Design of Mass Flow Coal Bunker with Four Different Liner Materials

D.Venkateshwarlu[1],

Ph.D. Scholar

Sriram Venkatesh[2],

Professor and Head of the Department

Y.Venkat Reddy[3]

Ph.D. Scholar

University College of Engineering,

Osmania University,

Hyderabad, Telangana

ABSTRACT

This paper presents the design of coal bunker with different liner materials. The bulk solids flow pattern depends on the flow properties such as angle of internal friction, Kinematic angle of wall friction and flow function of the bulk solid. These flow properties are affected by the physical characteristics of the material. Even mass flow silos/bunkers can give flow problems due to changes in the physical properties such as moisture content, particle size, size distribution and wall surface roughness. In this work, the influence of moisture content on the flow properties of the Coal material was studied by using four different liner materials. Ring Shear Tester was used for the measurement of flow properties of the Coal sample. Experiments were carried out to study the effect of moisture content was studied based on the change in the flowability value and it was found that there exists a critical moisture level, which affects the flow properties significantly. The flow characteristics of Coal such as bulk density, wall yield locus, internal angle of friction, wall angle of friction against four different liner materials of Stainless Steel-304-2B, Mild Steel, Ultra high molecular polyethylene and Cast Nylon are evaluated. Based on the data obtained, the design ensures the mass flow.

Key words: *Bulk solids, Silos, Ring shear tester, Flow factor, Flow function, Internal angle of friction*

1. Introduction

Bulk materials are stored, handled and processed in various manners throughout the industry. The behaviour of these materials is influenced by the composition as well as the ambient conditions. To secure a reliable performance from these materials we have to understand the behaviour and take into account the characteristics in the equipment design.

It is essential to determine the flow properties of the bulk solid for the range of operation conditions expected to occur in practice. Based on these flow properties, the geometrical parameters of the bin and discharge equipment can be determined to ensure that the desired flow pattern is achieved. The flow patterns, together with the relevant flow properties, permit the calculation of bin wall loads, feeder loads, and normal pressure and rubbing velocities at the boundary walls of hoppers and chutes.

1.1 Types of Flow Patterns:

The three basic modes of flow (Jenike, 1961; Jenike 1990; Sriram, 2003) are mass-flow, funnel-flow and expanded flow. In mass-flow, the bulk solid is in motion at every point within the bin whenever material is drawn from the outlet. There is flow of bulk solid along the walls of the cylinder and the hopper. Mass-flow guarantees complete discharge of the bin contents at predictable flow rates. It is a FIFO(First-In, First-Out) flow pattern as shown in figure.1(a) . This flow pattern is ideal for cohesive solids and those that degrade with time. Stagnant or "dead regions" are eliminated, thereby minimizing the possibilities of spontaneous combustion.

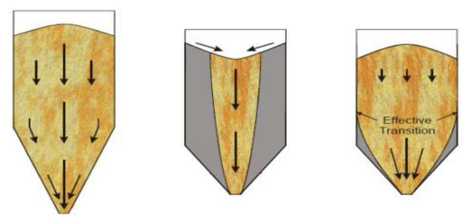


Figure.1 (a) Mass flow (b) Funnel flow (c) Expanded flow

Funnel flow as shown in figure.1(b) ,also known as core flow ,occurs when the hopper is less steep sloped and the walls of the hopper are not smooth enough .some material in the bin is in motion ,while some is stationary causing 'erratic flow' and gives rise to segregation problems.
The flow follows the FILO (First-In Last-Out) pattern which is unsuitable for bulk solids that degrade with time. Stable rat holes may be formed if the stored material develops cohesive strength, resulting in a severe loss of 'live capacity'. It is also unsuitable for fine bulk solids of low permeability. Expanded Flow as shown infigure.1(c). **-** This is a combination of both mass flow and funnel flow.
The upper portion is designed for funnel flow and the lower portion is designed for mass flow, in figure. 1(c).Usually this is achieved by placing a small mass flow hopper below a funnel flow hopper. The mass flow hopper section expands the flow channel from the outlet up to the top cross section of the mass flow hopper. It is important to ensure that this cross sectional area is sufficiently large so as to avoid rat holing in the funnel flow hopper section.

1.2 Bulk solid flow problems

Bulk-material handling problems (Maynard et al., 2013) can be experienced in a variety of equipment (e.g., feeders, transfer chutes, dust collectors), they most often occur in bins. The common flow problems include:
Arching or bridging — a no-flow condition in which material forms a stable arch (bridge, dome) across the outlet of a bin
Rat holing — a no-flow condition in which material forms a stable open channel within the bin, resulting in erratic flow to the downstream process
Flooding or Flushing — a condition in which an aerated bulk solid behaves like a fluid and flows uncontrollably through an outlet or feeder
Flow rate limitation — an insufficient flow rate, typically caused by counter-flowing air slowing the gravity discharge of a fine powder
Particle segregation — separation of particles by size, shape, density, etc.; segregation may prevent a chemical reaction or require costly rework.

Table 1. Mechanical properties of different liner materials

S.No	Materials /Properties	Tensile strength(	Tensile modulus	Density (g/cc)	Hardness BHN
1	MS	399	210	7.8	126 B
2	SS(304 2B)	505	193	8	123 B
3	UHMWPE	53	0.72	0.94	64 B
4	Cast Nylon	82.7	2.76	1.16	85 B

2 Experimental Procedure:

2.1 Bulk Material Sample Preparation

A typical coal sample of 50 kg was selected for shear testing. The whole sample was then screened through an 8 mesh (2.36mm) aperture screen. The –2.36 mm size sample (i.e. less than 2.36 mm size) was used for shear testing to generate flowability test data (Schulze, 2008***)***. It is widely accepted that the fine size particles in the bulk will largely contribute to the flow problems in silos or bunkers. In view of the problems associated with cohesive bulk solids, experiments are conducted on moist conditions. The experiments are focused on the problems associated with coal flow in coal fired thermal power stations.

2.2 Moisture Determination

A known weight of the coal "as received" coal sample of -2.36 mm is placed in an electric oven, maintained at 110°C for 2 hours. Subsequently these samples are allowed to cool down to ambient temperature and their final weights are measured. The loss of weight is computed as percent moisture in the sample and presented in following table 2.

Table2. Percentage moisture of coal

Moisture Content (-2.36mm size sample)	Saturation Moisture Levels
7.35%	As received (Dry coal)
17.10%	60% Saturation Level
23.30%	75% Saturation Level
26.40%	85% Saturation Level

2.3 Jenike-Schulze Ring Shear Tester (RST-01.pc)

The methodology of shear testing is based on the specialised procedure of compacting the samples to obtain packing conditions expected in the silos and then subjecting the samples for shear testing using Jenike-Schulze Ring shear Tester (RST-01.pc) shown in figure 2.

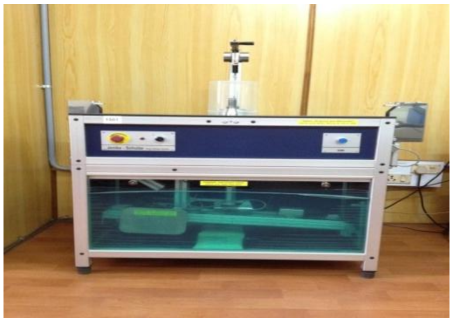


Figure.2 :Jenike-Schulze Ring Shear Tester

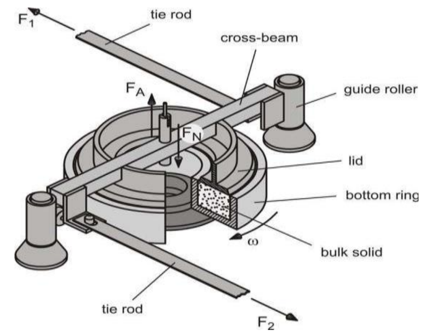


Figure .3 : Shear cell of a Ring Shear Tester

The Ring Shear Tester RST-01.pc shown in figure 2, provides computer controlled measurement of the flow properties (Schulze, 1992) of bulk solid materials, Ring Shear Tester is used here to evaluate effective angle of internal friction of the sample. The Ring Shear Tester RST-01.pc performs all steps automatically. The typical Shear cell of Ring Shear Tester is shown in the figure 3. The standard shear cell of Ring Shear Tester is homogeneously filled with the sample of coal by avoiding large voids and the excess material is scrapped off in level with the top of the shear cell. It is carefully placed on the driving axle of the ring shear tester and the sample is subjected to shearing as shown in figure 4, by following a sequence of instructions of RST-CONTROL software. During the process of testing, the resultant stress is continuously displayed on the PC monitor.

The wall friction tests were also carried on the Ring Shear Tester using different wall liners such as stainless steel 304-2B, Mild Steel and UHMWPE and Cast Nylon. The liners were cut to the required shape and dimensions and placed in the appropriate shear cell.

The sample to be tested is homogeneously filled up to top of the shear cell ensuring that the sample height does not exceed 8 mm between the wall liner and the shear cell bottom. The cell is placed on the driving axle of the ring shear tester and the sample is subjected to shearing against the wall liner under different stress conditions by following a sequence of instructions of RST-CONTROL software.

2.4. Experimental Data Generated

The interaction of coal flowing within itself and against different bunker wall liners (SS-304-2B, MS, UHMWPE and Cast Nylon) are determined from the shear test data obtained from RST- 01.pc (-2.36mm)

The shear test data generated at 60 %, 75 % and 85 % saturation moisture levels are analysed on computer using RSV 95 and SV 95 software for plotting yield loci and constructing Mohr stress circles to evaluate the relevant flowability parameters which form the basic design criteria for evaluating bunker geometry for reliable gravity flow of coal through the bunkers. Typical treatment of yield loci, wall friction curves and flow function curves are presented.

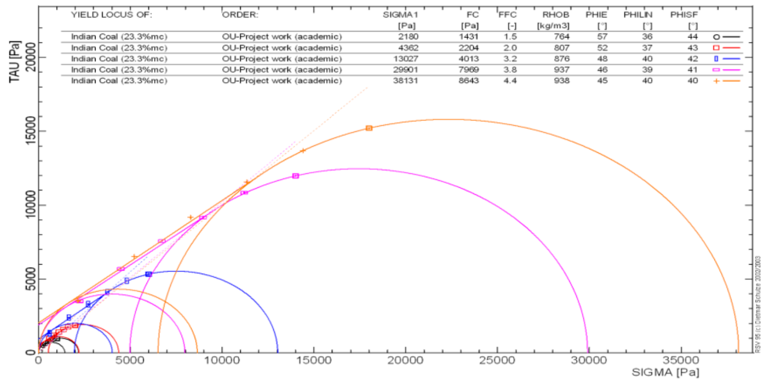
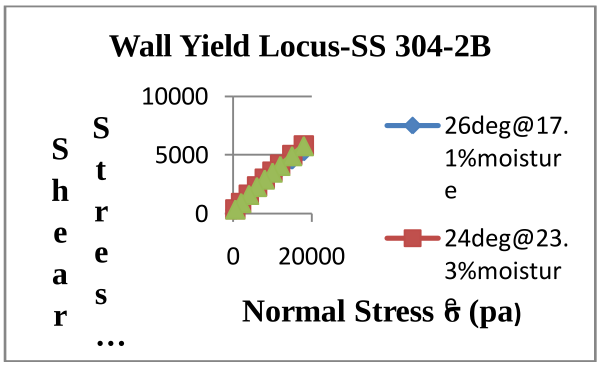
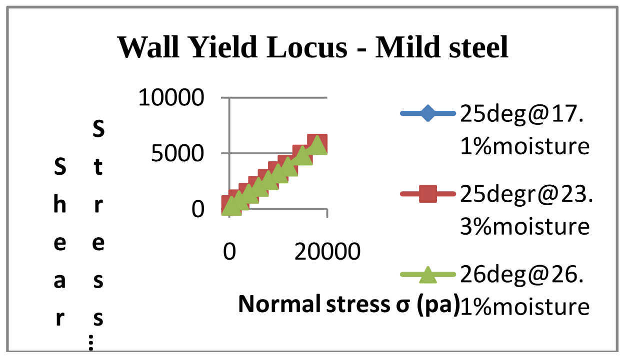


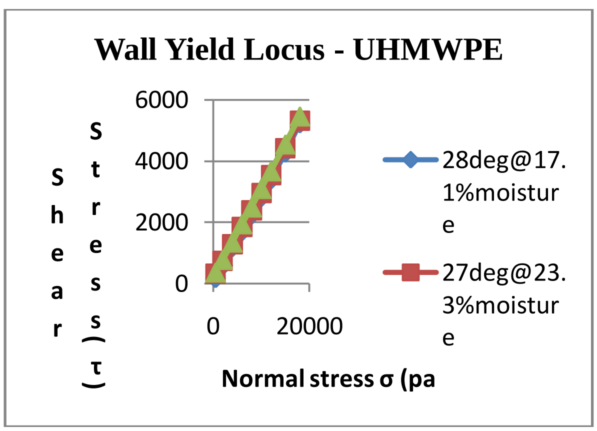
Figure. 4: Treatment of yield loci for coal at 23.3% of moisture at different levels



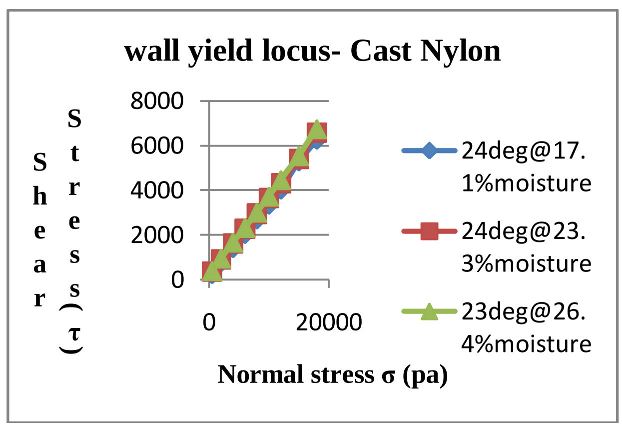
(a) SS304-2B



(b) MS



(c) UHMWPE



(d) Cast Nylon

Fig 5(a,b,c,d) Wall Yield loci of Liner materials at different moisture levels

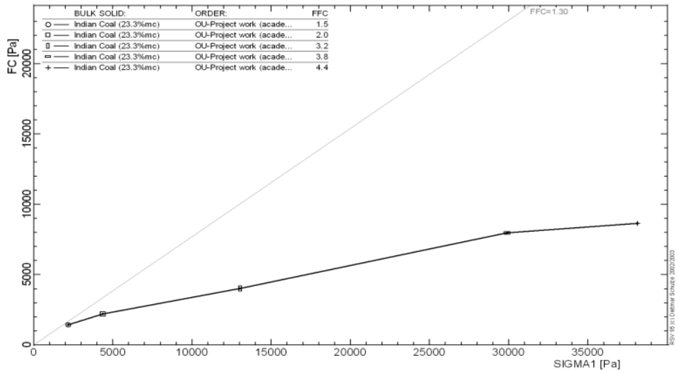


Fig 6: Flow function curve for coal at 23.3% Critical Moisture level

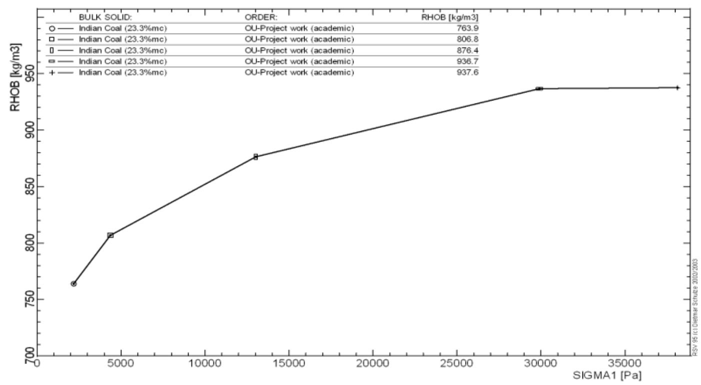


Figure.7: Bulk density variation at different pressure levels

Table 3: Kinematic angle of wall frictions and effective angle of internal friction at different moisture levels.

Moisture content (%)	Effective angle of internal friction (δ)	Kinematic Angle of Wall friction (ϕ_x)			
		Liner Material			
		SS304-2B	Mild Steel	UHMWPE	Cast Nylon
17.1	49.8°	17.5°	18°	16°	19°
23.3	49.6°	18.9°	18.3°	16.5°	19.6°
26.4	49°	18.6°	18°	17°	20.5°

Table 4: Design parameters for circular and wedge hopper with stainless steel 304-2B liner.

Moisture content (%)	Effective angle of internal friction (δ)	Kinematic angle of Wall friction (ϕ_x)	Stainless Steel 304-2B					
			Circular hopper			Wedge hopper		
			(θ_c)	D_c(m)	ff_c	(θ_p)	D_p(m)	ff_p
17.1	49.8°	17.5	26°	-	1.29	38°	-	1.18
23.3	49.6°	18.9	24°	0.41	1.29	36°	0.20	1.17
26.4	49°	18.7	25°	-		36°	-	1.25

Table 5: Design parameters for circular and wedge hopper with Mild steel liner.

Moisture Content (%)	Effective angle of internal friction(δ)	Kinematic angle of Wall friction (ϕ_x)	Mild Steel					
			Circular hopper			Wedge hopper		
			(θ_c)	D_c(m)	ff_c	(θ_p)	D_p(m)	ff_p
17.1	49.8°	18°	26°	-	1.28	37°	-	1.24
23.3	49.6°	18.3°	25°	0.41	1.29	37°	0.2	1.18
26.4	49°	18°	26°	-	1.3	37°	-	1.18

Table 6: Design parameters for circular and wedge hopper with UHMWPE liner.

Moisture content (%)	Effective angle of internal friction(δ)	Kinematic angle of Wall friction (ϕ_x)	UHMWPE					
			Circular hopper			Wedge hopper		
			(θ_c)	D_c(m)	ff_c	(θ_p)	D_p (m)	ff_p
17.1	49.8°	16°	28°	-	1.29	40°	-	1.24
23.3	49.6°	16.5°	27°	0.41	1.3	39°	0.20	1.24
26.4	49°	17°	27°	-	1.3	38°	-	1.26

Table 7: Design parameters for circular and wedge hopper with Cast Nylon liner.

Moisture content (%)	Effective angle of internal friction(δ)	Kinematic angle of wall friction (ϕ_x)	Cast Nylon					
			Circular hopper			Wedge hopper		
			(θ_c)	D_c(m)	ff_c	(θp)	D_p (m)	ff_p
17.1	49.8°	19°	24°	-	1.28	36°	-	1.17
23.3	49.6°	19.6°	24°	0.41	1.28	35°	0.20	1.17
26.4	49°	20.5°	23°	-	1.28	34°	-	1.16

Table 8: Design parameters for circular and wedge hopper at critical moisture level (23.3%) with selected liner materials.

Moisture content (%)	Effective angle of internal friction(δ)	Kinematic angle of wall friction (ϕ_x)	Circular hopper			Wedge hopper		
			(θ_c)	D_c(m)	ff_c	(θc)	D_p (m)	ff_p
SS304-2B	49.6°	18.9	24°	0.41	1.29	36°	0.20	1.17
Mild Steel	49.6°	18.3°	25°	0.41	1.29	37°	0.20	1.18
UHMWPE	49.6°	16.5°	27°	0.41	1.3	39°	0.20	1.24
Cast Nylon	49.6°	19.6°	24°	0.41	1.28	35°	0.20	1.17

3.0 Results and discussion

Flow properties and design analysis gives guidance to provide necessary structural supports to the silos.

a) The wall yield loci generated with different liners (SS 304-2B, Mild Steel, UHMWPE and Cast Nylon) at different moisture levels are plotted. The slope of this locus gives kinematic angle of wall friction (ϕx) as listed in table 3. From the results it is clear that the wall angle of friction varies between 17.5° to 18.9° for SS-3042B, 18° to 18.3° for Mild Steel, 16° to 17° for UHMWPE and 19° to 20.5° for Cast Nylon at different moisture conditions.
b) The effective angle of internal friction (δ) and flow factor (ff) values are read from the Mohr circle diagrams drawn for different moisture level and listed in tables 4-7. The effective angle of internal friction varies from 49.8° to 49° depending upon the moisture content of the coal. Flow factor values for all the liners varies between 1.28 to 1.32 for circular hopper and 1.16 to 1.26 for wedge hoppers.

c) For the material to flow by Gravity alone in mass flow mode, the required hopper critical slope angles (measured from vertical) are calculated for circular and wedge bunkers. These values are determined at different moisture levels and summarized in table 8. These critical slope (half hopper) angles for mass flow of coal varies from 24° to 26° for SS3042B, 25° to 26° for Mild Steel liner, 27° to 28° for UHMWPE and Cast Nylon 23° to 24° for circular hopper and 36° to 38° for SS3042B, 37° for Mild Steel liner, 38° to 40° for UHMWPE, 34° to 36° for Cast Nylon with wedge hopper.

d) The flow function (ff) curves of tested coal indicate that the coal is easy flowing up to 60% saturation moisture level. At 75% saturation moisture level a critical opening size of 0.41 m with all the liner materials tested is required for circular bunkers.

f) The Hopper half angle varies with the wall angle of friction values of different liners and the same is evident from the results obtained like 24° of SS-3042B and cast nylon with conical hopper.

4.0 Conclusions

The flow characteristics of coal such as bulk density, wall yield locus, internal angle of friction and wall angle of friction against four different liner materials of Stainless Steel-304-2B, Mild Steel, UHMWPE and Cast Nylon are determined using Ring Shear Tester. Mass flow bunker can be designed based on the experimental values obtained. The design ensures the mass flow Bunker and problems associated with funnel flow can be eliminated. Based on the hopper half angle, opening size of silo can be designed for the required capacity.

Acknowledgements

The authors would like to acknowledge Mr.TVS Subramanyam, AGM, bulk solids laboratory and authorities of NMDC (R&D), Hyderabad for providing test facilities and their constructive suggestions to carryout laboratory tests.

References

[1] Jenike, A.W. "Gravity Flow of Bulk Solids". Bul. 108, The Univ. of Utah, Engng Exp.Station, USA 1961, 52(29).

[2] Jenike A.W, "Storage and Flow of Solids", Bulletin No.123, Utah engineering experiment station, University of Utah, Salt lake city, (1990), 53(26).

[3] Sriram Venkatesh (2003) Investigations on the gravity flow of bulk solids through bunkers and silos for reliable flow. Ph.D. Thesis, University College of engineering, Osmania University, Hyderabad.

[4] Eric Maynard, Jenike & Johnson, Inc, "Ten steps to an effective bin design", American institute of chemical engineers (2013).

[5] Dietmar.Schulze Powders and Bulk solids, Behaviour, characterization, storage and flow. (2008)

[6] Dr.Ing. Dietmar Schulze, Ring shear Tester RST-01. Pc, Operating Instructions.