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ANGLE OF REPOSE WALKS ON ITS TWO LEGS: CARR INDEX AND HAUSNER RATIO

Kushal Nandi, Dr. Dhrubo Jyoti Sen, Dr. Falguni Patra, Dr. Bankim Nandy, Dr. Khokan Bera and Dr. Beduin Mahanti

Department of Pharmaceutical Chemistry and Pharmaceutics, School of Pharmacy, Techno India University, Salt Lake City, Sector–V, EM–4, Kolkata–700091, West Bengal, India.

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***Corresponding Author**
Dr. Dhrubo Jyoti Sen
Department of Pharmaceutical Chemistry and Pharmaceutics,
School of Pharmacy,
Techno India University,
Salt Lake City, Sector–V,
EM–4, Kolkata–700091,
West Bengal, India.

ABSTRACT

Every solid in dry state can flow on a surface to produce flowability according to the rheology. Flow property depends on the state of solid: Free flowing or Coarse flowing. The angle of repose of any solid in pulverized form represents an angle measured in theta (θ) which is measured in tanθ which is the ratio of height/radius of the conical shape. The equation for calculating the angle of repose is: $\tan^{-1}(2h/d)$. Using your scientific calculator, multiply height by 2 and divide this value by the distance. Then, hit the inverse tan key (or $\tan^{-1}$) and the answer just calculated. This will give the angle of repose. Angle of Repose (θ) In Degree (º) when it is less than **25º** then it is **excellent**, when it is in the range **25–30º** then it is **good**, when it is in the range **30–40º** then it is **average** and when it is greater than **40º** then the flow property is noted as **bad**. Flow Properties according to angle of repose comes under that range 0–90º. Carr Index of any solid is calculated for compressibility of a powder which is based on true density (ρT) and bulk density (ρB), CI=100[(ρT–ρB)/ρB]. A Carr index greater than 25 is considered to be an indication of poor flowability, and below 15, of good flowability. Another way to measure the flow of a powder is the Hausner ratio, which can be expressed as ρT/ρB. Excellent/very free flow for **Carr Index** is **≤10%** and for **Hausner Ratio** is **1.00–1.11**, **Good/free flow** for **Carr Index** is **11–15%** and for **Hausner Ratio** is **1.12–1.18**, **Fair flow** for **Carr Index** is **16–20%** and for **Hausner Ratio** is **1.19–1.25**, **Passable flow** for **Carr Index** is **21–25%** and for **Hausner Ratio** is **1.26–1.34**, **Poor/cohesive flow** for **Carr Index** is **26–31%** and for **Hausner Ratio** it is **1.35–1.45**, **Very Poor/very cohesive flow** for **Carr Index** is **32–37%** and for **Hausner Ratio** it is **1.46–1.59**

and **Very very poor/non flow Carr Index** is **>38%** and for **Hausner Ratio** it is **>1.60**. In a free–flowing powder, the bulk density and tapped density would be close in value, therefore, the Carr index would be small. On the other hand, in a poor–flowing powder where there are greater interparticle interactions, the difference between the bulk and tapped density observed would be greater, therefore, the Carr index would be larger. Compressibility of powder depends on true density and tap density and out of that flow property of powder comes in the category of **excellent flow (5–15% compressibility), good flow (16–18% compressibility), fair flow (19–21% compressibility), poor flow (22–35% compressibility), very poor flow (36–40% compressibility), extremely poor flow (>40% compressibility)**.

KEYWORDS: Angle of Repose, Carr Index, Hausner Ratio, Tap Density, True Density.

INTRODUCTION

Angle of repose is the angle that the plane of contact between two bodies makes with the horizontal when the upper body is just on the point of sliding: the angle whose tangent is the coefficient of friction between the two bodies.[1]

The angle of repose, or critical angle of repose, of a granular material is the steepest angle of descent or dip relative to the horizontal plane to which a material can be piled without slumping. At this angle, the material on the slope face is on the verge of sliding. The angle of repose can range from 0° to 90°. The morphology of the material affects the angle of repose; smooth, rounded sand grains cannot be piled as steeply as can rough, interlocking sands. The angle of repose can also be affected by additions of solvents. If a small amount of water is able to bridge the gaps between particles, electrostatic attraction of the water to mineral surfaces will increase the angle of repose, and related quantities such as the soil strength.[2]

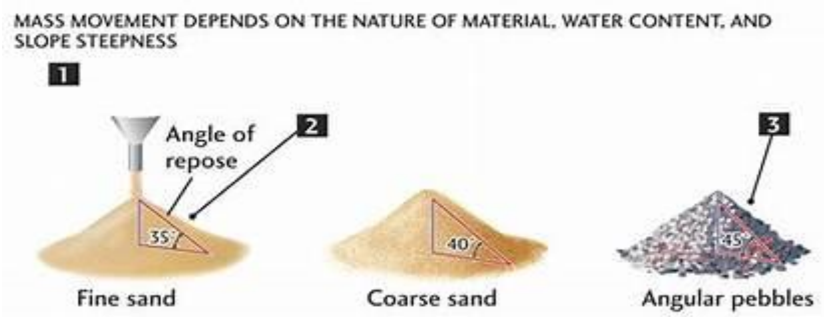


Figure 1: Angle of repose.

When bulk granular materials are poured onto a horizontal surface, a conical pile will form. The internal angle between the surface of the pile and the horizontal surface is known as the angle of repose and is related to the density, surface area and shapes of the particles, and the coefficient of friction of the material. Material with a low angle of repose forms flatter piles than material with a high angle of repose.[3]

Methods of Measurements: There are numerous methods for measuring angle of repose and each produces slightly different results. Results are also sensitive to the exact methodology of the experimenter. As a result, data from different labs are not always comparable. One method is the triaxial shear test another is the direct shear test. If the coefficient of static friction is known of a material, then a good approximation of the angle of repose can be made with the following function. This function is somewhat accurate for piles where individual objects in the pile are minuscule and piled in random order.

where, μs is the coefficient of static friction, and θ is the angle of repose.

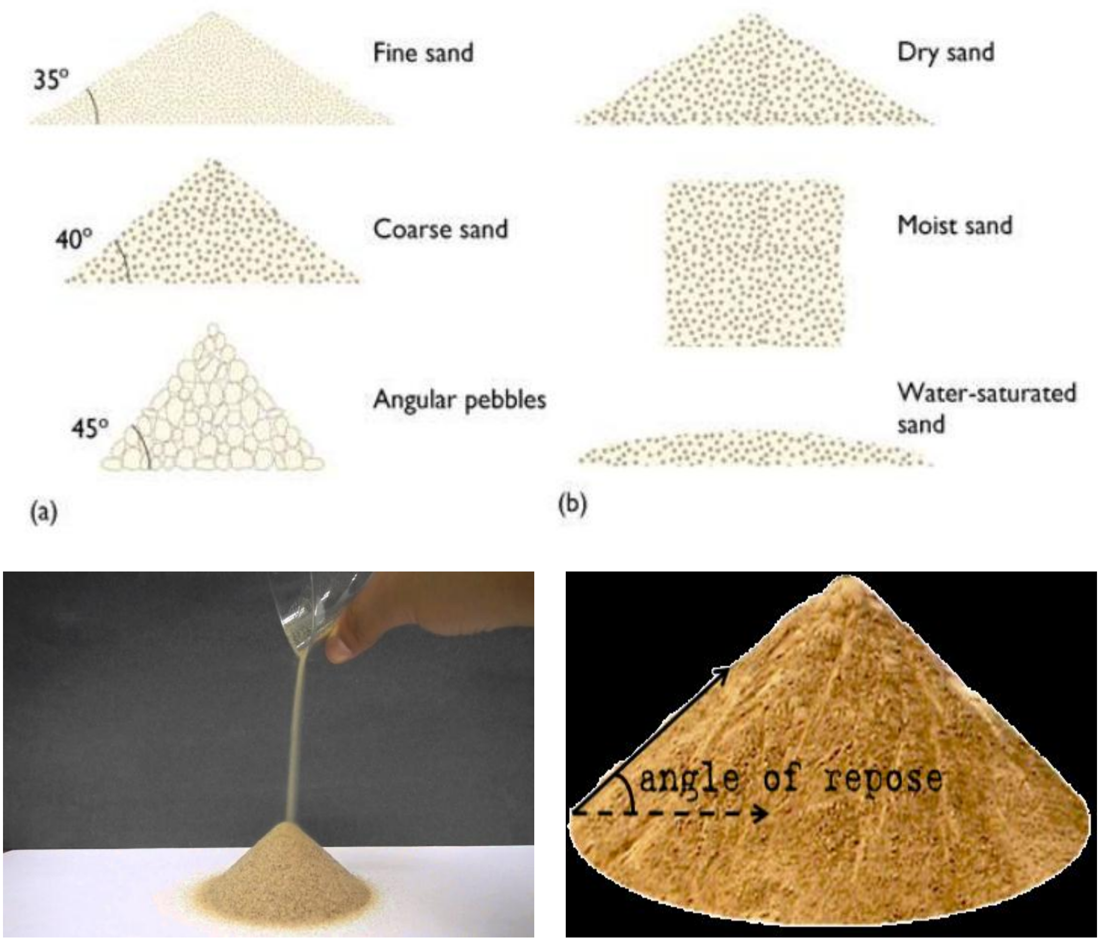


Figure 2: Flow of solid powder.

The measured angle of repose may vary with the method used.

Tilting box method: This method is appropriate for fine–grained, non–cohesive materials with individual particle size less than 10 mm. The material is placed within a box with a transparent side to observe the granular test material. It should initially be level and parallel to the base of the box. The box is slowly tilted until the material begins to slide in bulk, and the angle of the tilt is measured.

Fixed funnel method: The material is poured through a funnel to form a cone. The tip of the funnel should be held close to the growing cone and slowly raised as the pile grows, to minimize the impact of falling particles. Stop pouring the material when the pile reaches a predetermined height or the base a predetermined width. Rather than attempt to measure the angle of the resulting cone directly, divide the height by half the width of the base of the cone. The inverse tangent of this ratio is the angle of repose.

Revolving cylinder method: The material is placed within a cylinder with at least one transparent end. The cylinder is rotated at a fixed speed and the observer watches the material moving within the rotating cylinder. The effect is similar to watching clothes tumble over one another in a slowly rotating clothes dryer. The granular material will assume a certain angle as it flows within the rotating cylinder. This method is recommended for obtaining the dynamic angle of repose, and may vary from the static angle of repose measured by other methods of various materials. Here is a list of various materials and their angle of repose. All measurements are approximated.

Table 1: List of Angle of Repose of substances.

Material	**Angle of Repose (degrees)**	**Material**	**Angle of Repose (degrees)**
Ashes	40°	Clover seed	28°
Asphalt (crushed)	30–45°	Coconut (shredded)	45°
Bark (wood refuse)	45°	Coffee Bean (fresh)	35–45°
Bran	30–45°	Earth	30–45°
Chalk	45°	Flour (corn)	30–40°
Clay (dry lump)	25–40°	Flour (wheat)	45°
Clay (wet excavated)	15°	Granite	35–40°
Sand (dry)	34°	Gravel (crushed stone)	45°
Sand (wet)	45°	Gravel (natural w/ sand)	25–30°
Snow	38°	Wheat	27°

Bulk density and tapped density of powders

Bulk Density: The bulk density of a powder is the ratio of the mass of an untapped powder sample and its volume including the contribution of the interparticulate void volume. Hence, the bulk density depends on both the density of powder particles and the spatial arrangement of particles in the powder bed. The bulk density is expressed in grams per millilitre (g/ml) although the international unit is kilogram per cubic metre (1 g/ml = 1000 kg/m^3) because the measurements are made using cylinders. It may also be expressed in grams per cubic centimetre (g/cm^3). The bulking properties of a powder are dependent upon the preparation, treatment and storage of the sample, i.e. how it was handled. The particles can be packed to have a range of bulk densities and, moreover, the slightest disturbance of the powder bed may result in a changed bulk density. Thus, the bulk density of a powder is often very difficult to measure with good reproducibility and, in reporting the results, it is essential to specify how the determination was made.

The bulk density of a powder is determined by measuring the volume of a known mass of powder sample, that may have been passed through a sieve, into a graduated cylinder (Method A), or by measuring the mass of a known volume of powder that has been passed through a volumeter into a cup (Method B) or a measuring vessel (Method A. Bulk Density=Mass/Volume [gm cm^{-3}]

Method A. Measurement in a graduated cylinder

Procedure. Pass a quantity of powder sufficient to complete the test through a sieve with apertures greater than or equal to 1.0 mm, if necessary, to break up agglomerates that may have formed during storage; this must be done gently to avoid changing the nature of the material. Into a dry graduated cylinder of 250 ml (readable to 2 ml), gently introduce, without compacting, approximately 100 g of the test sample (m) weighed with 0.1% accuracy. Carefully level the powder without compacting, if necessary, and read the unsettled apparent volume (V_0) to the nearest graduated unit. Calculate the bulk density in (g/ml) using the formula m/V_0. Generally, replicate determinations are desirable for the determination of this property.

If the powder density is too low or too high, such that the test sample has an untapped apparent volume of either more than 250 ml or less than 150 ml, it is not possible to use 100 g of powder sample. Therefore, a different amount of powder has to be selected as test sample, such that its untapped apparent volume is 150 ml to 250 ml (apparent volume greater than or equal to 60% of the total volume of the cylinder); the mass of the test sample is specified in the expression of results.

For test samples having an apparent volume between 50 ml and 100 ml a 100 ml cylinder readable to 1 ml can be used; the volume of the cylinder is specified in the expression of results.[4]

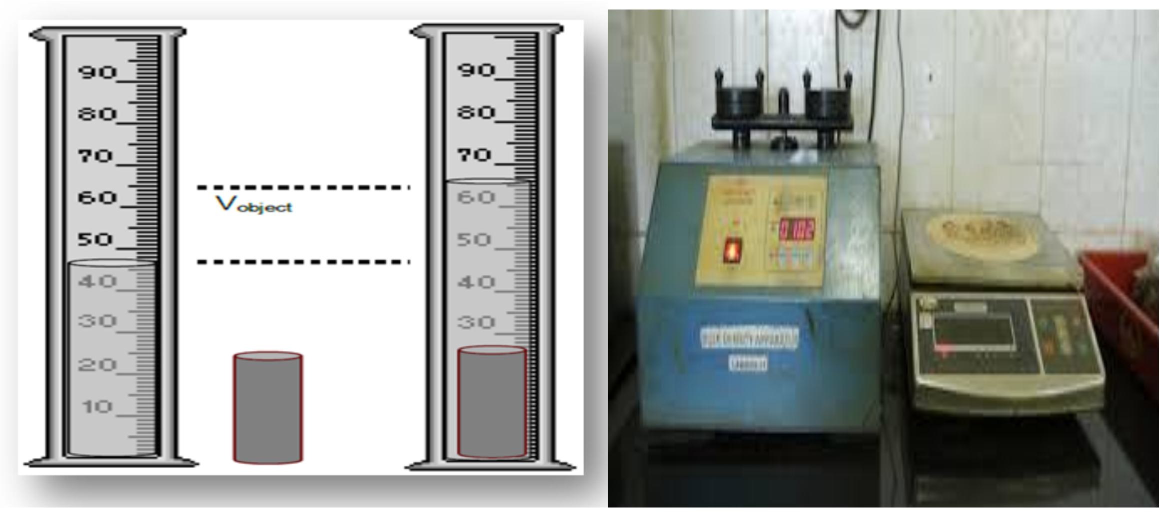


Figure 3: Bulk Density measurement.

Method B. Measurement in a volumeter

Apparatus. The apparatus[1] (Figure 1) consists of a top funnel fitted with a 1.0 mm sieve. The funnel is mounted over a baffle box containing four glass baffle plates over which the powder slides and bounces as it passes. At the bottom of the baffle box is a funnel that collects the powder and allows it to pour into a cup mounted directly below it. The cup may be cylindrical (25.00 ± 0.05 ml volume with an inside diameter of 30.00 ± 2.00 mm) or cubical (16.39 ± 0.20 ml volume with inside dimensions of 25.400 ± 0.076 mm).

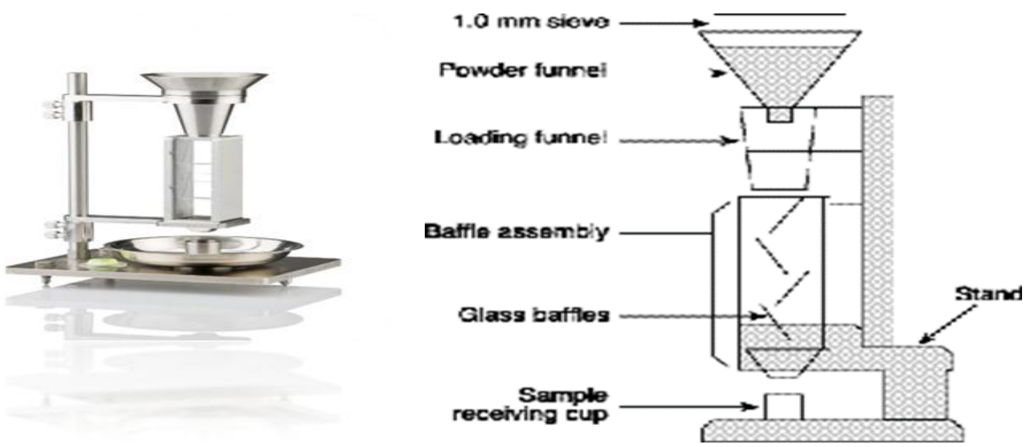


Figure 4: Volumeter and Digital volumeter.

Procedure. Allow an excess of powder to flow through the apparatus into the sample receiving cup until it overflows, using a minimum of 25 cm^3 of powder with the cubical cup and 35 cm^3 of powder with the cylindrical cup. Carefully, scrape excess powder from the top of the cup by smoothly moving the edge of the blade of a spatula perpendicular to and in contact with the top surface of the cup, taking care to keep the spatula perpendicular to prevent packing or removal of powder from the cup. Remove any material from the side of the cup and determine the mass (*M*) of the powder to the nearest 0.1%. Calculate the bulk density (g/ml) using the formula M/V_0 in which V_0 is the volume of the cup and record the average of three determinations using three different powder samples.

Method C. Measurement in a vessel

Apparatus. The apparatus consists of a 100 ml cylindrical vessel of stainless steel with dimensions as specified in Figure 2.

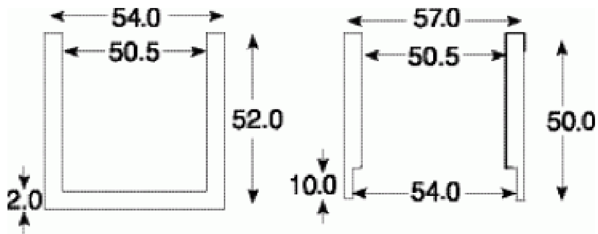


Figure 5: Measuring vessel (left) and cap (right) – Dimensions in mm.

Procedure. Pass a quantity of powder sufficient to complete the test through a 1.0 mm sieve, if necessary, to break up agglomerates that may have formed during storage and allow the obtained sample to flow freely into the measuring vessel until it overflows. Carefully scrape the excess powder from the top of the vessel as described for Method B. Determine the mass (M_0) of the powder to the nearest 0.1% by subtraction of the previously determined mass of the empty measuring vessel. Calculate the bulk density (g/ml) using the formula $M_0/100$ and record the average of three determinations.[5]

Tapped Density: The tapped density is an increased bulk density attained after mechanically tapping a container containing the powder sample.

The tapped density is obtained by mechanically tapping a graduated measuring cylinder or vessel containing the powder sample. After observing the initial powder volume or mass, the measuring cylinder or vessel is mechanically tapped, and volume or mass readings are taken until little further volume or mass change is observed. The mechanical tapping is achieved by raising the cylinder or vessel and allowing it to drop, under its own mass, a specified distance by either of three methods as described below. Devices that rotate the cylinder or vessel during tapping may be preferred to minimize any possible separation of the mass during tapping down.[6]

Table 1: Correlation between hausner Ratio & Carr Index.

Flow Character	Hausner Ratio	CI (%)
Excellent/very free flow	1.00-1.11	≤10
Good/free flow	1.12-1.18	11-15
Fair	1.19-1.25	16-20
Passable	1.26-1.34	21-25
Poor/cohesive	1.35-1.45	26-31
Very Poor/very cohesive	1.46-1.59	32-37
Very, very poor/ approx. non-flow	>1.60	>38

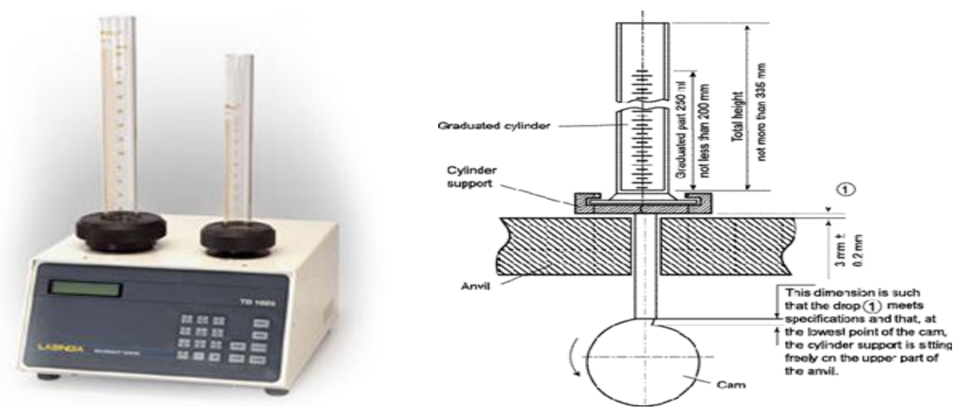


Figure 6: Tap density tester.

Method A

Apparatus. The apparatus (Figure 3) consists of the following:

— a 250 ml graduated cylinder (readable to 2 ml) with a mass of 220 ± 44 g; and

— a settling apparatus capable of producing, in 1 minute, either nominally 250 ± 15 taps from a height of 3 ±0.2 mm, or nominally 300 ± 15 taps from a height of 14 ± 2 mm. The support for the graduated cylinder, with its holder, has a mass of 450 ± 10 g.

Procedure. Proceed as described above for the determination of the bulk volume (V_0). Secure the cylinder in the holder. Carry out 10, 500 and 1250 taps on the same powder sample and read the corresponding volumes V_{10}, V_{500} and V_{1250} to the nearest graduated unit. If the difference between V_{500} and V_{1250} is less than or equal to 2 ml, V_{1250} is the tapped volume. If the difference between V_{500} and V_{1250} exceeds 2 ml, repeat in increments such as 1250 taps, until the difference between succeeding measurements is less than or equal to 2 ml. Fewer taps may be appropriate for some powders, when validated. Calculate the tapped density (g/ml) using the formula m/V_f in which V_f is the final tapped volume. Generally, replicate determinations are desirable for the determination of this property. Specify the drop height with the results.

If it is not possible to use a 100 g test sample, use a reduced amount and a suitable 100 ml graduated cylinder (readable to 1 ml) weighing 130 ± 16 g and mounted on a holder weighing 240 ± 12 g. The modified test conditions are specified in the expression of the results.

Method B

Procedure. Proceed as directed under Method A except that the mechanical tester provides a fixed drop of 3 ± 0.2 mm at a nominal rate of 250 taps per minute.

Method C

Procedure. Proceed as described in Method C for measuring the bulk density using the measuring vessel equipped with the cap shown in Figure 2. The measuring vessel with the cap is lifted 50–60 times per minute by the use of a suitable tapped density tester. Carry out 200 taps, remove the cap and carefully scrape excess powder from the top of the measuring vessel as described in Method C for measuring the bulk density. Repeat the procedure using 400 taps. If the difference between the two masses obtained after 200 and 400 taps exceeds 2%, carry out a test using 200 additional taps until the difference between succeeding measurements is less than 2%. Calculate the tapped density (g/ml) using the formula $M_f/100$

where M_f is the mass of powder in the measuring vessel. Record the average of three determinations using three different powder samples. The test conditions including tapping height are specified in the expression of the results.[7]

Measures of powder compressibility: Because the interparticulate interactions influencing the bulking properties of a powder are also the interactions that interfere with powder flow, a comparison of the bulk and tapped densities can give a measure of the relative importance of these interactions in a given powder. Such a comparison is often used as an index of the ability of the powder to flow, for example the Compressibility index or the Hausner ratio.

The Compressibility index and Hausner ratio are measures of the propensity of a powder to be compressed as described above. As such, they are measures of the powder ability to settle and they permit an assessment of the relative importance of interparticulate interactions. In a free– flowing powder, such interactions are less significant, and the bulk and tapped densities will be closer in value. For poorer flowing materials, there are frequently greater interparticulate interactions, and a greater difference between the bulk and tapped densities will be observed. These differences are reflected in the Compressibility Index and the Hausner Ratio.

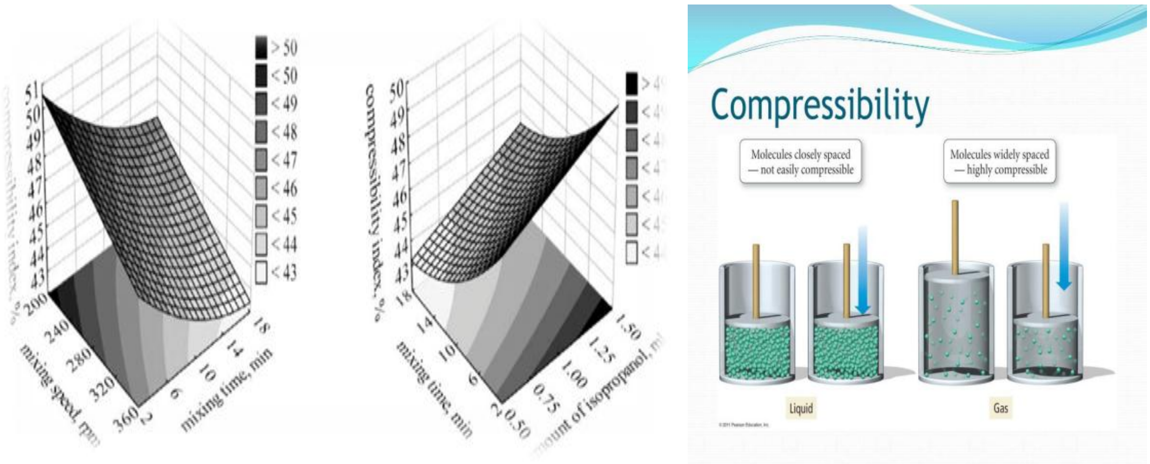


Figure 7: Compressibility index.

$$\frac{100\left(V_0 - V_f\right)}{V_0}$$

Compressibility index:

V_0 = unsettled apparent volume,

V_f = final tapped volume.

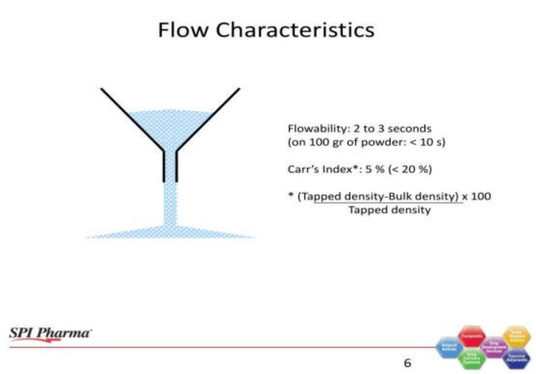
$$\frac{V_0}{V_f}$$

Hausner ratio

Depending on the material, the compressibility index can be determined using V_{10} instead of V_0. If V_{10} is used, it is clearly stated in the results.

The Carr index (Carr's index or Carr's Compressibility Index) is an indication of the compressibility of a powder. It is named after the scientist Ralph J. Carr, Jr. The Carr index is calculated by the formula=100[ρT–ρB/ρB] , where ρB is the freely settled bulk density of the powder, and ρT is the tapped bulk density of the powder after "tapping down". It can also be expressed as C=100[1–ρB/ρT].[8]

The Carr index is frequently used in pharmaceutics as an indication of the flowability of a powder. In a free–flowing powder, the bulk density and tapped density would be close in value, therefore, the Carr index would be small. On the other hand, in a poor–flowing powder where there are greater interparticle interactions, the difference between the bulk and tapped density observed would be greater, therefore, the Carr index would be larger. A Carr index greater than 25 is considered to be an indication of poor flowability, and below 15, of good flowability. Another way to measure the flow of a powder is the Hausner ratio, which can be expressed as ρT/ρB. Both the Hausner ratio and the Carr index are sometimes criticized, despite their relationships to flowability being established empirically, as not having a strong theoretical basis. Use of these measures persists, however, because the equipment required to perform the analysis is relatively cheap and the technique is easy to learn.



Carr's compressibility index

Relationship between powder flowability and % compressibility

Flow description	% Compressibility
Excellent flow	5 – 15
Good	16 – 18
Fair	19 – 21
Poor	22 – 35
Very Poor	36 -40
Extremely poor	> 40

Figure 8: Flow characteristics & Carr Index.

The Hausner ratio is a number that is correlated to the flowability of a powder or granular material. It is named after the engineer Henry H. Hausner (1900–1995). The Hausner ratio is calculated by the formula H=ρT/ρB

where ρB is the freely settled bulk density of the powder, and ρT is the tapped bulk density of the powder. The Hausner ratio is not an absolute property of a material; its value can vary depending on the methodology used to determine it. The Hausner ratio is used in a wide variety of industries as an indication of the flowability of a powder. A Hausner ratio greater than 1.25 is considered to be an indication of poor flowability. The Hausner ratio (H) is related to the Carr index (C), another indication of flowability, by the formula H=100/(100–C). Both the Hausner ratio and the Carr index are sometimes criticized, despite their relationships to flowability being established empirically, as not having a strong theoretical basis. Use of these measures persists, however, because the equipment required to perform the analysis is relatively cheap and the technique is easy to learn.[9]

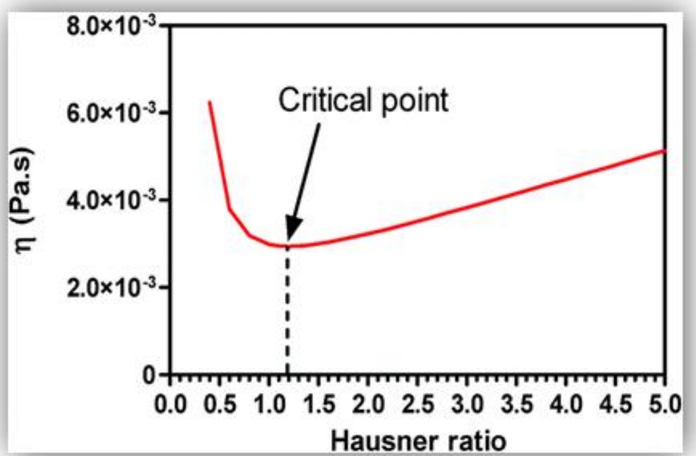
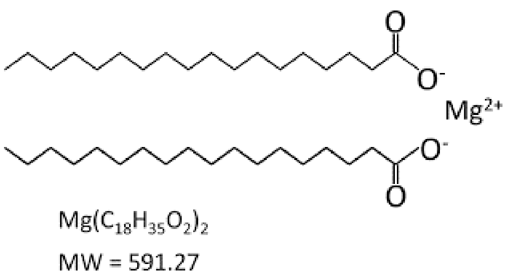


Figure 9: Graphical Representation of hausner's ratio.

Experimental protocol



Chemical required: Magnesium Stearate

Apparatus required: Funnel, Clamp Stand, Beaker, Balance, Stirrer, Weight Box

Procedure: i) Supplied Magnesium Stearate granules are taken approximately 5g accurately weighed.

ii) The funnel is properly fitted so that the tip of funnel should not be away from the pile. A paper is placed below the funnel.

iii) Holding the funnel tip with thumb, the sample is poured into funnel.

iv) The height of the pipe (h) and the radius (r) of the base is measured after taking the thumb out & keep the sample.

v) Same process is repeated by adding various concentration of glidant.

vi) The result was recorded.[10]

CALCULATION

Amount of Glidant Used–

0.1% (w/w) in g = (0.1×5/100) = 0.005g

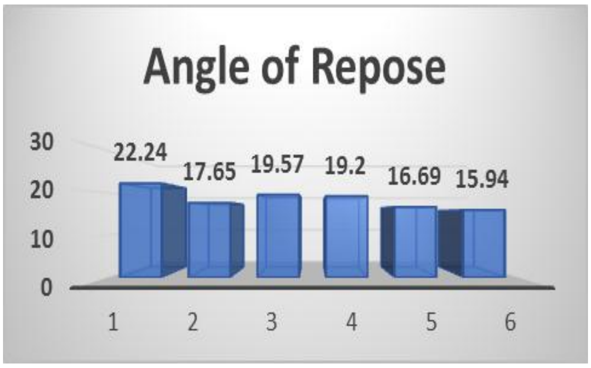
0.6% (w/w) in g = (0.6×5/100) = 0.03g

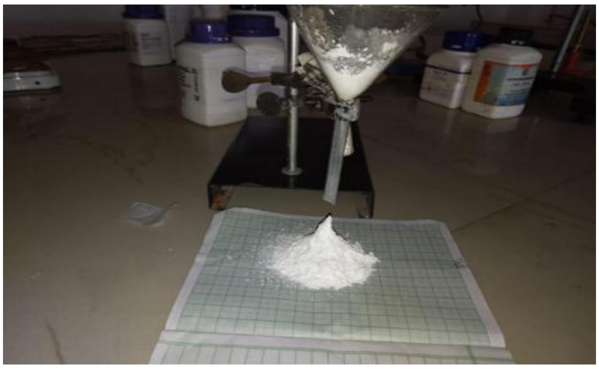
0.8% (w/w) in g = (0.8×5/100) = 0.04g

1.2% (w/w) in g = (1.2×5/100) = 0.06g

Table–1

Serial No	Amount of Powder (g)	Concentration of Glidant (%)	Height (h; cm)	Radius (r; cm)	Diameter (d; cm)	tanθ=2h/d	θ=tan^{-1}(2h/d; °)
1	5	0	0.9	2.2	4.4	0.409	22.24
2	5	0.2	0.7	2.2	4.4	0.318	17.64
3	5	0.4	0.8	2.25	4.50	0.355	19.54
4	5	0.6	0.7	2	4	0.35	19.29
5	5	0.8	0.6	2	4	0.30	16.69
6	5	1.2	0.6	2.1	4.2	0.285	15.90





Histogram

Table 2.

Angle of Repose in Degree	Flow Properties
θ<25º	Excellent
θ=25–30º	Good
θ=30–40º	Passable/Average
θ>40º	Bad

RESULT

The sample was mix concentration various concentration of glidant & most of the exhibits angle of repose is below 25º. Hence flow is excellent.

CONCLUSION

A smooth cone is produced for each solid powder having height of cone (h) and a radius (r) of diameter of the cone produced when flowing from a conical funnel on a smooth surface producing and angle of repose (θ)=$\tan^{-1}$(2h/d; º). This indicates the flow property of the solid powder and Hausner's Ratio & Carr Index by bulk density & tapped density represents the flow characteristics. Angle of Repose depends upon the cohesive forces of the particles. Frictional forces are measured and maximum angle formed between the surface of a pile of powder and horizontal surface. Angle of Repose is high in case of the powder which have rough and irregular surface. Angle of Repose decreases to certain extent when we use lubricants in less amount. In excess quantity of lubricant increases the Angle of Repose. Angle of Repose 25º=powder flows smoothly and greater than 40º=does not flow. Hausner's Ratio H=ρT/ρB; value greater than 1.5 indicates poor flow (33% Carr Index), value less than 1.25 indicates good flow (20% Carr Index), value in between 1.25 & 1.5=added glidant normally improves flow. Bulk Density/Apparent Density/Volumetric Density is ρB=M/V; where M=weight of powder, V=volume of powder. Tapped Density is ρT=M/Vt; where M=weight of powder, Vt=minimum volume of occupied after tapping. Bulk Density (Vb)=Mass/Bulk Volume. Tapped Density (Vt)=Mass/Tapped Volume. Hausner's Ratio=ρT/ρB. Carr index (I)=[Tapped Density–Bulk Density]/Tapped Density×100

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