Compaction and Flow of Evaporated Salt from Bins and Hoppers

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ABSTRACT

Data on flow properties which may be used in design of hoppers and bins are given for evaporated salt. A graphical method of determining presures in a salt bin or hopper is presented. This sketch is useful in locating the most advantageous placement of flow-inducing devices. Air diffusion tests results on laboratory size bins are reported along with recommended air supply rates for improving the recovery of salt from storage.

INTRODUCTION

Several times in the past when designing hoppers, bins or retaining structures for use in salt, particularly food grades, reference has been made to Civil and Chemical Engineering texts. Most of the design equations in these fields depended on angles which defined the material. Information was available for the angular properties of many materials, but very little was found specifically on evaporated salt.

A study of the literature indicated a need to differentiate between free-flowing and caked salts. Therefore, this paper is basically divided into two parts: the first includes data on salt as a free-flowing material; the second discusses a treatment which allowed recovery of salt from a bin which would have otherwise been caked. As particle size and shape vary considerably between salts manufactured by vacuum pans, or by grainer and Alberger methods, and because these differences affect the data, most of the tests are given for one vacuum-pan salt and one each of the Alberger Flake and Fine-Flake salt.

DENSITY

For bin and hopper designs, the bulk density is of interest. A common method of determining bulk density is to loosely cascade the granular material into a standardized container and avoid any handling which might compact the powder. Often after weighing, this container is rapped, tapped or vibrated to settle the material. In the ASTN specification for sand compaction in concrete work, the material is compacted by rodding the sand a specified number of strokes while filling the container in three lifts.

Bulk density is given in Table I for three types of salt as determined by loose-cascading into the containers, rodding in place by ASTM methods and vibrating on an electric sander for five minutes.

CHARACTERISTIC ANGLES OF SALT

When the flow velocities are limited to those induced by gravity, granular materials exhibit lines of force which are usually measured by angles from the horizontal. Although often used in

Table I

BULK DENSITY OF SALT

Type of Salt	Loose Cascaded #/Ft.^{3}	ASTM (25 Roddings) #/Ft.^{3}	Vibrated 5 minutes #/Ft.^{3}
Flake (Alberger)	45.04	51.87	55.73
Fine-Flake (Alberger)	48.97	59.77	63.02
General Purpose Granulated	79.06	83.41	91.46

design applications and discussed in the literature, especially that of the petroleum industry, no common method of measurement or definition exists. Zenz and Othmer (1) correlated the literature in a useful manner and gave certain definitions and tests which we have applied to salt. For clarity of reference, their notations and definitions are used here.

These angles are specific for each type of material but the flow characteristics of a material become more difficult or impossible to predict as the material is compacted or compressed. The absolute characteristics of a granular material depend mainly on compaction and effect of moisture. The angle of internal friction is probably the most important but least determined of any of the five angles.

1. The angle of repose (β, beta) is most commonly seen and used. It represents static equilibrium between free solids and surrounding fluid (air). In general, the finer the material, the steeper the angle.

2. The angle of rupture (δ, delta) is the angle formed if bulk solids (not individual particles) slide (under gravity forces) against stationary solids. This is used extensively in civil-engineering under the name of "wedge of maximum thrust" and is of direct interest for design of retaining walls or bulk rock salt buildings. Most literature assumes this angle the same as the angle of internal friction. In some cases they are close, but in general the angle of internal friction is always higher.

3. The angle of slide (ω, omega) gives the absolute minimum slope and varies according to the manner of tests on salt. It is purely a measure of friction force between the grains and an inclined plate surface. A steel plate is commonly used. The material is always assumed as being in a free-flowing state, i.e., no caking present and no moisture effect.

4. The angle of internal friction (α, alpha) is the most important but least recognized and determined of the angles that represent properties in granular solids. It occurs in the most varied ways, and is often affected by other variables. It represents dynamic equilibrium between the moving particles and the stationary bulk solids as shown by the interface of the same while under flow.

   As the angle of internal friction is used in calculating the angle of wall friction, a correct determination of it becomes of use in any attempt to design bins, silos, and large containers. Several tests are outlined to determine the angle of internal friction. The results are given here following an outline of tests and manners in which the angle shows its effect.

   a. A glass faced case resembling a two dimensional cross section of a bin is filled with salt. Colored layers may be used to show the flow pattern better. As the center opening in the bottom allows free flow a photograph can be made or the glass face marked. A center core of material will do all the moving whether or not a cone effect is seen. The line between the moving core and the standing bulk material is clearly seen and is much steeper than the angle of repose. The angle between this standing line and the horizontal is the angle of internal friction.

      When a cone does form, the top plane of the bulk material will follow the angle of repose. Likewise, if wedging action occurs, it represents masses of material lumping down into the cone which are themselves the quantity of material lying between the angle of rupture and the angle of repose.

b. Another variation of this test consists of using a cylinder with a small hole in the flat bottom. When the material moves down, the top surface remains level until the angle of internal friction is reached, at which time a cone is formed. The length of the tube (bed height) where this cone first starts to form divided by the diameter of the tube gives the tangent of the angle of internal friction. The material was placed in the container loosely and not compacted or vibrated.

c. Another way to find the angle of internal friction is by putting loose material into a tube fitted with a removable piston without material going past the piston). The piston and bed may be easily moved up the tube until a critical height of material is reached. Once reached, and even an additional 1/4 inch of salt may make the difference, the piston cannot be run up the tube. Bed height divided by tube diameter gives the tangent of the angle of internal friction.

d. The angle of internal friction enters into the pressure at the base of a silo also. The pressure at the base will build up in direct proportion to the height of the bed of solids. This can be graphed as heights of bed versus pressure and will plot a straight line as the tangent of the angle of internal friction until the curve breaks upward and becomes a constant. Any change in this curve is related to the angle of wall friction and angle of internal friction.

5. Angle of wall friction (γ, gamma) is usually given as a coefficient of wall friction, i. e., tangent of the angle. A well-known text in this field is Ketchum's "Walls, Bins and Grain Elevators" (2). By the use of the coefficient of wall friction and the angle of repose, Wilfred Airy gave a tangent of the angle of internal friction. However this was verified only by tests in wheat and could be checked only by bin stress analysis. In actual practice it is probably not the best factor or design in salt, but if the lateral forces in bins were desired it is possible to use the relation of the angle of internal friction and angle of repose, as suggested in Zenz-Othmer,

Eq. 1 $$N' = \operatorname{Tan}\beta \left[\frac{1 = (\operatorname{Tan}\beta)^2}{(\operatorname{Tan}\alpha - \operatorname{Tan}\beta)^2} - 1 \right]$$

Where N' = Tan of the angle of wall friction
β (beta) = Angle of repose
α (alpha) = Angle of internal friction

to get an angle of wall friction. This in turn should be used with the Jensen (3) or Airy equations and a design procedure outlined by the Ketchum text used to calculate bin stresses. Also Merrits "Building Construction Handbook" (4) relates this design problem for excavation, backfill on a wall, etc.

The results of several of these tests follow, (see Table II) particularly with respect to determining the angle of internal friction for Alberger, Flake and Fine-Flake, and Granulated salts.

INTERNAL FLOW THEORY

An explanation of what happens internally during flow of a granular material was developed by Brown and Hawksley (5), which explains why caking is often in separate lumps within the containing vessel. Their work in combination with that of Osborne Reynolds who in 1885 developed the theory of dilitancy to describe the overall behavior of the granular mass, confirmed that two dimensional study of packings by photographing through a glass cross-section of a bin would be typical of the action of a three dimensional bed.

Reynolds showed that any deformation of a granular material, say by moving a wall or opening a gate, would cause the material to expand or dilate. This created movements of groups of particles which left gaps between regions of loosely and tightly packed material. Arching across the gaps by groups of particles also resulted from the deformation of the material. Sometimes the internal structure of the material collapsed and compaction resulted in certain regions.

Table II

ANGULAR PROPERTIES FOR SALT

Alpha (α) Angle of Internal Friction as Determined by Three Tests

Test	General Purpose Granulated α	Flake Alberger α	Fine Flake Alberger α
Bin Flow	77°	80°	80-3/4°
Tube and Small Orifice	63-3/4°	77°	80-3/4°
Piston and Cylinder	78-1/2°	85-3/4°	85°
Average suggested angle for use	77°	80°	81°

Beta (β) Angle of Repose as Determined by Bin Flow Tests

Test	β	β	β
Bin Flow Test	31°	39°	52-1/2°

Delta (δ) Angle of Rupture as Determined from Photos of "Dilitancy" Tests

General Purpose Granulated = 39-1/2°

Alberger Flake = 53°

Alberger Fine Flake = Unable to get test

Gamma (γ) Angle of Wall Friction as Calculated from Zenz-Othmer Equation

General Purpose Granulated = 30°-10'

Alberger Flake = 37°-03'

Alberger Fine Flake = 51°-44'

Omega (ω) Angle of Slide as Determined by "Tilted Steel Plate" Test

Note: Minimum angle = where first few grains move.

Maximum angle = where entire mass moves.

Salt	Minimum Angle	Maximum Angle
General Purpose Granulated	22°-09'	35°-53'
Alberger Flake	34°-45'	44°-55'
Alberger Fine Flake	40°-23'	60°-14'

These patterns of arches are not able to withstand forces from any direction. By spacing two plates approximately one to two particles apart with thin sheet aluminum, and by either tapping gently or moving one "wall" of aluminum, we could show that dilation of the bed created arches, gaps and zones of tight and loosely packed material.

Brown and Hawksley by two dimensional study confirmed the tendency for regions to become or remain tightly packed and developed an explanation of how flow develops from a bin. By building a glass-faced, 1 inch thick, 16 inch square cross section of a hopper and using alternate layers of dyed and white salt we were able to photograph flow and verify that the zones of flow as described by Brown and Hawksley's diagram of "pattern of flow" applied to salt.

The pattern of flow as exhibited by granular materials and confirmed in salt tests is given below. (Figure 1) On starting, this flow occurs entirely in the region of opening and the top

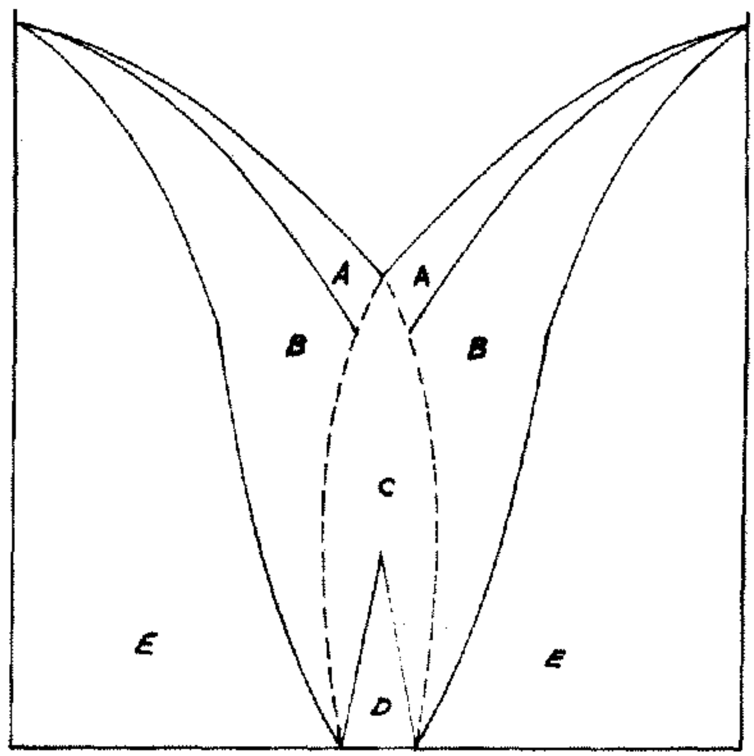


FIG. 1. BROWN & HAWKSLEY'S "PATTERN OF FLOW"

layers do not move until considerable dilation of packing occurs. In the following description of flow the numbered observations are not to be construed as occurring consecutively.

1. On top surface particles roll on layer A.
2. A slides as group over B.
3. B slides as a group over E (more slowly).
4. Lines remain constant and exceed angle of repose.
5. C is fed from A and B.
6. C feeds into tongue D which flickers.
7. Speed in D is highest but is only at speeds of approximately 1/100 free fall velocity.
8. Flow is symmetrical and asymmetrical and always irregular.

9. Flow ends by C shrinking and A feeding directly into D.

10. E may or may not feed down to the angle of repose of the material.

Because arches cannot resist forces from any direction, the usual result of flow from a hopper or bin is settlement and compaction due to the weight of overlying material. Compaction and resultant pressures are also affected by the walls which usually inhibit settlement. To differentiate between a hopper and bin we are referring to the parts separated by the junction where the wall angles change. However, the material usually makes it's own "natural" hopper regardless of where we junction the hopper and bin walls. This is not too important if we can derive an estimate of what pressures to expect for design purposes. Of use also is an equation to predict salt flow through the orifice or pipe.

EQUATIONS TO PREDICT FLOW THROUGH AN ORIFICE OR PIPE

There are several equations available to predict the quantity of salt through an orifice or pipe. After trying several of them and comparing them to salt flow from a steel experimental tank in the lab, we found the following to be simple and give reasonable and slightly conservative values for flow through a cone bottom hopper.

Equation by "Gregory" (1) for stick-slip downflow of powder in pipes:

Eq. 2 $$W_A = 0.278\, D_o^{2.5}$$ Where W_A = solid flow, lb./sec.

D_o = diameter of orifice, in inches

An alternate equation which takes into account the head of material is "Newtons" (1):

Eq. 3 $$W_A = 0.1416\, D_o^{2.96}\, H_s^{0.04}$$ Where H_s is in feet of material above orifice, D_o in inches, and W_A is in lb./sec.

This equation is intended for use with flat-bottom bins and a central orifice, such as silos, and therefore gives lower values than the "Gregory" equation above.

A very complete discussion of the subject may be found in Zenz and Othmer (1), "Fluidization," Chapter 4. There, a more complex table is given which takes into account such factors as gravity effect, bulk density, slope of hopper wall and ratio of orifice to particle diameter.

DESIGN PRESSURES

To estimate the pressures which are ultimately needed for design of hoppers, bins, etc., the usual practice is to consider the material as developing pressure "hydrostatically," or to use angles as defined above and apply them to Coulomb or Rankine (4) formulas. A third approach which allows a simple sketch to be drawn at the time any particular container is under consideration was recommended by Andrew Jenicke (6) based on work at the Utah Engineering Experiment Station. As Jenicke's work was done with sand and ore, it was necessary to develop gauges, confirm that the trend of his work could be applied to salt and still be conservative enough to be safely used in salt. The pressure at the centerline is taken as representative of pressure throughout the bin. If the salt is subjected to pressure it will build up strength, and on opening the gate the salt will form arches due to a change of support conditions. At this point the material can only flow if the stresses on the arches are high enough to break them, otherwise "doming" will occur. This pressure sketch will also indicate where a dome is most likely to occur, and alternately the best location for mechanical flow inducing devices.

This report will discuss the tests used and show the difference for water, sand, and salt and includes plots of the tests with salt and an explanation of Jenicke's results which allows a simple generalized diagram to be used to find the pressures created by salt in a bin and/or hopper.

The build-up of pressure within the bin portion is different than within the hopper. As layers of salt are piled up the pressure increases uniformly with the depth, due to the weight of the overlying mass, provided there are no side wall effects or restrictions. Also at some depth or other the material will subside and compact. This subsidence is restricted at the walls but if we consider the pressure in layers at the center a good indication of the over-all pressure at a certain depth, we can then measure this pressure (lb./sq. ft.) by guages, and if divided by the density of the material (lb./cu. ft.) a linear dimension (feet) results. This is analogous to the head created by depth of fluids. Therefore the greater this pressure deviates from hydrostatic, the less the compaction experienced and consequently the better the flow-ability of the material.

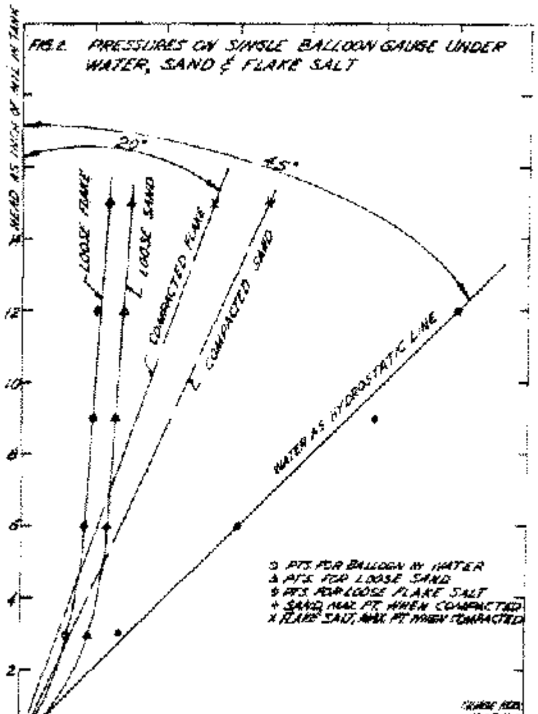
HOPPER PRESSURE

For hoppers alone, the pressure curve formed by plotting this "unit pressure" as abscissa against height of material (h) started at zero on the top of the material and went to zero at the extreme theoretical point of the hopper. Jenike's work in sand gave a family of curves at (α, alpha) 45° off the horizontal at the top and a different angle (ψ, psi) at the bottom which varied with the shape and size of the hopper and the material used. As the hopper portion of experiment was not run in salt, Jenike's conclusions will be presented directly. Assume that fresh material will form a natural crater of approximately 60-65°.

If the hopper slope is between 0° and 55°, a natural crater may or may not form but the pressure on the opening gate is usually hydrostatic and therefore equal to the head of material. As the hopper slope rises to between 55° and 85° the wall influence increases and improves flow conditions, in this range a natural crater should not form. These pressures are for the hopper portion only, as the material above the junction of straight and slope walls has little or no effect on pressure in the mass or on the resulting rate of flow through the hopper.

CALIBRATION OF GAUGE

Our tests utilized inexpensive pressure measuring devices instead of strain gauges. A balloon was attached to a copper tube taped to a glass tube. This gauge was placed level on the flat bottom of a tank and filled with colored water until water stood in the glass tube and any changes of pressure on the balloon were reflected as changes in elevation of water in the glass tube. (Figure 2)



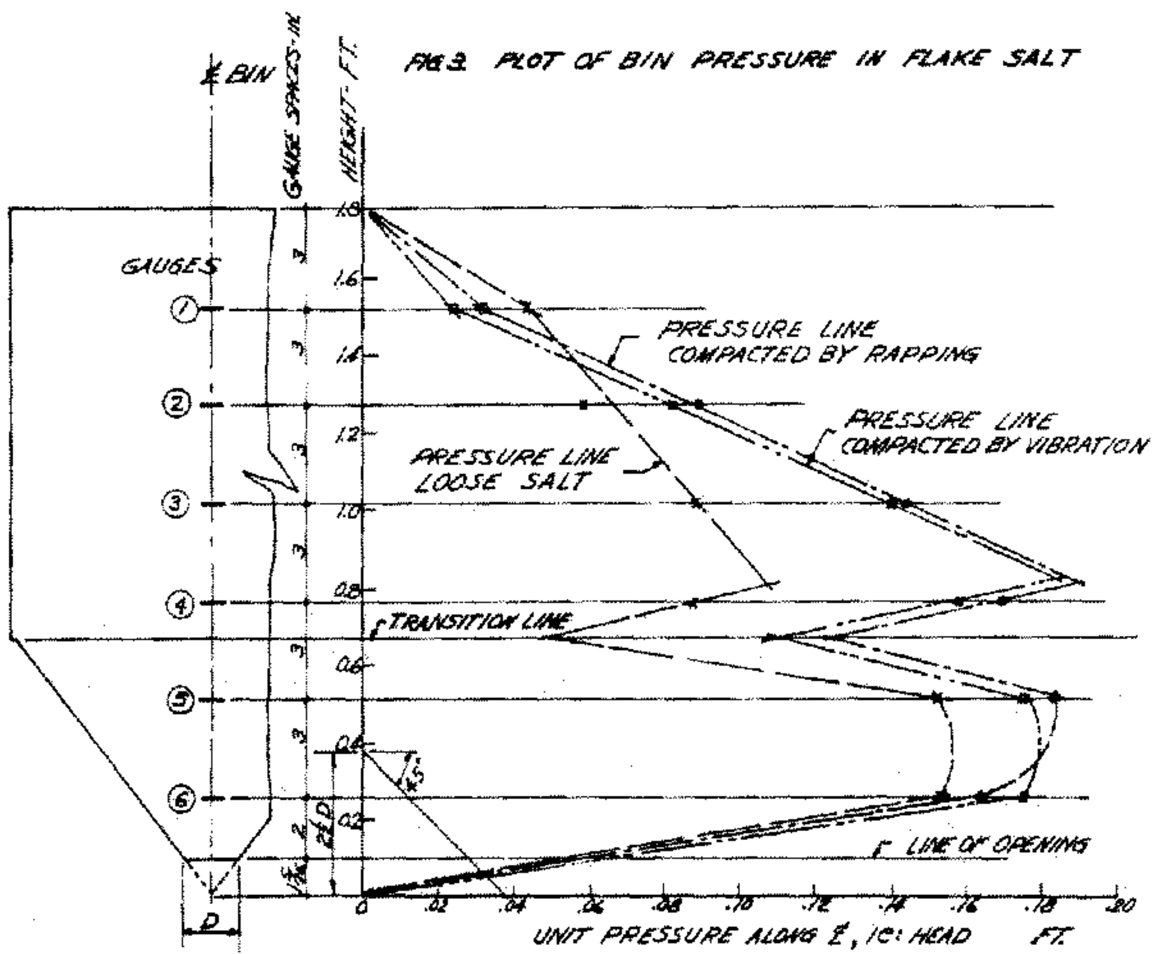
The tank was then filled with water to a known elevation above the balloon and water pressures calculated to compare with changes of head in the gauge. This gave a correction factor for the balloon gauge by using water as hydrostatic medium (45° line). Following this the tank was filled with mortar sand, both loose and compacted and then with Alberger Flake salt, loose and compacted. Lastly, brine was added to the bed of salt.

These tests when plotted show a rapid build-up of the pressure for salt and then a quick leveling off. The highest angle for salt (compacted) was approximately 20° (30° in sand) compared to 45° for water. On considering the change of density of the material due to compaction from 45 lb./$ft.^3$ to 60 lb./$ft.^3$, and a 30° angle compared to water at 45° and 62 lb./$ft.^3$, it seems that a natural safety factor of 1.5 exists by using the hydrostatic line to predict build-up of pressure. In granulated salt this safety factor drops to 1.0 due to weight changes from 60 lb. to 90 lb. Therefore a bin for granulated should have the design pressures multiplied by 1.25 or more for safety.

BIN MODEL TEST

To graph the pressures within the vertical portion of a bin, a tank was made from an eight inch funnel fastened to a five gallon pail. Six balloon gauges were connected through the sides of the tank. Jenicke's report claimed sand was hydrostatic in its action but we could not confirm this directly due to small size and wall effect (Figure 3). However, by plotting our data for sand and salt against a scale expanded by 10 to 1 on the horizontal the typical pattern of pressure along the angles as given by Jenicke was apparently true for the mortar sand, Alberger Fine-Flake and Flake salt. Therefore, we feel Jenicke was correct in using the 45° line (i.e., hydrostatic as a good indication of pressure build-up.

FIG 3. PLOT OF BIN PRESSURE IN FLAKE SALT



Note that there is a distinct drop-off at the transition line from bin to hopper. If the opening of the hopper were large, and high enough up on the hopper to be above the center of the hopper curve, the pressure build-up could be sketched by 45° lines for each.

DRAWING OF A PRESSURE CURVE

In drawing a pressure curve for a given type of salt, the difficulty is to locate the starting point of the 45° line. However, other experiments have confirmed Jenicke's claim that pressure is nearly a constant at a distance of 2 to 3 diameters below the top, therefore, using 2 1/2 diameters to locate peak pressure points and enclosing the lines at 45°, a generalized diagram of the pressure (Figure 4) along the centerline in any combination of bin and hopper can be shown. It is important to note that these pressures referred to are the compacting pressures that contribute to arching in the salt and are undesirable.

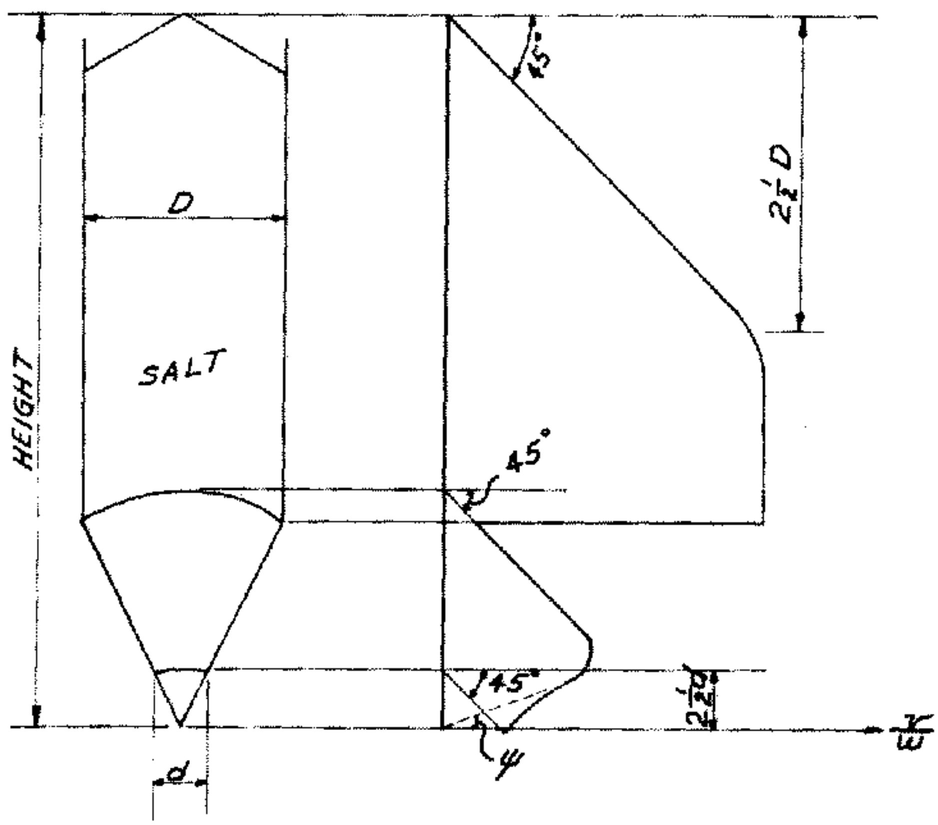


FIG. 4 JENICKE'S GENERALIZED PLOT OF PRESSURES IN A BIN

Because separate pressure tests for hoppers alone were not run, the angle (Ψ, psi) (off the bottom horizontal) was taken from the pressure curves of Fine-Flake and Flake. From the graphs the angles varied from 10°-30°, therefore if 20° were used for the angle (Ψ), the pressure in the hopper may then be compared directly with the pressure in the bin.

Another use for this pressure graph occurs in predicting where the pressure will be highest within any given bin and hopper, and consequently where arching of the material will occur. By using 45° lines for simplicity in the diagram and comparing the pressure peaks with the height of the portions of the tank and bin, it also shows the best locations for devices to break arches and promote flow. In general, if the height of the hopper portion of a bin is greater than the height of the bin portion, doming will occur at the hopper outlet region. If the converse occurs, doming tends to occur at the transition joint.

PROCEDURE TO SKETCH PRESSURE ALONG CENTERLINE OF SALT BIN

1. Draw schematic of bin and heap material to angle of repose on top as zero pressure point.
2. Draw vertical reference line. Salt builds up at less than a 45° hydrostatic, but use 45° line for safety factor.
3. Stop at 2 1/2 X diameter down from top and draw pressure line vertically down from there to intersection of hopper and bin.
4. At this point sketch the hopper sides on figure to slopes desired and extend to the theoretical point.
5. As the hopper pressures are relatively unaffected by pressure above in the bin, sketch the material in place above the hopper and start at zero pressure here also. Project this point to the vertical reference line.
6. Return pressure drop off line (between hopper and bin) to left horizontally to meet a junction point with the 45° hopper pressure curve as sketched in 5 above.
7. From theoretical point of hopper, sketch up to right a line of pressure on angle (ψ) from the horizontal and round off the intersection with the hopper pressure line coming down from top of hopper.
8. Mark line of opening on hopper and project across to diagram and start 45° line down to the right. Thus treat pressure above opening as increasing hydrostatically above the gate.
9. Connect the 20° pressure line from point equivalent to pressure on the opening down to the 45° pressure point.

PRESSURE ON THE BASE

In using this pressure graph as developed by Jenicke, one should try to keep the peak pressures below that which occur on the opening. Most mechanical devices have been unsatisfactory in salt if caking occurs, but any such method is aimed at preventing or breaking arches. Although bin design is not an exact science most of the literature seems to be in good agreement. Smith (3) of Cornell University devised mathematics for prediction of base pressures and showed good agreement between prediction and measured results using polystyrene cubes.

The pressure diagram and comparison of height of bin versus height of hopper indicate where failure will occur (if it does) in the bin or hopper being designed. The question then is how to predict whether or not, at this particular depth in the hopper, arching of the material will stop flow. Work in bin and silo designs is usually based on the Jannssen (3) equation for vertical sides and flat bottomed containers. As a change from vertical to sloped sides is made, the base pressures have been recorded as both greater and less than the Jannssen equation predicts. The change varies with the slope angle, and the pressure on the side and base is usually greater because the sides carry more than their proportional load in a sloped hopper, therefore the Jannssen equation is no longer sufficient.

Smith's work agrees with Jenicke's as to a plane of failure existing in a hopper and gives a mathematical approach to determine pressure at a given depth in the material. Smith further claims all bins with vertical walls (±5°) may be treated by the original Jannssen equation. Therefore as pressure is constant on the base, the rate of flow from tall, flat bottom containers varies with the exponent of the diameter of the opening.

Flow rate changes entirely with hopper bottom containers where the lateral pressure remains nearly constant but the vertical pressure on the opening rises when flow is shut off and falls when the gate opens. As a general rule all openings should be a minimum of ten times the maximum particle size, and for the coarsest salts a base pressure calculated from the Smith equations should be at least 10-20 lb./ft.^{2}. For evaporated type salts the pressure at the opening preferably should be 50 lb./ft.^{2} or more.

EFFECT OF HEIGHT OF SALT IN BIN VERSUS RATE OF DISCHARGE

The statement that the rate of flow is not affected by the height of the material in a bin, or slightly so, has been made several times. Conversely, that the pressure in the hopper portion of a bin is slightly affected by the material in the bin above has also been made. To confirm this and also point out where the natural hopper effect comes into play, i. e., a height determined by multiplying the tangent of the angle of internal friction by the inside diameter of the bin or tube, the following data was taken with a 4 foot long, 4 inch I.D. glass tube. For this particular tube and salt the effect of the natural hopper occurs at 16 inches above the base. A flat bottom was used with a 3/4 inch diameter opening. Note that when the material flows out from the bottom and is timed by a drop in elevation of the top surface, one is really timing the speed of a one foot depth of salt at the bottom which is under a certain head of material above it. In effect one then gets the average at the six inch marks, for each overall foot of length of the tube.

Flake salt, both oven-warmed and at room temperature, was used and the data are given below. (See Table III)

Table III

EFFECT OF SALT HEAD ON FLOW RATE

Flow Quantity / Elevation	At 4 ft. level	At 3 ft. level	At 2 ft. level	Into range of natural hopper at 1 ft. level
Warm Flake	62.8 gm/sec	58 gm/sec	58.2 gm/sec	56.3 gm/sec
Cool Flake	62.4 gm/sec	59 gm/sec	59 gm/sec	57.5 gm/sec

EFFECT OF HOPPER SLOPE ON DISCHARGE RATE

A Mr. Yee Lee (7) of the Taiwan Power Co. in China developed a design for hyperbolically curved hoppers which decreases the lateral friction and increases the downward component of pressure. The downward pressure is kept uniform through the outlet by balancing two major factors of design: one, the rate of contraction, i.e, (area change) per foot of descent and two, the variation of wall friction per foot of descent. He claimed that on low-grade coal, such a hopper was successful when vibrator-equipped, 70° stainless steel hoppers failed to flow.

To test this and other common hopper slopes in salt, the glass front bin was refitted with wood blocks of varying slopes which in effect converted it into different hoppers (Figure 5).

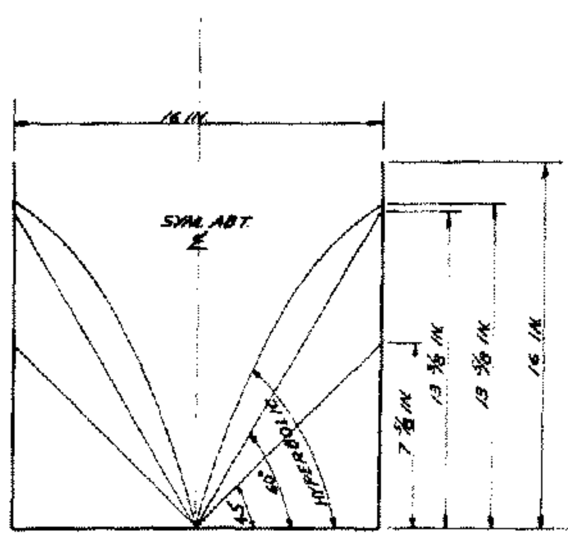


FIG. 5. HOPPER MODIFICATIONS OF 1 IN. DEPTH CASE

Precautions to avoid any effect of caking or lumps in the salt were taken. A description of the test and the data expressed in terms of rate of flow, and as a percentage recovered of the original quantity put in the bin follows.

A vertical 16 inch square, 1 inch depth, plywood case was faced with plate glass. A flat 1 inch wide strip of aluminum metal with a 1/2 inch square opening at the center was placed on the bottom of the case. A removable plug was placed in the bottom and the case filled level with salt from a funnel mounted to discharge at top center. The side areas of the cone of salt were filled until the case was level. One-inch-thick wood blocks cut to different angles were placed in the corners so that the bin was changed into a hopper with sloping sides.

The quantity of salt placed in the case and the time to run out were taken for 0° (flat bottom, no block), 45°, 60°, hyperbolically curved and hyperbolically curved with aluminum skin facing. These tests were repeated for Granulated, Flake and Fine-Flake salt. All salt was warmed at least 2 hours in the oven, screened, and thus dry salt was used throughout the tests (see Table IV).

When the first series of tests were run the 0° and 45° hopper trials were allowed to fill to a natural angle of repose but the corner of the case was not filled until 60° and hyperbolic runs were made. This was because the latter two types of bin pieces filled the bin corners nearly to the top while the 45° cover filled the case only to the 7 3/4 inch height.

STORAGE CAPACITY FOR VARIABLE SLOPES IN HOPPER

The objection often given to increasing the hopper slopes is that a loss of storage capacity results. The volume available and quantity stored varies considerably with the bulk density of the various salts. Therefore the same case and hopper bottoms were used to show the change in storage capacity or hopper weights that resulted from changing the hopper slopes (see Table V).

AIR USE TO PROMOTE SALT RECOVERY FROM BINS AND HOPPERS

A study of the effect of diffused air on the reclaimability of salt from model bins was made in order to obtain design data for large bins. Two lab-size bins were constructed. One was 16 inch square wood with a four sided, 60° hopper and the second was 16 inch diameter round steel with a 60° cone hopper. Both held 200# of salt with half of it in the top section. Tests showed the steel cylinder, as expected, had the best flow characteristics and flowed in the pattern indicated by Brown and Hawksley's diagram of internal flow. Arching was apparent in the corners of the square wood bin.

Vibration and resultant compaction showed that salt could be prevented from flowing by this alone. Another test showed that under the best of bin characteristics, 0.1% artificially added moisture on any salt was sufficient to cake the bins and prevent flow within 2-24 hours.

After considering numerous devices to promote flow as described in the literature, a test was run with a perforated copper sparger in the tank. Salt of 0.1% moisture could be recovered in 24 hours and it was found that the air would follow the walls and neutralize the "corner effect" so common in square bins.

As the air quantity used was small, in the range of 0.3 to 1.2 C.F.M. per 100 lb. of salt at 70° F. and 20% relative humidity, 8 oz. pressure, (approximately 1 C.F.M. per sq. ft. of surface) it could not dry the salt which had been deliberately moistened to 0.1%. By keeping the tank completely sealed, with a vent at the top center, the slight pressurization helped the air diffuse through the salt. As a result of the natural tendency of the salt to pull away from the sides of a bin the central mass of salt was not aereated and better results were obtained by "using" a porous metal core as a central diffuser. The air flow was increased from 0.3 to 1.2 C.F.M. and at the same time "Flo-Bin" (trade name) diffusion pads were added on the lower side of the hopper slopes. Under this combination it was possible to recover salt from the wood tank after two weeks storage where previously it had refused to flow within 2-24 hours. Although one rap was required start flow of the above wood bin, the steel bin used as a control with no air supply was solidly

Table IV

SALT RECOVERY TESTS THROUGH HOPPER BOTTOMS OF VARIED SLOPES

Quantity / Salt	0° Slope		45° Slope		60° Slope		Hyperbolic (wool face)		Hyperbolic (Alum. face)	
	gm/sec.	% Recovered	gm/sec.	% Recovered	gm/sec.	% Recovered	gm/sec.	% Recovered	gm/sec.	% Recovered
Granulated	46.8	77.4	42.6	100	49.2	100	53.8	100	-	-
General Purpose	42.3	84.1	45.5	100	45.4	100	50.0	100	43.4	100
Flake Alberger	26.2	74	24.2	100	29.0	100	27.6	100	25.8	100
	23.8	80.4	27.6	100	25.8	100	27.8	100	26.3	100
									26.8	100
Fine Flake	24.4	64	20.5	100	26.4	100	28.0	100	30.7	100
Alberger							28.9	100	31.5	100
									31.0	100

Note: All test slopes were of sanded wood face except hyperbolically designed bin with smooth aluminum facing.

Table V

PERCENTAGE CHANGE IN HOPPER STORAGE (1" cross section)

DUE TO VARIED SLOPES

Type of Hopper by Slope Angle from Horizontal	Granulated Salt	Fine Flake Alberger	Flake Alberger	Comment
0°	100% (5244 gm)	100% (3709 gm)	100% (3200 gm)	Flow out to natural angle of repose only.
45°	83.4%	81.5%	84.8%	
60°	66.6%	64.0%	66.6%	
Hyperbolic	60.6%	58.0%	60.6%	
Hyperbolic with Aluminum Skin	58.7%	58.0%	59.8%	

Note: Hopper filled level full and struck off in all cases.

caked and had to be completely poked out. We therefore concluded that careful design and placement of any flow-inducing air devices would insure recovery of salt from bins over longer periods of time than would be the case for untreated storage.

SUMMARY

We feel the research presently being done by industry will eventually lead to a scientific method of designing holding vessels for granular materials based on the properties of the individual powders. Although these tests need refinement and further study to find application in the salt industry, we feel the use of Jenicke's sketch to describe pressures anticipated along the centerline of a bin should aid in placement of mechanical or air diffusing devices which in turn may substantially improve recovery of salt from storage tanks. Although this work has been on a laboratory scale, we also feel that the trend to bulk handling in the industry will encourage more study and large scale tests along these lines in the future.

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