of color offer suggestions for practical means of separation.

**The Problem**

Four different mixtures of seeds were selected, the separation of which though of economic importance, is not possible by means of existing commercial machines. These are:

1. Separation of oats from wild oats
2. Separation of clover from buckhorn
3. Separation of rush from chaff
4. Separation of bentgrass from ergot

In addition, the closely related problem of grading seeds such as wheat, grass seeds, garden seeds, etc. was attempted, and a design was perfected for a flax thresher
that will not injure the fibre.

With the exception of the separation of rush from chaff, the seeds to be separated have almost equal masses and areas.

Since screening has been very thoroughly developed, so as to make it applicable to the separation of practically all kinds of seeds, it was almost entirely excluded from the present study.

**Experimental Attack**

An examination of the different seeds yields the differences indicated in Table 1.

**Table 1**

<table>
<thead>
<tr>
<th>Name</th>
<th>Mass (each) milligrams</th>
<th>Unlike characteristics</th>
<th>Proposed method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oats</td>
<td>Friction</td>
<td>Air and carpet drapers</td>
<td></td>
</tr>
<tr>
<td>Wild Oats</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clover</td>
<td>1.83</td>
<td>Shape, Mass Friction, Force</td>
<td></td>
</tr>
<tr>
<td>Buckhorn</td>
<td>1.41</td>
<td>Resilience, Air</td>
<td></td>
</tr>
<tr>
<td>Rush</td>
<td>0.029</td>
<td>Mass, Roll, Area, Density</td>
<td></td>
</tr>
<tr>
<td>Chaff</td>
<td></td>
<td>Air and screens Spiral, Air</td>
<td></td>
</tr>
<tr>
<td>Bentgrass</td>
<td>0.114</td>
<td>Electric charge</td>
<td></td>
</tr>
<tr>
<td>Ergot</td>
<td>0.119</td>
<td>Electrostatic charge</td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>33.0</td>
<td>Mass, Area Screens</td>
<td></td>
</tr>
<tr>
<td>Wheat (small)</td>
<td>Variable</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
These characteristics were obtained as follows:

Relative mass, by weighing.
Relative area, by low power microscopic examination.
Relative density, by throwing from rotating tube.
Relative charge, by measuring effective distance raised against gravity.

A study of this table indicates that all of the separations cannot be made by means of a single device. Each separation was therefore attacked as a special problem, and several different machines were designed.

The Spiral Separator (Fig. 1)

The spiral separator consists of a cylinder or "body" of galvanized sheet iron surrounded by one or more spirals of suitable form. Each spiral is constructed from rings of metal whose internal diameter is larger than the diameter of the body by an amount sufficient to give the desired pitch. This construction also determines the slope of the flange with respect to the horizontal. If it is necessary to change the slope, a new machine must be constructed with a different body diameter.

This device can be applied to the separation of round seeds from those having stable equilibrium. One type of spiral separator, designed for separating peas from oats and barley, has been patented, but is not at
all suited for separating seeds of the size of rush.

In the commercial machines, the slope is too great for very small seeds such as rush or clover. A machine, however, designed to separate certain seeds will usually serve for other similar seeds.

Rush seed is a very small lemon shaped seed weighing on the average 0.029 milligrams. Fig's. 2 and 3 show these seeds and an ordinary dressmaker's pin to indicate comparative sizes. These seeds are usually separated from chaff by the use of screens and air, but due to their small size, the necessary fine mesh clogs easily. The consequent excessive labor expense makes the method impractical.

To determine the proper slope from the horizontal, a preliminary experiment is necessary. Allow seeds to move down an inclined plane, the slope of which is adjustable. The proper slope is that at which the stable seeds (or chaff) move with uniform velocity. This slope is of course great enough to give an acceleration to the round seeds.

The forces acting on the seeds are $F_g$, the force of gravity, and $F_c$, the centrifugal force. (Fig. 4)

By assuming a body diameter, the distance, $r$, from the seed to the center of the body can be determined. The velocity, $V_t$, of the round seeds is that which was
determined experimentally. $F_c$ is given by the ordinary expression for centrifugal force: $F_c = \frac{mv^2}{r}$. The slope should be such that $R'$, (Fig. 4), is considerably greater than the resultant $R$, which is perpendicular to $OB$.

It is obvious that by increasing the body diameter a sufficient amount, any desired flange slope can be obtained with a pitch slope equal to that of some smaller body diameter. Such a change, however, does not serve the purpose because increasing the body diameter necessitates increasing the pitch slope in order to increase the downward speed. This is easily seen from the formula $F_g = \frac{mv^2}{r}$. If $r$ be increased and $v$ held constant, (so as to keep the same pitch and height), $F_g$ becomes smaller. Since the resultant of $F_g$ and $F_c$ is the separating force, it is obvious that if $r$ is increased, the pitch must also be increased.

Experiments indicated that for rush, the dimensions should be as follows:

- **Body tube**: 8 inch diameter and 8 foot height.
- **Pitch of flange**: 29 inches.
- **Width of flange**: 12 inches.
- **Slope of flange**: 10° from the horizontal.

Although three flanges are shown in Fig. 1, only one flange is necessary for rush separation. The device illustrated was designed for separating buckhorn from
This design can be adapted to separate rush from chaff, peas from oats, etc. and also to seed grading. This type of machine can be used not only to separate rush from chaff, but also to grade rush. (See Fig. 3 for comparison of three rush seeds.) By a slight change in design, its efficiency for separating seeds can be greatly increased. The change consists in replacing the cylindrical body of the spiral separator by the frustum of an inverted cone, and making the flange a spiral of from 6 to 12 inches in width.

The angle of the flange of the spiral separator is determined from the resultant of the force of gravity and the centrifugal force, just as in the cylindrical body machine.

If the resultant of the force of gravity and the centrifugal force, (Fig. 4) is perpendicular to the flange, the seeds will roll to the bottom of the machine. If the resultant extends slightly outward from the perpendicular, the seeds will eventually roll off.

Then if the velocity be determined for the given seeds and a specified pitch, the radius of the body and the flange slope can be made such that certain seeds will roll off, whereas certain others, that travel somewhat more slowly, will remain on the flange. It may be
seen from Fig. 4 that \( \tan \theta = \frac{\tan \theta}{\frac{v^2}{r \cos \theta}} \). Therefore \( \theta = \tan^{-1} \left( \frac{v^2}{r \cos \theta} \right) \). This gives a flange angle such that the seeds would roll down the flange. If the slope angle be made slightly less than \( \theta \), the seeds will roll off the flange.

The advantage is obvious when the forces acting on each seed are considered. The force that throws the seeds off the flange is the resultant of the force of gravity and the centrifugal force. The force of gravity is of course constant, and with a given slope, the acceleration of a given kind of seed is also constant. As the velocity of the seeds increases, the radius of the arc (from the center of the conical body) through which they travel decreases. The velocity change is usually slight, but the radius change can be made as desired. By a suitable design, the centrifugal force can be increased until the seeds are thrown off the flange. This is at once evident from a consideration of the formula:

\[ F_c = \frac{mv^2}{r} \]

If \( v \) be increased and \( r \) decreased, \( F_c \) increases rapidly. Of course \( F_c \) for the chaff or uneven seeds increases also, but the rate of increase is much less than that of the fully developed seeds because the coefficient of friction is greater. This characteristic gives the frustum spiral machine a decided advantage over the
cylindrical body separator. The disadvantage is that it is more difficult to construct.

Fig. 5 shows the design of a machine that serves as a rush grader as well as a separator of rush from chaff.

Tests indicated that the same principle can be applied to the separation of clover from buckhorn, but no definite design was made for this particular case.

The Air and Inclined Plane Separator (Fig. 6)

Although the spiral gives the most nearly complete separation of rush of any method tried, it is not as fast as some of the others.

A faster separator is shown in Fig. 6, but it requires several sensitive adjustments. The seeds are allowed to roll down a slight incline which is set into vibration by the use of a 60 cycle vibrator. As shown in Fig. 6 the plate slopes about 15 degrees toward the rear and about 10 degrees toward the right. A light transverse air current is forced over the seeds from the tube at the right toward the left. This carries the chaff to the left and allows the seeds to roll to the right hand side of the machine. (The large pipe leading to the bottom of the machine is not necessary for rush.)

Small quantities of rush can be separated very effectively by the use of a smooth board 12" x 24". A groove about 3/8" x 1/4" deep facilitates the operation,
for when the rush rolls into the grooves the board can be tilted back before the chaff enters.

The Centrifugal Force and Air Separator (Fig. 9)

Fig. 7 shows a curve of RPM plotted against the dynes force upon 1 gram mass at a distance of 6 centimeters from the axis. From the common formula for centrifugal force, \( F_c = \frac{4m^2n^2r}{m} \), a parabola. At 5000 RPM the curve shows that the outward force would be 1370 times as great as the force of gravity. At this speed the outward force on a clover seed would be \( \frac{1370 \times 1.83}{1000} \), or 3.60 grams. For buckhorn the outward force would be \( \frac{1570 \times 1.41}{1000} \), or 2.35 grams. This means that there is a difference of 3.00 - 2.35, or 0.25 gram force per seed.

Now assume that the outward force be opposed by an air blast. A buckhorn seed has three fourths of the mass of the clover, has greater surface area and is not so nearly spherical. Since the mass is less, the air will have less momentum to overcome in stopping buckhorn than in stopping the clover.

At the same time, there will be a greater air force acting on the buckhorn because of its greater surface area and its uneven shape. This obviously means that there is considerably greater outward force than inward force on the clover and at the same time a greater inward
force than outward force on the buckhorn. Therefore they must separate. Suppose the air is set to give a force of 2.35 grams force on the buckhorn. Even though the seeds were of equal area and smoothness, this would not affect the clover so greatly and therefore would not retard it as much as the buckhorn. It may be seen from the curve, Fig. 7, that the clover has the same outward force exerted at 4270 R P M as the buckhorn at 5000 R P M. With increased R P M, this difference becomes greater.

Experiments with the centrifugal machine showed a definite separation of clover from buckhorn at 5000 R P M.

Fig. 8 is a diagram of the internal construction of this machine, and Fig. 9 is a picture provided the lower pan be removed.

The seeds enter tube A (Fig. 8) which is stationary. (The experiment was first tried with this tube as well as tube B rotating but the seeds clung to the sides and clogged.) Tube B rotates on shaft D. Six pipes C were threaded into B. As the pipes rotate, the seeds are thrown outward, E is a ring of pipe provided with a slot at the smallest diameter of the ring. High pressure air (100 pounds per square inch) enters E at two diametrically opposite points (not shown in Fig. 8) and leaves by way of the slot. This stream of air is directed against the seeds leaving tubes C, thus causing the
specifically lighter ones to be deposited nearer the axis of rotation than those more dense. Two details require mention: the slot E is slightly above tube C; E is provided with flanges as shown in Fig. 8a to more precisely direct the air stream so as to oppose the actual path of the seeds. The air is actually forced downward in a spiral. The spout F is necessarily circular and is fixed to case G. It was kept closed during the runs in order to force all the air toward the center. It was found necessary to leave the inner space entirely open and place the collecting pan about six inches below in order to avoid a back pressure of air in tubes C.

It is obvious that this machine should work better the greater the difference in density of the seeds. It did not function as a grader of wheat, probably because wheat grains of different sizes have practically identical densities. In this case even though there is a greater outward force on the large kernels, the large and the small kernels are slowed up equally because the inward force varies directly as the area.

Machines using screens and air, or machines of baffle plate construction give better results for grading wheat.
The Baffle Plate Separator. (Fig. 10 and Fig. 11).

Fig. 10 shows a baffle plate separator which was designed for flax and functions perfectly. It also gives a definite separation of clover and buckhorn, but is not as good for this purpose as the centrifugal force machine. Although there are several patented baffle plate separators, there are, to my knowledge, none like these shown in Fig. 10 and 11. The air, which is forced into the tube near the bottom, (Fig. 10), passes upward producing eddy currents under each plate. This insures thorough agitation of any material introduced through the spout on the upper right hand side. The lighter material is blown out through the semi-circular spout at the top. It may seem at first glance that air will be forced out at the side spout, but this is prevented by the high velocity of the air past a baffle inside the tube. Some air is actually drawn in at this spout; the amount varying directly as the ratio of the air velocity in the upper part of the tube to that at the inner end of the feed spout.

This device works well in separating any seeds having a fair difference in densities. The proper angles of the baffle plates and also the location of the spout at the lower left, were obtained by experimenting with flax. Flax was used because it was desirable to design
a cheap simple flax thrasher that will not injure the
fibre in the process. If the baffle plates and the upper
spout were made adjustable, this would be a good economi-
cal machine for many different pairs of seeds.

For use as a flax thrasher a simple accessory
machine is necessary as shown in Fig. 12. Two belts
are provided to serve as a feeder. The flax is to be
placed crosswise between the belts with the heads project-
ing beyond the belt so that the reel slats will strike
them and knock out the seeds without injury to the fibre.
The seeds and chaff may be fed directly into the baffle
plate separator.

Fig. 11 shows a baffle plate machine which operates
well in cleaning chaff from the heavier grains and which,
if somewhat modified, gives promise of being a successful
grader for wheat. With this machine the full effect of
the air can be utilised, since if the spouts A and B are
air tight, (and opened just for discharging) no air
enters or leaves the machine.

With both spouts open however, some air is drawn
in at B and an equal amount leaves at A. Although only
two spouts were used, it might be advantageous to use
more.
The Electrostatic Separator (Fig. 14, 14a).

Bentgrass and ergot seeds are so nearly of the same size and shape that screens are useless. Air and centrifugal force, likewise offer little hope of success because the mass, area, shape and density of these seeds are almost identical. (Table 1) A test, however, of these agents was made by Miss Cole, seed analyst of Oregon State College by means of the standard glass tube used for cleaning small quantities of seeds. The tube is \( \frac{3}{4} \) inch in diameter and is closed at the bottom by a cloth or other fine sieve. Air is forced through the cloth and the seeds resting upon it. By a suitable adjustment of the air, specifically lighter material can be blown out, leaving the more dense seeds in the glass. Practically no separation was obtained.

Evidently a method must be employed to separate these seeds that differs radically from any of those discussed thus far. Accordingly an electrical method was tried; fortunately it gave promise of ultimate success right from the start. In the preliminary experiment, two vertical metal plates, Fig. 13, parallel to each other and from four to six inches apart were oppositely charged by a static machine. The seeds were allowed to roll down a short inclined plane so as to fall between the two vertical plates. The inclined plate was
charged with the same sign as one of the vertical plates. The different seeds received different charges, and while falling were attracted and repelled with different forces, and consequently fell on different parts of a paper placed beneath the vertical plates. The separation was not complete, but became nearly so after the sample had been passed down the incline three times.

This suggested increasing the height of fall, but when this was tried, it was found that some of each kind of seed struck one or other of the vertical plates, became charged with the sign of that plate, and hopped over towards the other plate to become mixed with the other kind of seed. This indicated that better separation would probably be obtained by turning the charged plates into a horizontal position.

One design is shown in Fig. 14. The plates A and B are charged as indicated and the seeds are fed down the chute C. Plate A is bent into the arc of a circle and is provided with a flange as shown in the end view of Fig. 14. If a sufficient potential difference is applied between the plates both kinds of seeds will leave plate B and rise due to the static forces acting on them. By adjusting the distance between the plates or by adjusting the potential difference, the forces acting on the seeds can be made large enough so that the bentgrass all
reaches plate A but small enough so that the ergot barely touches A when it is nearest B. Due to the bent edge of A, the electrostatic field is unsymmetrical; hence seeds having the same polarity as B will move toward this bent edge. Both kinds of seeds when near the region of minimum distance between A and B will therefore have a force acting on them in the direction of the bent edge. The seeds will travel a zig zag path as indicated in Fig. 14. Due to the increasing distance between the plates as the bent edge is approached, a condition will be reached such that the ergot will not be attracted sufficiently to reach A whereas the bentgrass will still do so. Consequently the bentgrass eventually reaches A and drops down into a suitably placed container. The ergot remains on plate B, from which it can be removed as necessary. A projected form of this machine that is continuous in its action is shown in Fig. 14a. The lower plate B is replaced by a conducting belt P that travels around suitable pulleys.

The feeding of the seeds into plate B presented a rather difficult problem. It was impossible to feed the seeds evenly by hand. An electrostatic feed was successfully designed and built.

The seeds pass down the chute C and are attracted to plate A which is charged. As they strike plate A they
become charged with the same polarity and are therefore repelled, being fed uniformly onto plate B.

In trying to improve the machine, it was necessary to know whether or not there is an optimum voltage. The relative charge per unit mass was determined experimentally. The seeds were placed upon a metal plate above which was another similar plate, the distance between the plates being adjustable. A voltage was applied to the plates and the distance between them decreased gradually until the seeds were raised to the upper plate against the force of gravity. These distances were determined for several different voltages.

Table 2 shows the results of these tests. Columns 2 and 3 are plotted in Fig. 15. These curves show definitely that the bentgrass is affected at a considerably greater distance than is the ergot, and that the difference between these distances increases with increase in voltage. Column 4, giving the ratio of column 2 to column 3, is a measure of the relative charge per unit mass. This is shown graphically in Fig. 16. There is evidently an optimum voltage somewhere between 20,000 and 24,000 volts.
Table 2

Optimum Voltage Test

<table>
<thead>
<tr>
<th>Volts</th>
<th>Bent grass</th>
<th>Erect</th>
<th>Unit mass</th>
<th>( \frac{B_{cm}}{T_{cm}} )</th>
<th>Difference, Successive</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4000</td>
<td>1</td>
<td>1</td>
<td>0.4</td>
<td>0.4</td>
<td>0</td>
</tr>
<tr>
<td>8000</td>
<td>1.5</td>
<td>1.1</td>
<td>1.485</td>
<td>0.4</td>
<td>0</td>
</tr>
<tr>
<td>12000</td>
<td>2.2</td>
<td>1.3</td>
<td>1.615</td>
<td>0.9</td>
<td>0.5</td>
</tr>
<tr>
<td>16000</td>
<td>2.9</td>
<td>1.7</td>
<td>1.705</td>
<td>1.2</td>
<td>0.3</td>
</tr>
<tr>
<td>20000</td>
<td>3.4</td>
<td>1.9</td>
<td>1.790</td>
<td>1.5</td>
<td>0.3</td>
</tr>
<tr>
<td>24000</td>
<td>3.9</td>
<td>2.1</td>
<td>1.855</td>
<td>1.8</td>
<td>0.3</td>
</tr>
<tr>
<td>28000</td>
<td>4.3</td>
<td>2.5</td>
<td>1.970</td>
<td>2.0</td>
<td>0.2</td>
</tr>
<tr>
<td>32000</td>
<td>4.6</td>
<td>2.47</td>
<td>1.974</td>
<td>2.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>
The tests for optimum voltage were repeated after both samples had remained over night in a case beside a pan of water. The bentgrass apparently either lost some of its electric capacity or absorbed enough moisture to make its mass appreciably greater. No definite change in mass was indicated, however, by weighing 1000 seeds. The plate distance was only slightly greater than that for ergot, whereas the ergot remained about the same.

This seems to indicate that the electrostatic method may be applicable only to dry seeds. In actually using the machine some difficulty was experienced on moist days.

Column 2 at 12,000 volts shows 2.2 centimeters for bentgrass. Column 3 shows that for ergot to jump this gap, (2.1 centimeters), requires 20,000 volts. This indicates that it is a very simple matter to separate the ergot from bentgrass by using about 20,000 volts at somewhat less than 3.5 centimeters plate distance; this is verified by experiment. However, keeping them separated is not so simple, for when a charged seed hits the upper plate, it immediately loses its charge and receives a charge of opposite polarity. This polarity being the same as that of the upper plate, it causes repulsion, and the seed immediately falls to the lower plate and therefore into the ergot.

There is a definite minimum limit to the energy
required to operate this machine. In fact the first experiments made with it were unsuccessful because this was not recognized. The voltage could not be held at the required value because of the appreciable current required to charge the seeds. The difficulty was overcome by supplying the static machine with larger condensers. In a commercial installation, this difficulty would be minor, as suitable transformers and rectifying tubes would be used.

Germination tests indicate not only that the electrification does not injure the seeds, but that the more viable bentgrass seeds are separated from both the ergot and the less viable bentgrass. Fig. 17 shows a comparison of seeds charged but not separated. Fig. 18 shows a comparison between bentgrass separated by the electrostatic machine. These tests indicate that this method of separation should be applicable to an improvement in the quality of a given variety.
Conclusions

Several varieties of seeds, which had not been separated successfully, were studied with regard to their physical differences. Physical principles were sought that might distinguish between these differences and thus serve as a basis for building separators and graders. Successful machines utilizing these principles were constructed, among them being the spiral separator, the vibrating plane and air separator, the baffle plate and air separator and the electrostatic separator.

The accomplishments of these machines were as follows:

1. Either the spiral separator, or the inclined vibrating plane separator can be applied successfully to the separation of rush from chaff. Rush can be thoroughly graded by use of a spiral separator of proper design.

2. The baffle plate and air separator, and the centrifugal force and air separator are applicable to the separation of any kinds of seeds that differ in densities. Only slight differences are necessary. Clover can be separated from buckhorn by either machine.

3. The electrostatic separator can be successfully applied to the separation of seeds having equal densities provided the ratio of charge to mass is not the same for
the two kinds of seeds. This machine operates well on bentgrass and ergot.

Tests on sprouting of bentgrass indicate that the seeds are not injured by electrification; in fact, preliminary plantings apparently indicate that the less viable seeds are included with the ergot automatically on passing the mixture through the electrostatic separator.
Fig. 1.

The Spiral Separator.
Fig. 2.
Rush and Chaff.
Magnification 20.
Fig. 3.

Rush and Bentgrass.

Showing the difference in size of the same variety.
FIG 4.
Fig. 5.

The Spiral Separator.
Fig. 6.

The Incline Plane and Air Separator.
Fig. 9.

The Centrifugal Force Separator.
Fig. 10.

The Baffle Plate and Air Separator.
Fig. 11.
The Baffle Plate and Air Separator.
Fig. 12.

Proposed machinery for threshing flax.
To be used with the baffle plate separator.
Fig. 13.

Arrangement of plates for preliminary electrostatic separation.
Fig. 13 a.

Ergot and Bentgrass.

Magnification 20.
Fig. 14. The electrostatic separator.
Fig. 14a.
Proposed machine for electrostatic separation.

End view.
Relative charge per unit mass.

Fig. 16.
Fig. 17. The seeds planted in rows marked 1 were uncharged; the seeds in rows marked 2 were charged but not separated. The + and - signs indicated the polarity of the charge on the seeds. No difference in growth is indicated, thus showing that the seeds are not damaged by electrification.
Fig. 18.

Seeds planted on the right hand side were separated from ergot. Growth 92% of the seeds planted.

Seeds planted on the left hand side were left with the ergot. Growth 61% of the seeds planted.