# Design Review of Conical Stockpiles Comparing Mass Flow Hoppers and Vibratory Dischargers

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## Summary

Vibratory dischargers to reclaim material from under a stockpile have been widely applied in the coal industry and are claimed to have a higher efficiency than mass flow hoppers. There is currently an increasing trend to install vibratory dischargers in the heavy minerals industry such as bauxite and iron ore.

Observation of installations gives rise to concerns regarding the predictability of the actual live capacity which can be expected from vibratory dischargers. Usually such claims overestimate the actual live capacity which is achieved particularly where the use of mobile equipment is used to assist with reclaiming the material during normal operations.

Experience to date shows that the flowrates from a vibratory discharger are adequate to achieve current production rates but may be at their maximum possible at this stage of their development and will require multiple units to achieve higher production rates. Mass flow hoppers have the potential to achieve much higher production rates than a single unit.

This paper attempts to make an equitable comparison between mass flow hoppers and vibratory dischargers under a simple conical stockpile for reclaim efficiency and maximum flowrate. The hopper geometry is identical for both concepts but for comparative purposes the hopper size is larger than currently installed vibratory dischargers in the minerals industry and the mass flow hopper is smaller than possible and the shape restricted to a cylindrical hopper.

The calculations made to compare the two systems are taken from methodology published in technical literature and from observations made at a number of actual installations in Western Australia.

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## 1. Introduction

Conical stockpiles are economical to construct. The material may be totally reclaimed using mobile equipment such as front end loaders discharging to a reclaim hopper. Such an arrangement would have a low capital cost (excluding cost of mobile equipment) but a high operating cost but there is a safety risk reclaiming with front end loaders from a large pile due to overhang of very sticky materials.

Other methods of reclaiming use dozing to a central discharge hopper under the centre of the stockpile. A disadvantage of this concept is that compaction by the dozers could totally bridge the discharge hopper opening resulting in production delays.

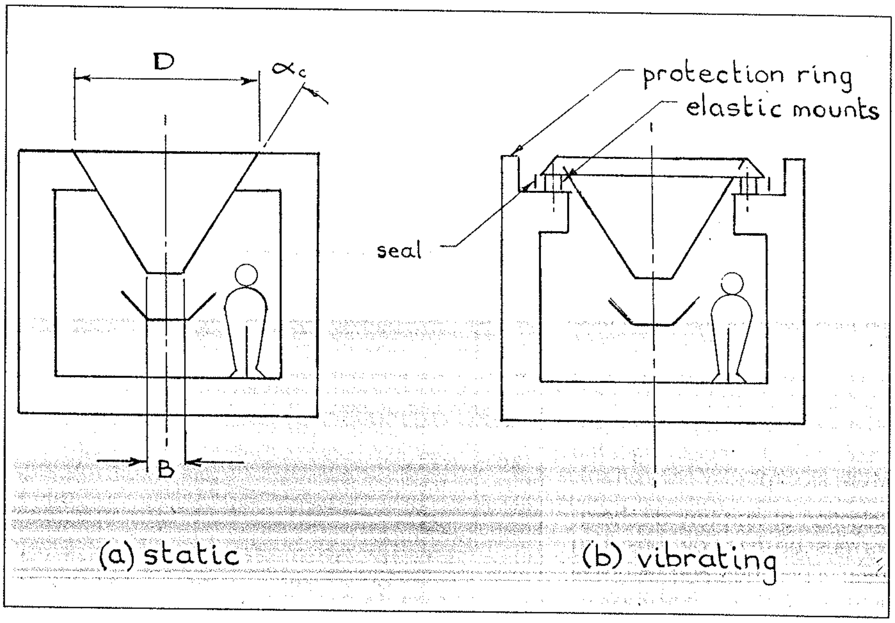
The design of the central discharge hopper under the centre is to maximise the live volume of the central crater avoiding bridging without increasing the risk of the dozing equipment falling into the crater causing production delays.

Conical stockpiles can be totally mechanised to reclaim all the material using circular stacking and reclaim equipment. This is a high capital cost with low operating costs depending on the maintainability of the equipment. This concept is not discussed in this paper.

An optimum conical stockpile design would be achieved if the central discharge hopper is designed to obtain a live capacity for normal operating requirements without the need to use mobile equipment and have a total on the ground capacity to meet strategic needs which is reclaimed by mobile equipment.

This paper looks at two options available for central hopper design to maximise the live capacity of the stockpile (a) using a circular discharge hopper designed as a static mass flow hopper and (b) using a vibrating stockpile discharger with similar hopper geometry. This similar geometry allows a reasonable comparison of the advantages and disadvantages of these concepts.

Fig. 1: Discharge hopper geometry



## 2. Stockpile Discharge Hoppers

### 2.1 Static Mass Flow Hoppers

A circular mass flow hopper is designed in accordance with the methods shown in JENIKE [1] and TUNRA [2]. Fig. 1a shows a typical arrangement with the hopper inlet flush with the top of a reclaim vault. The hopper half angle may range from 15 to 30 degrees and the hopper diameter *D* up to 10 m and more. The hopper half angle and the lining is selected to ensure that mass flow occurs for all conditions and requires that the material be tested for its flowability properties. The rathole crater may then be determined for a given stockpile height and required live capacity.

Observation of some existing operating stockpiles indicates that the theoretical approach using [1] and [2] underestimate the live capacity significantly.This may be due to the testwork being undertaken on a worst case condition that may not represent the material for most normal operating conditions and a degree of uncertainty in estimating the actual rathole discharge angle Testwork does not provide a means to quantify this parameter but it is usual to recommend an angle between 5 to 10 degrees. Also there is a phenomenon known as pressure dip (lower major consolidation stress) at the centre of the stockpile when the pile is active, BLIGHT [11].

A number of observations on stockpiles for specific bulk materials in the heavy minerals industries indicates that the actual rathole diameter may be twice that predicted by the traditional theory and similarly, an increase in the drawdown height.

### 2.2 Vibratory Dischargers

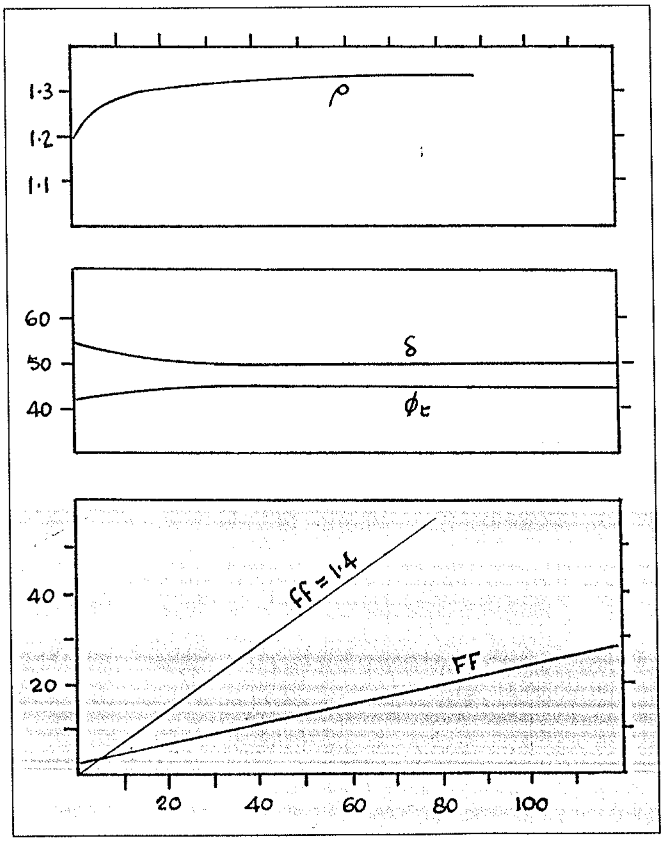
A discharger is usually designed and supplied by a proprietary manufacturer. Fig. 1b shows a typical arrangement. The figure shows that it must be sealed against ingress of material into the elastic supports which also need to be well drained to divert water and a protection ring must be installed to protect the discharger from mobile equipment when reclaiming the whole stockpile

Selection of vibratory dischargers must be made by consulting the manufacturer and technical literature for details and applications, DUMBAUGH [3]. However, from a conceptual point of view they may be considered as standard vibratory feeders arranged in a circular form and in this sense the vibrational effect on the material in the stockpile is similar with the upper cone ring of the discharger inducing vibrations more positively into the stockpile. It is recommended that the discharger vibrates cyclically. The periods of on-cycle and off-cycle are determined during commissioning. However, the discharger must never be allowed to continuously vibrate as this will compact the stockpile unnecessarily and restrict flowrate and live capacity.

Observation of existing stockpiles operating with vibratory dischargers indicates that the standard methodology from the manufacturer's literature tends to overestimate the live capacity of the reclaim crater. This may be due to the compacting effect of the vibrations, the rathole geometry not being a single angle (DUMBAUGH [3]) but a multiple angle similar to the JENIKE [1] and TUNRA [2] theory.

The geometrical shape of the crater is similar to the traditional mass flow approach but there is an increase in the rathole diameter and the drawdown height due to the induced vibrations in the stockpile. Observations suggest that the actual rathole diameter may be three times the value predicted by the traditional theory and similarly, an increase in the drawdown height.

Fig. 2: Material flow properties



## 3. Live Capacity

By way of an example to compare a static mass flow hopper and a vibratory feeder a typical bulk material is assumed for which testwork gives the following flowability properties, refer Fig. 2.

Bulk density $\rho$ = 1.3 t/m$^3$
Effective angle: $\delta$ = 50°
Static angle of friction: $\phi_t$ = 45°
Wall friction
stainless steel: $\phi_w$ = 15°

From these results the following parameters are selected from JENIKE [1]

$$G(\phi_t) = 4.3 \quad \text{and} \quad H(\alpha) = 2.45$$

For the purpose of comparison the above factors and the following hopper geometry were taken with an appropriate liner material for wear properties and a low friction for mass flow. Selection of the liner material is critical for the boundary conditions, [4], [5], [6] and [8].

Outlet diameter: $B$ = 0.9 m
Inlet diameter: $D$ = 4.5 m
Hopper half angle: $\alpha_c$ = 30°

For a conical stockpile height of 24 m, (Fig. 3), the crater geometry calculated in accordance with JENIKE [1], TUNRA [2] and ROBERTS and TEO [7] and the results are shown in Table 1. The JENIKE method is taken as the conventional base case. However, observation indicates that the actual crater may be larger by up to a factor of 2 for a circular mass flow hopper while for a vibratory discharger the factor may be in the order of 3.

It can be seen from Table 1 that the induced vibrations into the stockpile increase the live capacity by over a factor of 2 for the most optimistic live capacity for a static mass flow hopper

## 4. Flow Rate

### 4.1 Mass Flow

#### 4.1.1 Static Hopper

For a mass flow hopper the flow rate can be estimated for a given outlet diameter *B*. For the above data the flowrate is estimated as follows:

| | |
|---|---|
| $B$(min) = 0.5 m | no flow/flow boundary |
| $B$ = 0.9 m | 3,200 m$^3$/h |

#### 4.1.2 Vibratory Discharger

The flowrates achieved for the vibratory discharger during the off cycle are the same as the static hopper case.

| | $D_f$ [m] | $H_d$ [m] | Reclaim angle [°] | Crater volume [m³] | Eff [%] |
|---|---|---|---|---|---|
| Theoretical | 3.7 | 3.4 | 0 | 400 | 1.5 |
| Observation | 7.4 | 6.8 | 10 | 2100 | 7.0 |
| Discharger | 11.1 | 10.2 | 30 | 4800 | 16.0 |

Table 1: Results of crater geometry calculations

## 4.2 Funnel Flow

### 4.2.1 Static Hopper

If conditions exist which change the material flow properties then funnel flow conditions will prevail and reduce the live capacity and the flowrate for the static hopper and the vibratory discharger during its off-cycle.

Observation indicates that the flowrate could be reduced to between 40% and 60% of the theoretical mass flowrate calculated in 4.1.1.

The live capacity for the static hopper will be reduced because the rathole will initially be generated from the outlet diameter *B* and not from the inlet diameter *D*, depending on whether the hopper half angle is sufficiently steep to allow self cleaning of the circular hopper. If not, then flow inducing devices will be required to maintain the live capacity.

One such device is to retrofit a vibrating bin activator to the hopper. This device brings the concept very much closer to vibratory dischargers. However, these devices are not discussed in this paper.

### 4.2.2 Vibrating Hopper

The vibratory discharger, in effect, comes with a built-in flow promoter, a hopper vibrator. The flow rate is reduced as for the mass flow hopper during the off-cycle. On-cycle flow rates are not known but continuous operation is not recommended. However, the vibrations will maintain the live capacity.

The vibrating discharger provides some insurance if the material flow characteristics change unexpectedly but has no advantage if maximum flowrates are required for a given hopper geometry.

For excessive flowrates above requirements, both the static hopper and the vibratory discharger need to have the flowrate controlled by a feeder device such as belt feeder installed under the outlet. A cut-off gate would also be required for maintenance purposes.

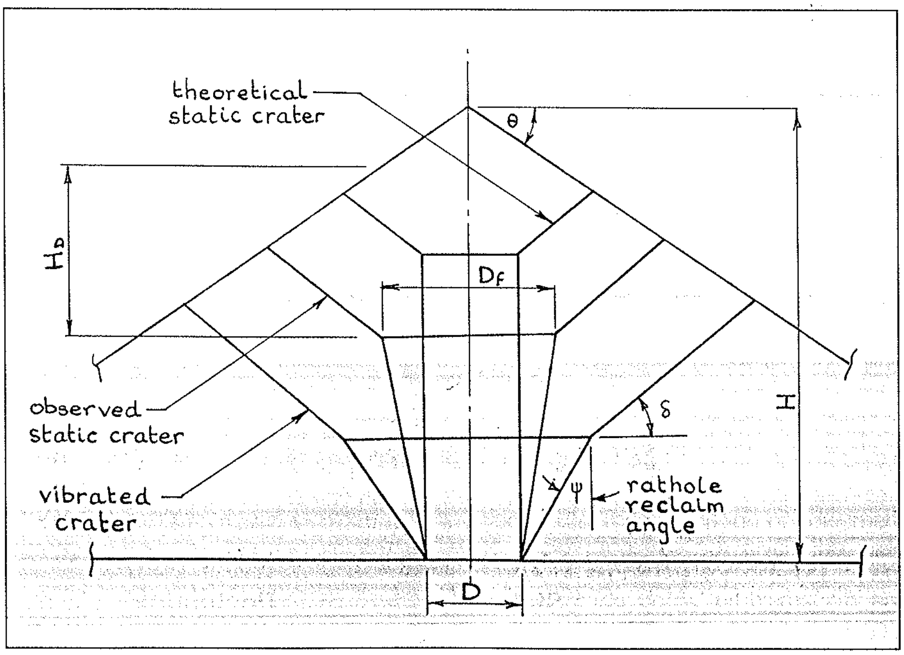
## 5. Concluding Remarks

For both the static hopper and the vibratory discharger it is important to design the hopper geometry for mass flow for the worst case material flow properties. To make sure that mass flow conditions will exist, stainless steel or heavy duty polymers may need to be considered as a liner material as they usually exhibit lower wall friction parameters than abrasive resistant alloy carbon steels. Abrasion resistance must also be considered but wear life parameters are more difficult to quantify and this usually requires extensive applications experience. Other techniques that may be considered are air or water films to reduce wall friction in order to promote flow on start up for borderline mass flow criteria.

The results obtained from the above comparison when the hopper geometry is identical shows that the vibratory discharger will have the larger crater geometry and hence greater live capacity.

However, vibratory dischargers observed do not have as large an inlet diameter *D* whilst static mass flow circular hoppers could be made larger. The static hopper may also be of the plane type with a slot length at least 3 x the width but the disadvantage of this concept is that an expensive belt or apron feeder is usually require to be installed under the hopper to control the flowrate. Gravity loading of unit trains requires high flowrates and, in this case, a planeflow hopper may be an advantage, MATON [10].

Fig. 3: Reclaim crater geometry



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