Investigation into flow rate characteristics of bulk materials through a Hopper

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Abstract: Hoppers/ Silos are material handling devices used for storage of bulk materials. The term bulk material refers to granular or lumpy mixture existing in a free flowing form. Bulk materials of different sizes have different flow characteristics. Flow of bulk materials through a hopper/silo depends mostly on bottom gate opening, flowability of the material, slope angle of the inclined supporting walls. Experiments have been carried out on a model hopper with a rectangular gate at bottom. The effects of all the parameters on the rate of flow of few bulk materials namely stone chips, dry sand and full wheat grains through rectangular gap of rectangular slide gate valve have been determined and analyzed. The lowest bottom gate gap widths at which flow almost stopped have been observed for above materials.

Keywords: bulk material, hopper/silo, gate valve, flowability, flow rate, slope angle, rectangular gate

I.Introduction

Storage and handling of bulk solids form an important aspect of materials handling both in the process industries as well as in agriculture.

Bulk materials which cannot be stored in open pile storage are either stored in closed and large containers like Bins/Silos/Hoppers or in the floor under sheds. Materials with poor flowability or which are friable and thus don't lend themselves to bin/silo storage are stored on floor under sheds. Most of the bulk materials like grains and industrial raw materials like woodchips, crushed stones, gravel, sand, coal, ashes, salt, clay, cement and gypsum to mention only a few representative products are stored in bins and silos [1, 2, 4].

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The major advantage of storing materials in bins/silos is ease of controlled discharge of the stored materials from the bottom through suitable gates provided at the bottom opening of these storage units, with or without the help of various feeder units [1, 3, 5].

The major influencing factor on the flow of bulk solids from silos is the flow behavior of bulk solids itself. Since many different bulk solids are stored in silos, it is very important to describe and determine the flow characteristics of respective bulk solids through discharge gate of a silo.

Gates are used in conjunction with various bulk materials storage bins and silos to close or open the outlet and adjust rate of discharge of materials in batches from the bottom [1-6]. According to the principle of operation, gates are divided into three main types:

Slide Gate: It is a flat plate valve which slides in guides and is actuated by hand or motor operated rack-pinion or lever mechanism. The shape of the sliding plate valve is normally rectangular. The design is simple but under material load, it may be difficult to move gate, the slide ways may be blocked and lumps of materials has a tendency to wedge in when gate is closed. These gates are therefore generally used with small lumped free flowing materials. Rate of material discharge can be controlled by controlling the gate opening. Depending on the particle size and flowability of the bulk material, a minimum gate opening is needed for initiation of material discharge

Trough Gate: It consists of a trough hinged at the bin/silo outlet. When trough is in raised position, it keeps the outlet closed, but when lowered, it allows flow of material using the trough as a chute. These gates exclude jamming and allow control of flow by controlling the angle of trough

gate. Its large height projecting below hopper outlet and the force required for closing are the disadvantages.

Pivoted Gate: It is a part of cylindrical plate pivoted about its horizontal axis, which can be pivoted easily up and down to close or open the outlet of silo. The gate may be made of one or two sectors. This type of gate can be operated with less effort but not good for controlling material flow rate.

II.Objectives of Present Work

The objectives and scope of work for the research work are as follows:

A. To design a small sized conical portion of a hopper fitted with a manually operated rectangular slide gate positioned at the central axis of the hopper for conducting experiments to study discharge flow characteristics of different solid bulk materials through the gate opening. The design should have the arrangement for adjusting the slope angle of the hopper bottom.
B. To fabricate a model hopperproviding all the design features and which is strong enough for conducting experiments repeatedly with dimensional stability.
C. To determine the minimum gate width opening of a rectangular slide gate required for initiation of discharge for different bulk solids.
D. To find out relationship between discharge flow rate of different bulk solids and width of gate opening, the height of material inside the hopper remaining constant.
E. To investigate the effect of angle of slope of the conical portion of the hopper on the discharge flow rate of different bulk materials.

III.Experimental Set Up

A Cardboard model of a hopper with wooden framework has been designed with suitable dimensions so that it is suitable to perform experiments on that model. Every part of silo is designed with highest possible accuracy and by keeping in mind that it has to withstand the heavy weight of about 60-70 kg of bulk materials.

The cardboard model of hopper consists of two pivoted side walls 450 mm height from the bottom plate of hopper. Bottom edges of these movable walls are hinged at the bottom plate while top edges can make angular movement upto 22.5 degrees with the vertical. Arrangement is made to fix these pivoted walls at predetermined angles in steps. These walls are fabricated from hard cardboard of 4mm thick.

A cut is made of 300mm x 100 mm from middle portion of bottom plate. Just above the bottom plate sliding gates are introduced which is fabricated from 2mm thick plywood. Sliding gates are made in such a way that they can slide from both sides to cover the cut and thus control gate opening. This operation is done manually. Sliding gates cannot be opened manually to the desired gap width for free flow of materials in a short time. In order to overcome this difficulty, a sliding door is introduced in conjunction with sliding gates whose dimensions are more than the dimension of the cut gap.

Other two vertical sides of the hopper are fabricated from hard cardboard of 4mm thick. The mounting is done in such a way that a small gap is maintained between vertical walls and hinged walls to allow the angular movement of the walls.

A cut out has been made on the front of model of 40mm width covered with transparent sheet to see and monitor top level of bulk materials.

IV.Experimental Results

Experiments were done with following parameters:

A.Gap width of 10mm,15mm,20mm,25mm and 15mm,20mm,25mm,30mmand 15mm,20mm,25mm,30mm for dry sand, 6mm sized stone chips and wheat grains respectively.

B. Total angle of inclinations of 20, 30 and 45 degrees for each experiment.

Table 1. Flow rate for dry sand at different slope angles

Gap Width (mm)	Flow Rate in kg/sec. at 20^0 angle	Flow Rate in kg/sec at 30^0 angle	Flow rate in kg/sec at 45^0 angle
7	0.32	0.26	0.18
10	1.03	0.96	0.89
15	2.01	1.95	1.84
20	3.01	2.9	2.78
25	5.18	4.57	3.81

Table 2. Flow rate for stone chips at different slope angles

Gap Width (mm)	Flow Rate in kg/sec. at 20^0 angle	Flow Rate in kg/sec at 30^0 angle	Flow rate in kg/sec at 45^0 angle
12	0.90	0.74	0.43
15	1.47	1.29	0.98
20	2.27	2.13	1.74
25	2.99	2.82	2.57
30	4.19	4.07	3.78

Table 3. Flow rate for full grain wheat at different slope angle

Gap Width (mm)	Flow Rate in kg/sec. at 20^0 angle	Flow Rate in kg/sec at 30^0 angle	Flow rate in kg/sec at 45^0 angle
10	0.21	0.18	0.14
15	0.94	0.82	0.60
20	1.46	1.28	1.09
25	2.11	1.85	1.67
30	2.75	2.56	2.39

V.Calculations

The formulae used for calculation purposes are as follows:

$$\boldsymbol{A}.\ Average\ amount\ of\ bulk\ material = Sum\ of\ three\ readings\ of\ material\ flown\ through\ gate \Big/ 3$$

$$\boldsymbol{B}.\ Flow\ Rate = Avg.amt.of\ bulk\ material\ (kg) \Big/ Time\ taken\ during\ discharge\ (sec)$$

The results are depicted in graphical form in the following six figures.

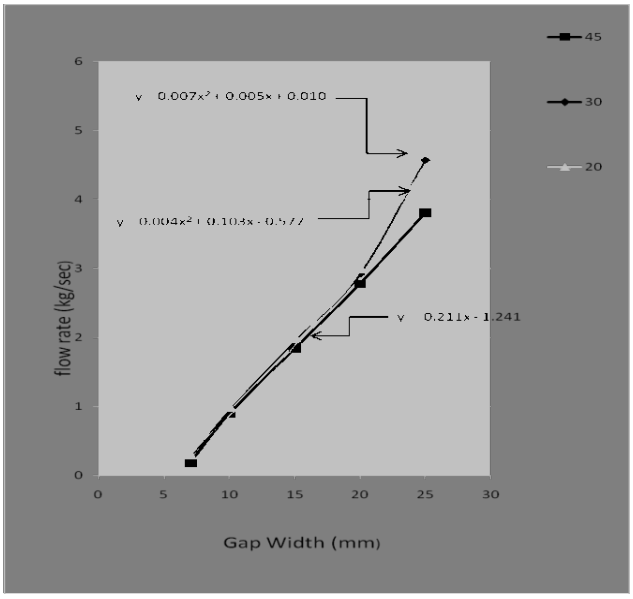

Fig.1: *Flow rate Vs gap width for dry sand for different angle of inclination*

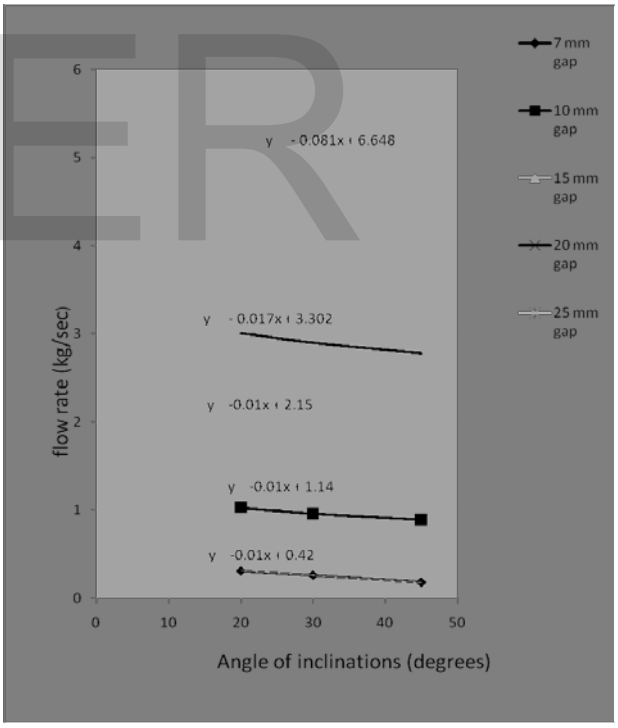

Fig.2: *Flow rate Vs Angle of inclinations for dry sand at different gate openings*

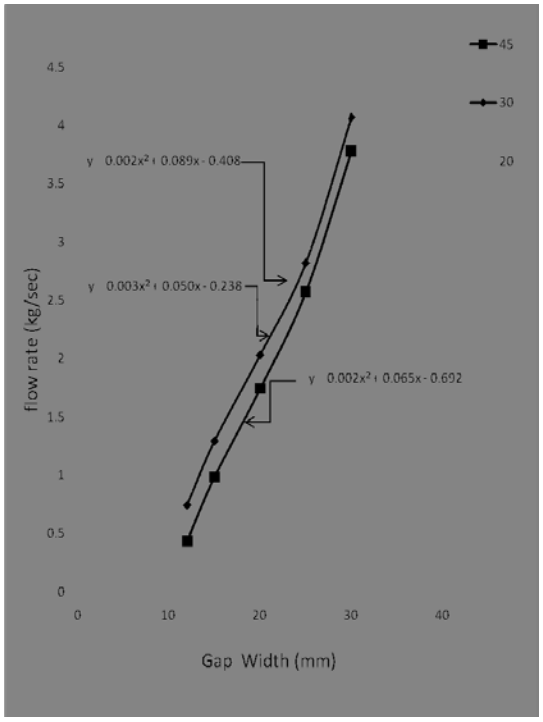

Fig.3: *Flow rate Vs gap width for stone chips(6mm size) at different slope angles*

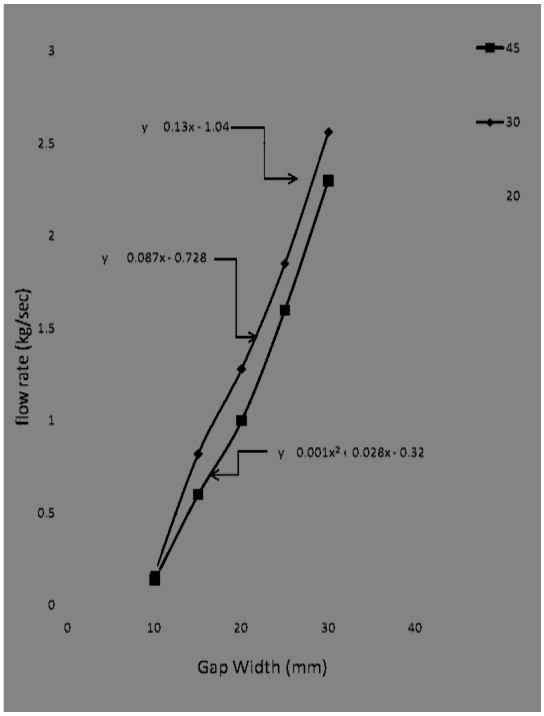

Fig.5: *Flow rate Vs gap width for full gains wheat at different slope angles*

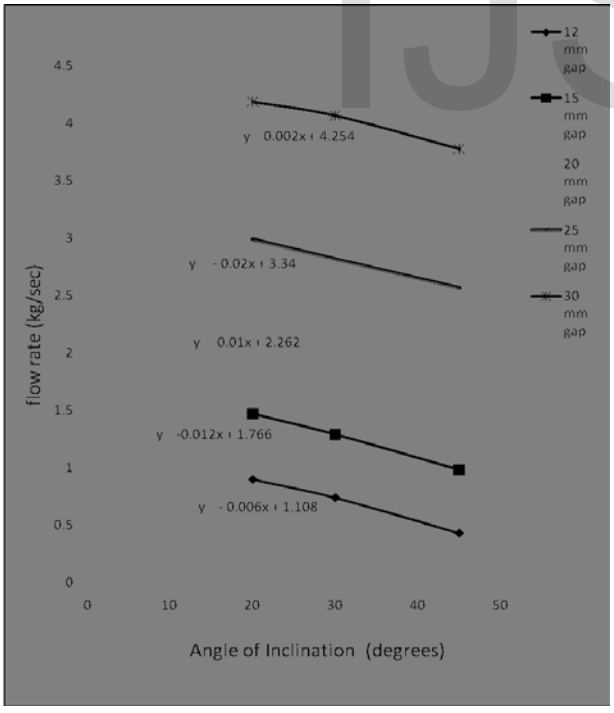

Fig.4: *Flow rate Vs Angle of Inclinations for stone chips (6mm size) at different gate openings*

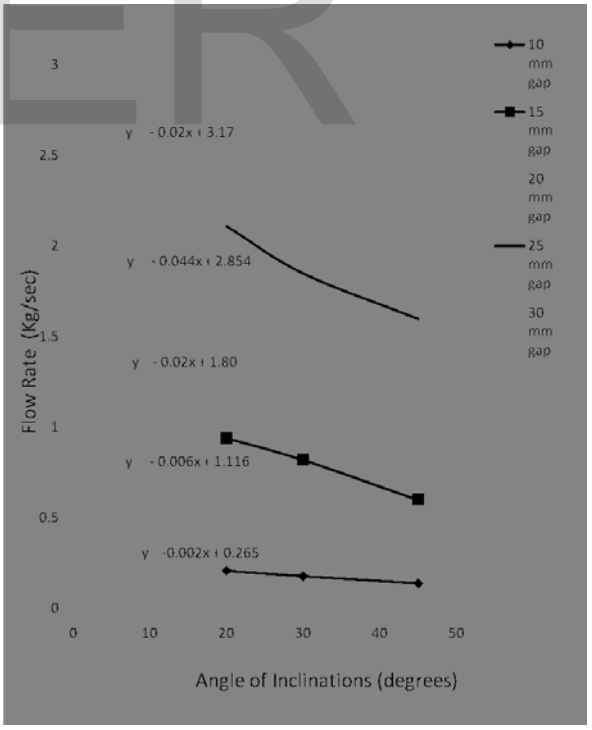

Fig.6: *Flow rate Vs Angle of Inclinations for full grains wheat at different gate openings*

VI. Conclusions

A. Depending on particle size and flowability of the bulk solid, there exists a minimum gap width of the gate below which the corresponding material does not flow of its own. In such minimum opening halting flow may be induced by inserting scraper in the gap or by external vibration of the hopper wall.

B.In the model hopper used, the minimum gap width observed for the three materials are :

(i) Sand: 7 mm approx.

(ii) Wheat: 10 mm approx.

(iii) Stone chips: 12 mm approx.

C.The flow rate with respect with gap width in general follows a parabolic curve. However, these curves get distorted at lower values of gap opening when the flow starts getting affected due to the minimum gap width restriction.

D.The effect of slope angle of the side walls of the hopper on flow rate is very distinct. The rate of flow varies linearly with the sloping angle with the horizontal. This is true irrespective of nature of material as well as the gate opening.

E.The effect of steepness of side walls on flow rate become more prominent for easy flowing material at higher gap widths, as observed for sand flowing through 25 mm gap width.

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