DESIGN AND DEVELOPMENT
OF A SLURRY SPINNER

by

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LIST OF SYMBOLS

Symbol	Dimensions	Description
A	-	Constant of integration
a	L	Radial location of inner end (pickup end) of vane, feet
a_o	L^2	Area of particle projected normal to V, square feet
a_1	-	0.1960
B	-	Constant of integration
b	L	Radius of curved part of vane, feet
b_1	-	$D/(1.677 x 10^{-4})$
C	-	$\sqrt{\mu_v^2 + 1}$
C_1	-	A constant
c	L^{-1}	Ballistics coefficient, reciprocal feet, $c_r(\frac{1}{2}\rho)a_o/m$
C_u	-	Christiansen uniformity coefficient, percent
c_d	-	Coefficient of drag
c_r	-	Coefficient of resistance
c_2	-	1.885
D	L	Particle diameter, feet
d	L	Deviation of individual observation from mean, centimeters
d_1	-	2.377
E	-	$\text{Cos } \phi - \mu_v \text{ Sin } \phi$
e	-	Base of Naperian logarithms, 2.72
F	-	$\sqrt{\mu_v^2 + 1} - \mu_v$
F_d	-	Drag force
f	-	0.9560
G	-	$\text{Cos } \phi - \mu_v \text{ Sin } \phi$
g	LT^{-2}	Acceleration due to gravity, feet per second squared

Symbol	Dimensions	Description
H	-	$\sqrt{\mu_v + G \text{ Cos } \phi}$
h	L	Height of spinner above the ground, feet
J	-	$\text{Cos } \gamma_o - \mu_v \text{ Sin } \gamma_o$
K	-	$\sqrt{\mu_v^2 + G/L}$
K_1	-	$-\rho_a a_o/(2m)$
k	-	$3/4 \ C_d \ (\rho_a/\rho_p) \ 1/D$
L	-	$\text{Cos } \gamma_o$
M	-	$\sqrt{\mu_v^2 + 1} + \mu_v$
m	-	Mass of particle, slugs
N	-	$\text{Sin } \gamma_o + \mu_v \text{ Cos } \gamma_o$
n	-	Number of observations
P	L	Length of vane, feet
Q	-	$\text{Sin } \phi_R$
R	L	Spinner radius, feet
R_e	-	Reynolds number = $D \nu \rho_a/(\mu g)$
r	L	Distance of a particle from the center of the disc, feet
r_o	L	Radial position at which particles are delivered to the spinner, feet
$\dot{S}$	LT^{-1}	Velocity of the particle with respect to the vane, feet per second
$\ddot{S}$	LT^{-2}	Acceleration of the particle with respect to the vane, feet per second squared
t	T	Time measured from feed-on of the particle on to the disc, seconds
t_a	T	Time particle is in the air, flight time of particle, seconds
U	LT^{-1}	Radial component of absolute speed of particle leaving the spinner, feet per second

Symbol	Dimensions	Description
μ_d	-	Coefficient of friction between particle and disc
μ_v	-	Coefficient of friction between particle and vane
V	LT^{-1}	Absolute speed of particle on leaving the spinner, feet per second
V_t	LT^{-1}	Tangential speed derived from the spinner's rotation, feet per second
X	L	Horizontal displacement, feet
$\dot{X}$	LT^{-1}	Horizontal component of particle velocity,feet per second
$\ddot{X}$	LT^{-2}	Horizontal component of particle acceleration, feet per second squared
$\bar{x}$	L	Mean of observations, inches
Y	L	Elevation or vertical distance, feet
$\dot{Y}$	LT^{-1}	Vertical component of particle velocity, feet per second
$\ddot{Y}$	LT^{-2}	Vertical component of particle acceleration, feet per second squared
ω	$\frac{\text{Radians}}{T}$	Angular velocity of the spinner, radians per second
z	-	$2cX$
α	Radian	Angle through which vane rotates to move a particle from radius a to R, radians
β	Degree	Angle of particle departure with respect to the spinner tangent, degrees
γ	Degree	Direction of particle motion, measured from the horizontal, degrees
γ_o	Degree	Spinner cone angle, degrees
γ_1	Radian	Angle of elevation, radians
ρ	mL^{-3}	Density of air, slug per cubic foot
ρ_a	mL^{-3}	Density of air, lbs mass per cubic foot
ρ_p	mL^{-3}	Density of particle, lbs mass per cubic foot

Symbol	Dimensions	Description
ϕ	Degree	Angle of dispatch, measured between radius at point of exit and path of the particle, degrees
ϕ	Radian	Angle of vane with respect to spinner radius, radians
ϕ_R	Radian	Angle of vane tip with respect to spinner radius, radians
$\frac{dP}{dt}$	LT^{-1}	Theoretical velocity of particle with respect to the vane, feet per second
$\frac{dr}{dt}$	LT^{-1}	Radial velocity of particle with respect to the vane at distance r, feet per second
$\frac{d^2r}{dt^2}$	LT^{-2}	Radial acceleration of particle with respect to the vane at distance r, feet per second squared

INTRODUCTION

With an increase in livestock confinement, farmers today are looking for better and more efficient ways to handle the wastes created by such enterprises. For Kansas alone there was an increase of 200,000 hogs (12%) on farms from 1975 to 1976 (Kansas State Board of Agriculture, 1976). Of those 200,000 hogs a large majority were held in buildings equipped with slotted floors.

Since good farm labor is hard to find and expensive, many large confinement operators are mechanizing there waste disposal operations. These operators are turning to high volume mini-center pivots or traveling big guns to be set on cropland adjacent the confinement operation. This irrigation equipment is not only expensive but its operation is extremely energy intensive. In order to disperse the waste material through high volume nozzles some dilution normally is required prior to the high pressure pumping.

The dilution and high pressure requirement currently to deliver livestock manures to croplands via current irrigation systems does not appear to be entirely environmentally sound. In an attempt to better engineer our vital resources of clean water, clean air, and energy, the concept of a slurry spinner was developed. The slurry spinner would take the undiluted animal waste, delivered to its surface under low pressure, and then by centrifugal force deliver the waste material uniformily to land.

REVIEW OF LITERATURE

Centrifugal Spreaders

The first centrifugal spreaders were built 45 to 50 years ago. Centrifugal fertilizer spreaders are the most widely used machines for the distribution of dry fertilizer. These spreaders have a wide variation in uniformity of coverage (Crowther, 1958; Hepherd and Pascal, 1958; Patterson and Reece, 1962; and Brinsfield and Hummel, 1975) and normally a high application rate near the center of the swath (Cunningham, 1963). Schaffer et al (1973) state additional effects result from the material properties of the fertilizer which include: partcle density, particle size distribution, bulk density, shape, texture, coefficient of friction, and angle of repose.

Particle Motion on the Disc and Vane Surface

The operating principle of the centrifugal spreader is based on the centrifugal and tangential forces imparted to the material to be spread. The terms "centrifugal spreader", "centrifugal distributor", and "spinner" are used to designate this device. By using some type of metering device, the material ideally is directed onto the spreader smoothly and without noticeable impact or bounce. Once the material is on the spinner the shape of the distribution pattern produced is influenced by the spinner configuration as well as the operational parameters. The parameters are: (a) spinner-vane pitch, (b) spinner speed, (c) friction, (d) whether the particles slide, bounce, or roll on the disc and vane surface, (e) spinner vane curvature, (f) spinner cone angle, (g) effect of wind, (h) air resistance, and (i) delivery position.

The loading of a spinning disc at its exact center was investigated by Crowther (1958) and Patterson and Reece (1962). Crowther, working with dry granular fertilizer, concluded that the distribution is concentric and the degree of segregation of the particles could be ignored in the working of the spinners. He further states that a centrally-fed distributor is not capable of giving an even distribution. Patterson and Reece analyzed the motion of particles on the disc and vane surface and showed that: (a) Particles fed onto the center of a spinning disc can acquire appreciable radial velocity as well as the full tangential speed of the outer radius of the disc; (b) the final radial velocity gained depends on whether the particle's shape will permit it to roll instead of sliding, and (c) upon the coefficient of friction between particle and disc and vane. In practice, particles can be expected to leave the disc with widely varying speeds and in different directions. This introduces a considerable random variation into the performance of the spinner. Their results showed reasonable agreement between theory and practice.

Inns and Reece (1962) fed spherical and irregularly-shaped particles vertically onto a horizontal rotating plate fitted with a number of vertical radial vanes. Motion of the particles was found to be both predictable and random. The unpredictable irregularly-shaped particles proved to be a complex, unsolveable problem due to the random element introduced by their shape. Those particles which remain in contact with the disc and vane surface will leave the spinner with some vertical velocity since the particle's initial vertical velocity is not lost in the impact onto the disc.

Working with four fertilizer spreaders' Cunningham (1963) developed theoretical equations for forward pitched straight vanes on a flat base, forward curved vanes on a flat base, and radial vanes on a concave base.

He studied fertilizer particle motion along the spinner vanes and developed relationships which predicted the effect of spinner vane pitch, the performance of curved vane and cone spinner configurations on the departure velocity of fertilizer, and the angular location of distribution patterns. It was shown that single spinner machines' asymmetrical patterns may be shifted by adjusting vane pitch to obtain more symmetrical patterns that can be more satisfactorily overlapped for uniform field coverage.

The theoretical equations representing particle motion imparted by forward pitched, straight vanes was studied by Cunningham and Chao (1967). They felt the forward pitched vanes had a special potential for improving the performance of spinners. So experiments were set up to determine the accuracy and applicability of the theory. The coefficient of dynamic fertilizer-vane friction had a significant effect on fertilizer motion for all of the conditions studied. Vane pitch was found to significantly influence the direction of the resultant velocity imparted to granular fertilizer particles. Their results indicated that the use of two values of vane pitch on a spinner, with alternate vanes set at the same value, should provide a positive means of imparting divergent velocities to granules of fertilizer.

In addition to the experiments above a special vane shape was also studied. The vane's inner portion was curved while its outer portion was straight. The curvature of the inner portion facilitated slicing into the stream of fertilizer flowing from the delivery tube opening. The slicing action permitted the vane to pick up the fertilizer smoothly without impact.

The distribution of granular fertilizer and wheat seed was determined by Davis and Rice (1973) for centrifugal distributors. They designed a truncated cone and installed it on the center of a standard spinner. The cone insured more accurate particle placement onto the spinner vanes. With the modified spinners the coefficient of variation was 2 to 4% less than that of the standard spinners while the swath width increased from 50 feet to 58 feet for a spinner rpm of 600.

Davis and Rice (1974) reported on a simulation language to predict fertilizer distribution from a 15-degree upswept spinner with a truncated cone mounted. Particles were placed on the spinner in the interval between the 6.00-inch and the 11.75-inch radii, 2 inches behind the center line of the spinner. The particle departure angle was then evaluated at 0.25-inch increments between the two radii. They concluded that centrifugal distributors can be simulated reasonably well.

Brinsfield and Hummel (1975) discussed the design of a radial, constant radius of curvature tube and a straight radial tube. The two tubes joined together were to maintain continuous control of the particles and greatly reduce or eliminate the random motion inherent to conventional distributor designs. Experimental results with fabricated nylon spheres indicated that restricting the motion of a particle to a tube produced a significant air effect on the particle's resultant velocity. The new distributor configuration functioned as a centrifugal blower. It was also determined that the particle's mode of travel (sliding, rolling, or both) contributed significantly to the theoretical resultant velocities. Transition from sliding to rolling occurs when the angular velocity of the particle matches its radial velocity. The particle's resultant velocity was shown to be a function of the particle's diameter squared.

Assumptions

Patterson and Reece (1962) assumed:

1. The particles moved gently onto the vanes.
2. The particles were smoothly accelerated along the vanes.

3. There was no interference by the adjacent particles.
4. The motion of particles could be studied individually.
5. No bouncing occurred when the particles were fed onto the spinner.
6. Air resistance was a negligible effect on particle motion on the disc and vane.
7. The friction value of the vane (μ_v) was equal to the friction value of the disc (μ_d).

The influence of spinner windage was neglected in Cunningham's (1963) analysis of spinner performance.

When fertilizer particles come into contact with the spinner vane Cunningham and Chao (1967) assumed their intial velocity to be zero.

In order to simulate the distribution of fertilizer, Davis and Rice (1974) assumed the following:

1. All particles leave the spinner with a velocity as calculated by the equation $V = \sqrt{\omega^2 R^2 + U^2}$ . . . . (1)

   where V = absolute speed of the particle as it leaves the spinner, feet per second

   ω = spinner speed, radians per second

   R = spinner radius, feet

   U = radial component of absolute speed of the particle as it leaves the spinner, feet per second.
2. All particles leave the disc tangentially.
3. All particles remain on the disc until they have rotated through the angle as given by the equation $R/a = \text{Cosh}\ \alpha$ . . . . (2)

   where a = radial location of inner end (pickup end) of vane, feet

   α = angle through which vane rotates to move a particle from radius a to R, radians.

4. Fertilizer particles were spherical.
5. There was no separation of particles due to their characteristics going onto the spinner.
6. Air currents above the spinner were neglible.
7. There was no breaking of particles struck by the vanes on the spinner.

The theoretical analysis of near-center loading by Brinsfield and Hummel (1975) was simplified by assuming that:

1. There was no air resistance to retard the motion of particles.
2. The particles are spherical in shape.
3. The mode of travel was sliding.
4. There was no particle interaction.
5. Once the particle entered the tube, it remained in direct contact with the tube wall until it discharged.
6. The velocity of the particle at the tube entrance was zero.

Equations of particle motion as derived by Alizadeh (1965) assumed the particles remained in contact with the vane along its entire length.

Theoretical Approaches

Patterson and Reece (1962) discussed the theory of a particle fed near the center of a horizontal rotating disc equipped with a number of flat radial vanes that were perpendicular to the disc. Depending on the shape of the particle, two main forms of motion are possible. The particle may slide along the vane and disc or it may roll along the vane and disc. Consideration also was given to the particle which both slides and rolls.

When the case of sliding all the way with friction was considered, an approximation reduced the differential equations of motion

$$r = \frac{\mu_d g}{\omega^2} + Ae^{\omega Ft} + Be^{-\omega Mt} \quad \ldots\ldots \quad (3)$$

where r = distance of a particle from the center of the disc, feet

μ_d = coefficient of friction between the particle and disc

g = acceleration of gravity, feet per second squared

A and B are constants of integration

e = natural number, 2.72

$F = \sqrt{\mu_v{}^2 + 1} - \mu_v$

μ_v = coefficient of friction between the particle and vane

t = time, seconds

$M = \sqrt{\mu_v{}^2 + 1} + \mu_v$

also $$\frac{dr}{dt} = A\omega Fe^{\omega Ft} - B\omega Me^{-\omega Mt} \quad \ldots\ldots \quad (4)$$

and $$\frac{d^2r}{dt^2} = A\omega^2F^2e^{\omega Ft} + B\omega^2M^2e^{-\omega Mt} \quad \ldots\ldots \quad (5)$$

where $\frac{dr}{dt}$ = radial velocity of particle with respect to the vane at distance r, feet per second

$\frac{d^2r}{dt^2}$ = radial acceleration of particle with respect to the vane at distance r, feet per second squared

to $$U = \text{maximum } \frac{dr}{dt} = F\omega R \quad \ldots\ldots \quad (4a)$$

$$\theta = \text{Arc Tan } \frac{1}{F} \quad \ldots\ldots \quad (4b)$$

where θ = angle of dispatch measured between radius at point of exit and path of the particle, degrees

and $$V = \omega R(\sqrt{1 + F^2}) \quad \ldots\ldots \quad (4c)$$

(see figure 1).

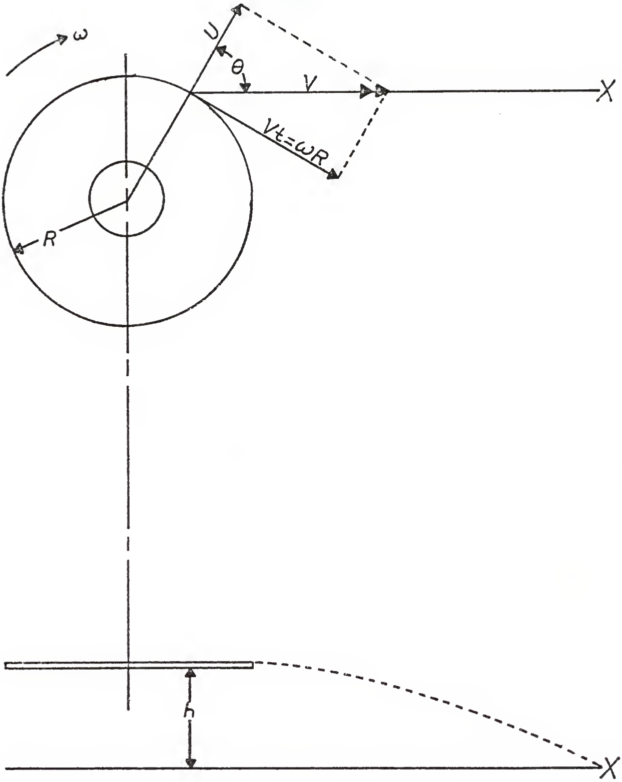

Figure 1: Important variables in the flat spinner analysis (from Patterson and Reece (1962)).

For forward-pitched vanes, Cunningham (1963) developed the following differential equation of motion for the fertilizer particle departure velocity with respect to the vane:

$$U = [\omega R/2C][\sqrt{(r_o/R^2) - Q^2} - \mu_v Q - \mu_v g/\omega^2 R][e^{(C - \mu_v)\alpha} - e^{-(C + \mu_v)\alpha}] \quad . \quad (7)$$

where $C = \sqrt{\mu_v{}^2 + 1}$

r_o = radial position where fertilizer particles are delivered to the spinner, feet

$Q = \text{Sin } \phi_R$

or $Q = -\text{Sin } \phi_R$ if vanes are backward pitched

ϕ_R = angle of vane tip with respect to spinner radius, radians.

(see figure 2).

Cunningham went on to state that greater acceleration and more positive action near the spinner hub can be developed with forward curved rather than forward pitched vanes. The differential equation of particle velocity with respect to the vane for forward curved vanes is:

$$U = G\left[\frac{r_o - \mu_v g/G\omega^2}{2H}\right][e^{(H - \mu_v)^{\alpha}} - e^{-(H + \mu_v)\alpha}] \quad . . . . \quad (8)$$

where $G = \text{Cos } \phi - \mu_v \text{ Sin } \phi$

or $G = \text{Cos } \phi + u_v \text{ Sin } \phi$ if vanes are backward curved

ϕ = angle of vane with respect to spinner radius, radians

$H = \sqrt{\mu_v{}^2 + G \text{ Cos } \phi}$

(see figure 3).

With either forward curved or forward pitched vanes, the angle of particle departure, β, is determined by the two components of velocity; velocity with respect to the vane, U, and peripheral spinner velocity, ωR. Using the law of sines, Cunningham developed the following formula:

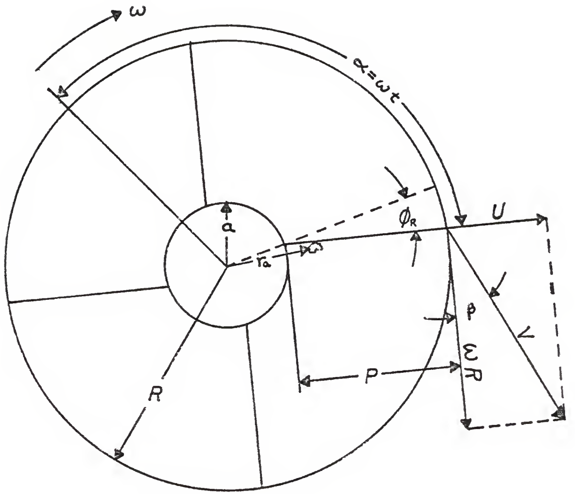

Figure 2: Top view of spinner with forward pitched straight vanes.

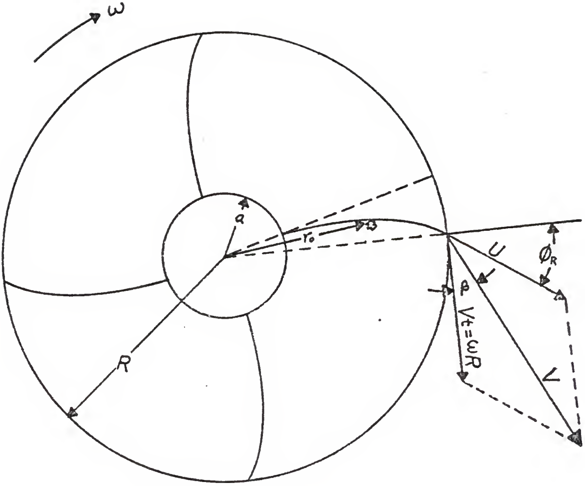

Figure 3: Top view and components of resultant velocity for forward curved vaned spinner.

$$\beta = \text{Arc Cot}[\frac{\omega R}{U\text{Cos } \phi_R} + \text{Tan } \phi_R] \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad (9)$$

(see figure 2 and figure 3).

The differential equation, as developed by Cunningham, for particle velocity with respect to the vane on cone shaped spinners is:

$$U = (J\omega/L)\ [\frac{r_o - Ng/J\omega^2}{2K}][e^{L(K - \mu_v)\alpha} - e^{-L(K + \mu_v)\alpha}] \ldots \ldots \ldots \quad (10)$$

where $J = \text{Cos } \gamma_o - \mu_v \text{ Cos } \gamma_o$

γ_o = spinner cone angle, degrees

$N = \text{Sin } \gamma_o + \mu_v \text{ Cos } \gamma_o$

$K = \sqrt{\mu_v{}^2 + G/L}$

$L = \text{Cos } \gamma_o$

(see figure 4).

To obtain the vertical component of velocity, velocity with respect to the vane, U, must be multiplied by Sin γ_o.

Cunningham and Chao (1967) stated the most widely quoted relationship to describe the motion of solid particles along radial fan blades. The equation being: $R/a = \text{Cosh } \alpha$ . . . . (2)

When the equation is differentiated with respect to time, t; the radial component of velocity imparted by the fan is obtained:

$$\frac{dr}{dt} = a\omega \text{ Sinh } \alpha \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad (11)$$

where $\omega = \frac{d\alpha}{dt}$, the angular velocity of the fan, radians per second.

For Cunningham and Chao's special vane shape the following nonlinear differential equation describes the particle motion along the curved part of the vane.

$$\ddot{S} + (\frac{\mu_v}{b})\dot{S} + 2\omega\mu_v\dot{S} - \omega^2(a + b)(\text{Sin } \frac{R}{b} + \mu_v(\omega^2 b + g) = 0 \ldots \ldots \ldots \quad (12)$$

where b = radius of the curved part of the vane, feet

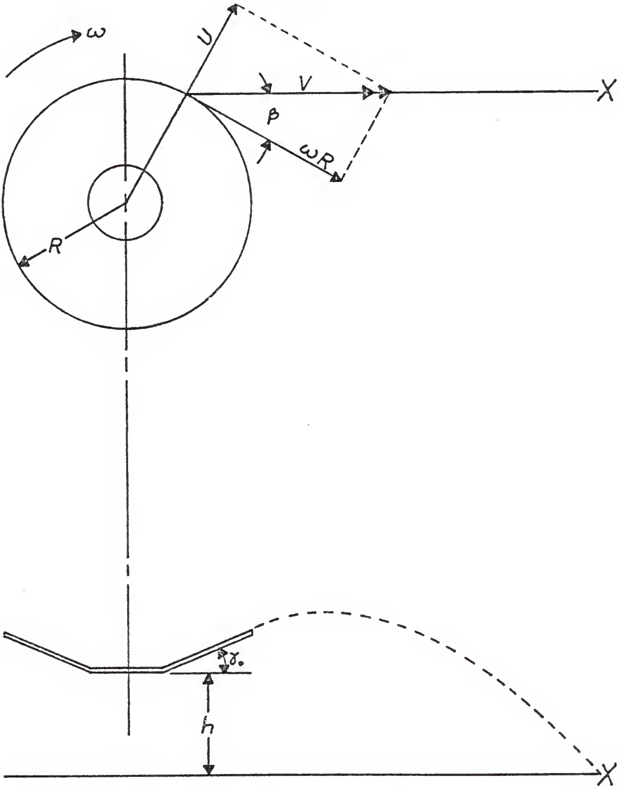

Figure 4: Important variables in the cone spinner analysis.

$\dot{S}$ = velocity of the particle with respect to the vane, feet per second

$\ddot{S}$ = acceleration of the particle with respect to the vane, feet per second squared.

The differential equation which describes the particle motion as the particle departs the vane is:

$$\ddot{S} = R\omega^2 + [\sqrt{a^2 + 2ab} - b\ \mathrm{Cos}^{-1}(\frac{b}{a + b})]\omega^2 - \mu_v g - 2\mu_v \omega \dot{S} \quad . . . . (13)$$

Equations (12) and (13) were then solved by electronic analog computer.

α was calculated using the equation

$$P = \frac{Ea - \mu_v/\omega^2}{2C}[(C + \mu_v)e^{(C - \mu_v)\alpha} + (C - \mu_v)e^{-(C + \mu_v)\alpha} - 2C] \quad . . . . \quad (14)$$

where P = the length of the vane, feet

E = Cos ϕ - μ_v Sin ϕ.

β was determined by differentiating equation (14) to obtain the theoretical velocity of fertilizer with respect to the vane, $\frac{dP}{dt}$; and then analyzing the vector triangle formed by $\frac{dP}{dt}$ and the peripheral velocity (V_t) of the spinner (see figure 5).

For the prediction of fertilizer distribution, Davis and Rice (1974) used Inns and Reece's approximation equation to determine the velocity of a spherical particle after being struck by a spinner vane. The equation used was: $V = \sqrt{\omega^2 R^2 + U^2}$ . . . . (1)

The equation $R/a = \mathrm{Cosh}\ \alpha$ . . . . (2)

was evaluated at 0.25 inch increments from a radius of 6.00 inch to 11.75 inch to find the angle through which the spinner rotated to discharge a particle.

Differential equations of particle motion with respect to a tube wall were developed by Brinsfield and Hummel (1975). They used the vector sum of three acceleration components to determine the total particle acceler-

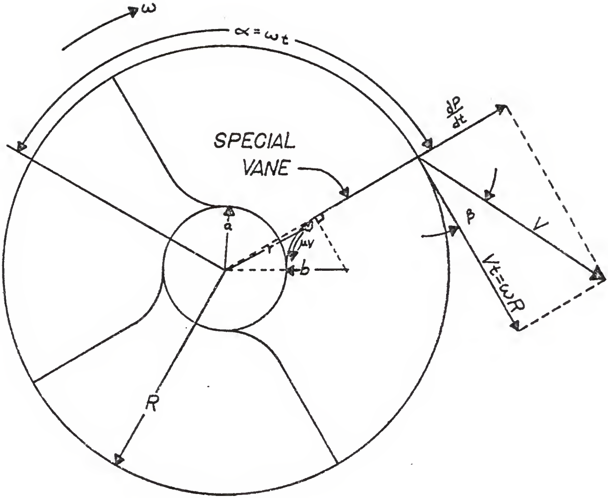

Figure 5: Top view of spinner with special curved vanes.

ation as previously used by Patterson and Reece (1962), Cunningham (1963), and Alizadeh (1965). The three components were:

1. The acceleration of the particle with respect to its path.
2. The acceleration of the point on the path coinciding with the location of the particle.
3. The Coroilis acceleration, which is twice the vector cross product of the angular velocity of the path and the particle velocity with respect to the path.

Solutions to the differential equations were analyzed by an electronic analog computer to obtain an optimum design.

Apparatus

Crowther (1958) worked with a horizontal spinning apparatus which consisted of a 15-inch diameter disc with four equally-spaced 1x1x1/4 inch angle sections bolted onto its upper surface. The 1500 gram granular fertilizer distributor was driven by an electric motor through a variable speed pulley, and the speed was measured by a tachometer. Test speeds ranged between a low of 200 rpm and a high of 500 rpm.

Patterson and Reece (1962) fed 1/8 inch diameter steel balls and 1/8x 1/8x1/4 inch pieces of steel onto a spinning disc through a glass tube in such a way that they did not bounce. The flat disc was 14 1/4 inch in diameter with four radial, one-inch high vertical vanes. The disc could be driven by a 1/2 h.p. motor at speeds between 200 and 900 rpm. A camera clamped about three feet above the spinner photographed the discharging particles. Camera shutter speeds used were on the order of two to three seconds.

In studying the particle motion on the disc with off-center feed, Inns and Reece (1962) used the same 1/4 inch thick disc that Patterson and Reece used. The disc was driven by a 1/2 h.p. electric motor through a Croft variable-speed unit. A revolution counter was used to determine the disc speed. During the experiments, the disc was fitted with 16 vanes made from 3/4-inch aluminum angle-section, flat on one face and fluted on the other. The flat side was used as the striking face during most of the experiments. Once again, a camera was fixed over the disc center to take photographs looking vertically down.

Cunningham and Chao (1967) experimented with six, 6.78-inch straight vanes mounted perpendicular to a 20-inch diameter flat spinner surface. Two vane pitches, 14.5 degrees forward and 4.7 degrees backward, were studied separately to measure the direction of velocity imparted to granular fertilizer. The off-center delivery tube opening provided 24, 76, and 153 lb. per minute of fertilizer to the spinner during each of the 10-second tests. Spinner speeds of 380±10, 540±15, and 635 rpm were provided by a 3/4 h.p. electric motor through a variable-speed drive and miter gears located underneath the spinner. A special vane shape was also studied. The inner portion of the vane was curved toward the direction of travel while the outer portion was straight, either radial or pitched with respect to the radial direction.

During a laboratory study, Davis and Rice (1973) used two spinners each 2 feet in diameter with a 15-degree upsweep. Each spinner had 6 vanes and operated at 600 rpm. After preliminary tests, the standard discs were modified to reduce the heavy application rate near the center of the swath. A truncated cone was constructed and installed at the center of each spinner. The cone had a lower diameter of 1 foot and an upper diameter and height of 6 inches.

Replacing conventional spinner vanes with tubes was studied by Brinsfield and Hummel (1975). Each tube consisted of two shapes: region 1 and region 2. Region 1 was trapezoidal at the particles entrance and gradually progressed to circular while maintaining a constant radius of curvature of 0.50 ft. throughout the transition to region 2. Region 2 was the straight section of the tube which was parallel to the flat spinner surface. Commercially fabricated nylon spheres with a specific weight of 70 lbs per cubic foot were metered through the tubes. The particle sizes investigated were 0.187, 0.156, 0.125, and 0.093 inch in diameter. Particle departure angles and velocities were measured by using a Fastax WF4 highspeed movie camera. Smoke bomb tests were used at the tube entrances to show the air velocity as being greater than the particle velocity.

Trajectory Analysis

The study of particle motion through the air allows prediction of the distribution pattern and maximum radius of particle coverage for a given spinner. A trajectory analysis adds to the equations of particle motion on the disc and vane surface discussed in the previous section. Trajectory equations can be developed once the velocity imparted with the spinner and the particle pathes are known.

The type of trajectory equations applicable to distribution problems depends on the form of the relationship between particle velocity and air resistance. At low Reynolds numbers (Re), streamline flow, the air resistance is proportional to the velocity and Timoshenko and Young (1948) developed the following equations of particle motion:

$\ddot{X} = -C_1 V \operatorname{Cos} \gamma$, and $\ddot{Y} = -C_1 V \operatorname{Sin} \gamma - g$ . . . . (15, 16)

where $\ddot{X}$ = horizontal component of acceleration, feet per second squared

C_1 = a constant

γ = direction of particle motion, measured from the horizontal, degrees

$\ddot{Y}$ = vertical component of acceleration, feet per second squared.

Timoshenko and Young also developed an approximation for the case when the air resistance is proportional to the velocity squared. The equation of the path becomes

$$Y = X \tan \gamma_1 - \frac{gX}{2V^2 \text{Cos}^2 \gamma_1} \left(\frac{e^z - z - 1}{1/2\ z^2}\right) \quad . . . . (17)$$

where Y = elevation, feet

X = horizontial displacement, feet

γ_1 = angle of elevation, radians

$z = 2cX$

$c = \dfrac{c_r(1/2\ \rho)a_o}{m}$, ballistics coefficient, reciprocal feet

c_r = coefficient of resistance

ρ = density of air, slugs per cubic feet

a_o = projected area of particle, square feet

m = mass of particle, slugs.

Aerodynamic properties of seed grains was studied by Bilanski et al (1962) to help determine individual grain behavior in combines, seed cleaning plants and pneumatic conveying systems. They developed the equations

$$X = (V^2/g)\ln \cosh (g/V)\ t_a \text{ and } V = \sqrt{2\ mg/c_d a_o \rho} \quad . . . . \quad (18, 19)$$

where t_a = time particle is in the air, seconds

c_d = coefficient of drag

when the drag force is proportional to the square of the velocity and the flow regime remains constant.

Cunningham (1963) used equation (17) for trajectory analysis of dry fertilizer granules and assumed all the particles to be spherical with diameters equal to the mesh sizes of 0.094 and 0.047 inches. For a typical phosphate fertilizer a drag coefficient of 0.42 was used in determining the ballistics coefficient. The coefficient of variation was considered acceptable if its value was determined to be 20 percent or less. For the velocities involved in granular fertilizer distribution the coefficients of drag were assumed to be essentially constant. Cunningham concluded that trajectory equations which take into account air resistance complement the theoretical spinner equations and provide a rational method for calculating fertilizer particle distribution pattern width.

While working with two typical granular fertilizers and a sample of sulphate of ammonia, Mennel and Reece (1963) determined there particle trajectories. For spherical particles in the turbulent flow region, Reynolds number greater than 800, the drag coefficient was assumed approximately constant and the following two equations of motion were developed:

$$X = \frac{V^2}{g}\int_0^{\gamma} \frac{d\gamma}{\mathrm{Cos}^2\gamma[1 + \frac{kV^2}{mg}\ \tan\gamma\sec\gamma + \ln\{\tan\gamma + \sec\gamma\})]} \quad \ldots\ldots\ldots \quad (20)$$

$$Y = \frac{V}{g}\int_0^{\gamma} \frac{\tan\gamma d\gamma}{\mathrm{Cos}^2\ [1 + \frac{kV^2}{mg}(\tan\gamma\sec\gamma + \ln\{\tan\gamma + \sec\gamma\})]} \quad \ldots\ldots\ldots \quad (21)$$

where $k = c_d(\frac{3\rho_a}{4\rho_p D})$

ρ_a = density of air, lb per cubic foot

ρ_p = density of particle, lb per cubic foot

D = particle diameter, feet.

A lengthy process of graphical integration was then performed to develop a family of curves to be used in solving equations 20 and 21.

In trying to keep undesireable variation in particle motion to a minimum, several vane types were tried. A sigma-section (Σ) was determined to be the best when it projected 82% of the particles within a $\pm 3^{\circ}$ zone.

While using the sigma-section vanes, ball bearings were projected at a known speed in the turbulent region. Trajectories were measured by allowing the ball bearings to hit vertical screens where they marked a white paper placed behind a sheet of carbon paper, or by allowing them to fall into a corrugated tray. Experimental trajectories agreed very closely with computed values.

Mennel and Reece concluded:

1. Air resistance cannot be neglected in the computation of the trajectory of even the largest fertilizer particles.
2. Air flow around granular fertilizer particles is turbulent.
3. A spinner with low projection velocities will have a particle range that is less affected by particle size than one with high velocities.

Reints (1963) used the equation developed by Daugherty and Ingersoll (1954): $F_d = \frac{1}{2}(c_d \rho_a V^2 a_o)$ . . . . (22)

where F_d = drag force

to show the drag force as a fraction of the particle weight. He showed that at the beginning of the trajectory the drag force was 66% of the particle weight and decreased to a minimum of 4.5% of the particle weight.

During a trajectory study of seeds and granular fertilizers Reints (1963), and Reints and Yoerger (1967) determined the equations for the trajectories of spherical particles in free flight through an undisturbed medium. They are:

$$\ddot{X} = K_1 \sqrt{\dot{X}^2 + \dot{Y}^2}\, e^{[a_1 \ln b_1 \sqrt{\dot{X}^2 + \dot{Y}^2} - c_2]^{d_1}} - f_{\dot{X}} \quad . . . . (23)$$

$$\ddot{Y} = K_1 \sqrt{\dot{X}^2 + \dot{Y}^2}\, e^{[a_1 \ln b_1 \sqrt{\dot{X}^2 + \dot{Y}^2} - c_2]^{d_1}} - f_{\dot{Y}} - g \quad . . . . (24)$$

where $K_1 = \dfrac{-\rho_a a_o}{2m}$

$a_1 = 0.1960$

$b_1 = \frac{D}{0.0001677}$

$c_2 = 1.885$

$d_1 = 2.377$

$f = 0.9560$

$\dot{X}$ = horizontal component of particle velocity, feet per second

$\dot{Y}$ = vertical component of particle velocity, feet per second

Air resistance due to a variable-drag coefficient is built into these two equations.

It was shown that the drag coefficient varies considerably when the Reynolds number is low, and remains essentially constant at higher Reynolds numbers. Experimental verification of the computer solutions showed actual trajectories within ten percent of the theoretical solutions.

Shoemaker et al (1972) used an optimum angle of 35 degrees as the initial inclination to horizontal to test a high speed belt thrower operating at 10,000 rpm. They showed that the damping effect of air is not a linear relation and the displacement of a fertilizer particle increases at a decreasing rate as the velocity increases. A damping coefficient proportional to the velocity to the 2 1/2 power closely approximated the experimental throwing distance of the belt spreader for various initial velocities.

Schaffer et al (1973) used Timoshenko and Young's (1948) approximation for the case when the air resistance is proportional to the square of the velocity (equation 17) to study fertilizer distribution patterns. Equation 17 was rearranged to solve for the initial velocity that would be required to propel a particle a desired horizontal distance. The equation now becomes

$$V = \sqrt{\frac{gX^2}{2\{X\tan\gamma_1 - Y\}\mathrm{Cos}^2\gamma_1}\left(\frac{e^{2cX} - 2cX - 1}{2c^2X^2}\right)} \quad . . . . (25)$$

Evaluation over a range of horizontal distances was then accomplished on the computer.

Davis and Rice (1974) used Mennel and Reece (1963) equations of motion with a computer simulation language to predict fertilizer distribution from a spinner.

Sprinkler Irrigation

Current big gun irrigation systems often are used to disperse both manure slurries and water. Trajectory angles vary from approximately 20 degrees to 27 degrees. Flow varies from around 75 gpm at 50 psi with a .6-inch diameter nozzle to over 1000 gpm at 130 psi with a 1.93-inch diameter nozzle. The claimed diameter of coverage varies from just over 200 feet to around 550 feet respectively. Big gun operational criteria and technique require review in order to better understand the distribution process of water and slurries.

Trajectory Analysis

Since water drops deform at high velocities, the drag coefficient depends on both the Reynolds number and the Weber number (Seginer, 1965). Seginer went on to say that when the drag coefficient of any given drop is related to the velocity of the drop, a minimum of the drag coefficient is observed. When the velocity is increased beyond this minimum, a region is reached where the drop deforms, vibrates, and eventually breaks down to form smaller droplets. In the region of this minimum, the drag force may by considered as practically proportional to the square of the velocity.

Using a trajectory angle of 30 degrees Seginer showed, through the use of a hodograph, that the drag force acts as a power function of velocity and varies continuously throughout a drops trajectory depending on whether the drop is accelerating or decelerating. Drops of diameter smaller than 2.5 mm appeared to deform significantly only at velocities higher than their terminal velocities. For drops larger than 2.5 mm deformation occurs at high velocities. Since the actual velocities of raindrops and sprinkler drops are close to their terminal velocities, the drag coefficients of medium-sized drops (3 mm diameter) is not far from their minimum. Therefore, the drag coefficients may be considered as constant and a velocity exponent of 2 should be used in their computation. Drop sizes ranging from 1 to 6 mm diameter cover most drops of interest in irrigation and heavy natural rains.

Kohl (1974) reported on the effects of pressure and nozzle size on water drop size distributions from medium-size agricultural sprinklers. Increasing the relative velocity of the water with respect to the air decreased the drop size, decreasing nozzle diameter decreased the mean drop size, and increasing pressure decreased the mean drop size.

INVESTIGATION

Research Objectives

The research objectives were: (1) to determine experimentally the applicability of current spinner theory as applied to the disposal of manure slurry; (2) to determine relationships involved and required for the design of special vane configurations by expansion of spinner theory; and (3) to determine the feasibility of using a spinning disc to distribute swine wastes onto cropland. Feasibility of the operation was to be determined by measuring: (a) the flow rate onto the spinner; (b) power consumed by the spinner; (c) the spinner coefficient of uniformity; and (d) the spinners maximum diameter of coverage.

Materials and Equipment

A prototype slurry spinner was constructed in the Agricultural Engineering Department laboratory at Kansas State University. The spinner was designed to be simple, easy to handle, and capable of quick changes in the field.

The spinner tripod structural stand was built from 1x1x1/8-inch angle section. The upper and lower 1 7/16-inch self-aligning ball bearing mounts were made from available scrap, 4-inch channel sections, and 1/2-inch flat iron, respectively. The power transmitting shaft was 1 1/2-inch square, cold rolled steel turned down to 1 7/16-inch in diameter except for the upper 1/4 inch. A 1/2-inch threaded hole at the upper square end of the shaft provided the means to fasten the spinning disc to the rotating shaft. The height of the disc base (h) is 4 feet. Sheaves were installed on the shaft below the lower bearing and were powered by 1, 2, and 5 h.p. electric motors mounted vertically to the spinner stand (see figure 6).

Figure 6. Side Views of Machine without Cowling and with a 26-inch Disc, Adjustable Center Cylinder, and 1 h.p. Electric Motor Installed.

Two square-holed disc blades with diameters of 26 inches and 20 inches and cone angles of 30 degrees and 22 degrees, respectively, were used. Provisions were made on the 26-inch blade (1/4-inch in thickness) to accommodate 2, 4, or 8 straight 2-inch tall vanes pitched approximately 25, 15, 10, and 5 degrees forward, 15 and 5 degrees rearward, and/or neutral (see figure 7). The 20-inch blade had provisions for 2, 4, or 8 vanes only at the neutral pitch. Four straight vanes were later modified by adding a strip of material to the forward surface (see figure 8). All the vanes used in the study were mounted perpendicular to the disc surface. Eight hooded, 2-inch tall forward curved and two hooded, 2-inch tall rearward curved vanes were also used during the research (see figures 9 and 10). About half way through the testing, Mennel and Reece's (1963) straight sigma-section vanes were used. Eight short (8 3/4-inch) and four long (11 3/4-inch) sigma-vanes were constructed and tested (see figure 11). The center mounted, adjustable metering cylinder, 6 inches in diameter and 10 inches long, was replaced after considerable testing with a plastic funnel mounted in the center of the disc blade (see figure 12).

During the early testing phase, the spinner speed was monitored with a Hasler mechanical tachometer. Later in the research a remote counter and stop watch were used to determine the spinner rpm. A modified hand calculator counted the number of times a reed switch closed when a magnet rotated past its stationary location.

Power was monitored with a Weston 1500-watt meter during part 1 of the work. For the actual slurry testing, 3 and 6-kilowatt Weston meters were used to determine the 3-phase power consumed. Photographs were taken by a Nikkormat FT-3 camera and f1.4, 55 mm Nikkor lens. Film speeds ASA 25, 64, 100, and 200 were used with various shutter speeds.

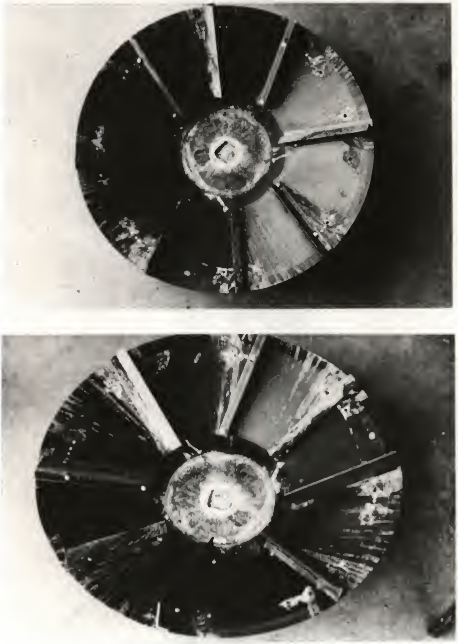

Figure 7. Top Views of 26-inch Diameter Disc with Provisions for Various Pitches and Vane Configurations.

Figure 8. Side Views of Perpendicular Metal Strip Installed on the Surface of a Straight Vane.

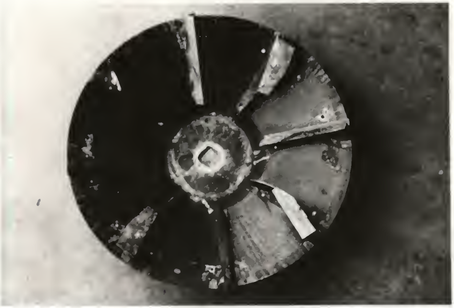

Figure 9. Top View of Disc Equipped with 2 Neutral Sigma-Vanes, 2 Rearward Curved Hooded Vanes, 2 Rearward Pitched Sigma-Vanes, and 2 Forward Curved Hooded Vanes.

Figure 10. End Views of Forward and Rearward Curved Vanes, Respectively.

Figure 11. Four Short and Four Long Sigma-Vanes Installed on a 26-inch Diameter Disc with Plastic Funnel.

Figure 12. Plastic Funnel Installed on a 26-inch Diameter Disc.

The first part of the research was conducted at the Kaw Valley Experiment field just west of Topeka, Kansas. Facilities used were: electric irrigation turbine pump, 3 inch aluminum irrigation pipe, and single phase 220 volt electrical power source.

Part two of the research effort was performed at the south Wolf Brother's swine establishment located 3 miles south of Longford, Kansas. A small centrigugal pump with a 3-inch flexible hose inlet and 3-inch aluminum irrigation pipe outlet was used to deliver swine waste material into the spinner funnel. Three-phase electrical power was provided by the portable Kansas State University Agronomy farm generator.

Throughout the entire research project the flow rate was measured by the use of a 32-gallon trash can and stop watch.

Procedure

This research study was broken down into two distinct areas of research. Part 1 consisted of the literature review, initial design, prototype construction, and testing of the spinner with water. Part 2 concerned the actual slurry testing of the most promising vanes and vane configurations as determined by the maximum radius of coverage, power consumed, and uniformity coefficient.

RESULTS

Part 1 of Research

After reviewing the current state of the art of spinner technology, the first water tests were performed. Thirteen sets of data were collected and analyzed for their uniformity of coverage. Three rows of catch cans, A, B, and C, were spaced on the ground four feet below the center of the rotating disc, three feet apart radially outward from the spinner center, approximately 120 degrees apart. Wind was a constant problem. Many observations were made and a large number of different vanes and vane pitches along with various vane configurations were tried at approximately 600 rpm. Early testing at 400 rpm produced a small radius of coverage (about 12 feet) and was, therefore, thought to be too slow. The flow rates varied from approximately 20 gpm to 40 gpm (see table 1 for a typical data set). Only the 26-inch diameter disc was used during the water tests.

The uniformity of distribution was determined through the use of Christiansen's (1942) uniformity coefficient, C_u. The uniformity coefficient expressed as a percentage is defined by the equation

$$C_u = 100\left(1 - \frac{\Sigma d}{\bar{x} n} \right) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (26)$$

where d = deviation of individual observations from the mean, centimeters

$\bar{x}$ = mean of observations

n = number of observations.

An absolute uniform application is represented by a uniformity coefficient of 100 percent, while a less uniform application will result in a lower percentage.

Many pictures were taken of the water motion on the disc and vane surface from the top of a ladder placed adjacent to the spinner. These

Table 1: Typical data set collected during water testing with straight vanes and powered by a 1 h.p. electric motor.

Date: 20 Mar 78 Test #: 4 Wind: Speed--Calm, Direction-- --

Power: No Load 500 watts, Full Load 1300 watts Length of Test 10 min.

Vane Configuration: 1 & 5 none, 2 & 6 25° fp*, 3 & 7 none, 4 & 8 25° fp

Spinner rpm: @ Start 635, During 585 Ending Flow Rate: 40 gpm

Depth of water in catch cans spaced every 3 feet from spinner (cm):

	@A†	@B	@C
3	.47	.77	1.03
6	.81	1.56	2.07
9	1.42	1.34	2.09
12	2.80	1.07	1.42
15	2.77	.89	.91
18	1.48	.36	.26
21	1.17	T¶	T
24	.26		
27	T		
C_u	56%	68%	57%

* fp = forward pitch
† Rows radiate from spinner spaced at 120° intervals
¶ T = Trace

pictures were later analyzed to determine the interactions that occured on the spinner and action of the water as it departed from the spinner. It was very difficult to interpret the early pictures. Using a shutter speed of one-thousandth of a second, the action of the water could be stopped sufficiently to allow for close inspection of its behavior.

The initial flat, straight vanes and hooded foreward and rearward curved vanes produced great quantities of fog and mist at both 400 and 600 rpm with 20 to 40 gpm flow rates. Most of the water stream broke down into small droplets soon after it departed from the spinner surface; something was needed to prevent this from occuring. A metal strip was installed perpendicular to the surface of the straight vanes one-half inch above the disc surface to help channel the water into small streams (see figure 8). It was thought that these streams would help prevent mist formation as the water left the spinner and possibly give a greater radius of coverage. Mist formation was somewhat reduced and high speed photographs clearly showed the small streams of water leaving the spinner (see figure 13). The radius of coverage did not change, but wind deformation of the area of coverage was reduced. The radial coefficient of uniformity increased somewhat over the previous vane shape (see table 2).

No-load power consumed by the 1 h.p. electric motor was found to increase with the addition of vanes. That apparently was caused by the spinner's acting as a centrifugal blower. Vane pitch was found to have little or no effect on no-load power consumption when the number of vanes remained constant. Full-load power was found to be dependent mainly on the spinner rpm and flow rate onto the spinner. Number of vanes. vane pitch, and vane configuration appeared to have little effect on the

Figure 13. A 26-inch Diameter Disc with Adjustable Center Cylinder Delivering Approximately 35 gpm.

Table 2: Typical data set collected during water testing with metal strip installed perpendicular to the vane surface and powered by a 1 h.p. electric motor.

Date: 20 Mar 78 Test #: 6 Wind: Speed--1 to 2 mph, Direction--WNW

Power: No Load 510 watts, Full Load 1300 watts Length of Test 16 min.

Vane Configuration: 1 & 5 none, 2 & 6 15° fp*, 3 & 7 none, 4 & 8 15° fp

Spinner rpm: @ Start 640, During 580, Ending Flow Rate: 35 gpm

Depth of water in catch cans spaced every 3 feet from spinner (cm):

	@A†	@B	@C
3	.41	1.03	1.48
6	1.32	1.96	2.27
9	1.92	1.86	2.43
12	2.13	1.46	2.13
15	1.70	1.15	1.17
18	1.42	.67	1.22
21	.87	T¶	.43
24	.22	T	T
27	T		
C_u	55%	70%	68%

* fp = forward pitch
† Rows radiate from spinner spaced at 120° intervals
¶ T = Trace

power consumed when the rpm of the spinner remained the same and the flow rate was constant.

The adjustable center delivery cylinder was modified to include an internal funnel to help direct the water onto the exact center of the spinner. The cylinder proved unsatisfactory when repeated attempts to keep it one-half to two-thirds full during operation proved fruitless.

Part 1 showed the need for precise center loading of the water to achieve even distribution. In order to minimize wind drift and misting, it was felt another blade with a smaller trajectory angle should be used. The spinner's maximum radius of coverage with a 1 h.p. electric motor operating under full load (approximately 1250 watts), at 600 rpm with a 26-inch disc and a 40 gpm flow rate was 20 feet. It was felt that a coefficient of uniformity greater than 80% could be achieved through the use of 8 sigma-vanes alternately pitched neutral and slightly forward (5 to 10 degrees).

Part 2 of Research

Since the dispersal of small streams seemed to be a step in the right direction, Mennel and Reece's (1963) sigma-vanes were tried. Eight short (8 3/4 inch) straight vanes were built from 16 gage sheet metal. A 2 h.p., three-phase motor was used with the sigma-vanes for the beginning tests with a thick swine slurry that contained a large quantity of cracked grain. Over 2 tons of grain had been accidentally deposited in the 20x24x4-foot nursery pit when the operation of an auger malfunctioned. The pit was full when pumping began. Continued winds hampered almost all efforts of trying to collect a uniform set of data.

Fourteen sets of information were collected with both 2 and 5 h.p., three-phase electric motors installed on the spinner. No attempt was made to pour the thick slurry from the catch cans into the graduated cylinder to determine the volume as was done with water (see table 3). Hence, depth in each can was estimated. The data in table 3 were the best obtained during the entire slurry testing. The wind was almost always blowing, 15 to 30 mph, and only during a lull could data be gathered (see figure 14).

Various tests were run for the sake of observation and taking pictures of the slurry on the disc and sigma-vanes (see figure 15) and to record the power consumption for each vane configuration. The photographs were later analyzed to determine the slurry's behavior on the spinner's surface. The sigma-vanes worked quite well at both 600 and 800 rpm. Less misting occured with 8 alternate long and short sigma-vanes operating at 600 rpm. After repeated belt problems at 600 rpm, the pulley on the 5 h.p. motor was replaced with a larger one that pushed the spinner rpm to approximately 800 rpm at 60 cycles per second on the three-phase generator.

Many times the small centrifugal pump was not able to pump the heavy slurry at a uniform rate. The manure pit was not agitated and consequently inconsistent flow rates occurred when a more dense section of material came into contact with the inlet line.

At 600 rpm the no-load power consumed was 1.9 kilowatts with the 26-inch disc and 8 alternate long and short neutral sigma-vanes. The full-load power consumption was 7.8 kilowatts at a spinner loading rate of approximately 200 gpm (pump engine running at its maximum speed). Both were fairly common power consumption figures. A 200 gpm flow rate was required to load the 5 h.p. motor. The addition of a plexiglass

Table 3: Typical data set collected during slurry testing with sigma-vanes and powered by a 5 h.p. electric motor.

Date: 31 Mar 78 Test #: 8 Wind: Speed--1 to 3 mph, Direction--SW

Power: No Load 1600 watts, Full Load 6300 watts, Length of Test 4 min.

Vane Configuration: Alternate 8 3/4 and 11 3/4-in. neutral pitch sigma-vanes

Spinner rpm: @ Start 590, During 520, Ending Flow Rate: 200 gpm

Depth of water in catch cans spaced every 3 feet from spinner (cm):

	@A†	@B	@C
3	2.5*	2.5	2.5
6	2.5	2.5	2.5
9	2.5	2.5	2.5
12	2.5	2.5	2.5
15	2.5	2.5	2.5
18	2.5	2.5	2.5
21	2.5	2.5	2.5
24	2.5	2.5	2.5
27	.5	2.5	2.5
30	T¶	2.5	.5
33		2.5	T
36		.5	
39		T	

† Rows radiate from spinner spaced at 120° intervals

* Due to the heavy consistency of the material handled no attempt was made to measure the actual depth of material caught.

¶ T = Trace

Figure 14. Typical Side View of Slurry Spinner When the Wind was Calm.

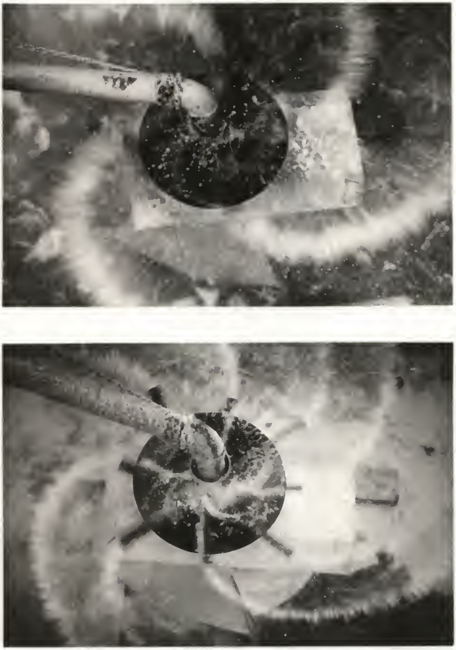

Figure 15. Top Views of Spinner Operating with a Swine Slurry.

cover to minimize the blower effect, as discussed earlier, reduced the power required by 200-300 watts.

Part 2 of the research demonstrated that, with favorable winds, slurry could be spread relatively uniform with a spinner equipped with 8 alternate long and short neutral sigma-vanes. The radius of coverage, with no wind, was approximately 27 feet. The 20-inch diameter disc equipped the same as above produced similar results with a small drop in power consumed. Different flow rates delivered to the spinner affected the misting problem. A flow rate capable of keeping a 5 h.p. electric motor under full load produces fewer small droplets and thus less mist.

DISCUSSION

During the early tests the critical nature of the precise center placement of water was discovered. Several different funnel arrangements were studied and tried. A specific funnel matched to a given flow rate will be the answer to directing flow onto the spinner's exact center.

From all the data taken, it is evident that wind is the chief deterent to achieving a uniform distribution pattern. The data collected lack accurate flow readings since no flow meters were available to handle both part 1 and part 2 of the testing. Variations in pump output had unknown effects on the water and especially the slurry distribution patterns.

CONCLUSION

After all the observations have been noted and all the data analyzed it appears that the spinner's small diameter of coverage with water (approximately 40 ft.) severely limits its feasibility for water distribution. A centrifugal water spreader probably cannot economically compete with the coventional sprinkler nozzle. Small water droplet formation, as soon as the water stream departs the spinner, prevents the attainment of diameters of coverage larger that the 40 feet reported above. With precise center loading of the water, a high uniformity coefficient (80% or higher) can easily be attained when the wind is calm. Power consumption is affected more by the increase in spinner speed than the increase in flow rate onto the spinner.

A thick swine slurry can be spread evenly by the use of a spinning disc. The misting problem with slurry is somewhat reduced and a larger diameter of coverage is therefore attainable as compared to water. Uniform coverage up to 54 feet can be expected.

A centrifugal slurry spreader is likely to be feasible to operate at the present time if the farmer has a means to agitate the slurry and successfully pump it to the spinner. The spinner would be powered by a small gas or diesel engine (approximately 10 h.p.) capable of operating the spinning disc as well as the drive wheels. This particular set-up would handle approximately 200 gpm.

SUGGESTIONS FOR FUTURE RESEARCH

Further work in this area should be done in an enclosed area where there is no wind. A large variable speed motor should be used to power the spinner. This would enable the spinner speed to be altered while all the other factors remain constant. Flow rates, disc diameters, and flatter trajectories could also be studied to determine their effects on droplet sizes and distances propelled.

There is also a need for the development of a low pressure slurry pit removal system.

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DESIGN AND DEVELOPMENT
OF A SLURRY SPINNER

BY

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AN ABSTRACT OF A MASTER'S THESIS

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ABSTRACT

As more animal confinements come into being, large waste disposal problems begin to occur. In an effort to better engineer our vital resources of clean water, clean air, and energy, the concept of a slurry spinner was explored.

This study was undertaken to determine the feasibility of operation for a slurry spinner. Part 1 of the research centered around the testing of the spinner with water. It was found that the maximum diameter of coverage possible was approximately 40 feet at 600 rpm with a 26 inch disc and a 40 gpm flow rate. Power consumption was approximately 1250 watts with a 1 h.p. electric motor operating under full load. The wind constantly plagued the research effort. Vanes used and vane configurations made little difference in the spinner performance due to the misting effect.

Part 2 of the research showed that slurry could be spread relatively uniform with a spinner equipped with 8 alternate 8 3/4 inch and 11 3/4 inch sigma-vanes. The diameter of coverage with no wind was 54 feet for the 26 inch diameter spinner. The 20 inch diameter spinner performed similar to the larger disc with a 2 to 4 foot diameter of coverage reduction and a small drop in power consumed. A 5 h.p. motor is capable of handling a flow of 200 gpm with a 26 inch spinner equipped with 8 vanes of any type or configuration.