FE-483 FOOD OPERATION LAB.

MIXING AND SOLIDS HANDLING STUDY BENCH Dr. Mustafa BAYRAM

[NOTE: BEFORE THE EXPERIMENT;

- Watch Demo Video at: **https://youtu.be/Meet7utO1N8**
- Read the [Bayram, M. and Göğüş,F. "Mixing of Solid Particles", Chapter 1, *Experiments in Unit Operations and Processing Foods*, (Ed.: M.M. Cortez Vieira, P. Ho), Springer Pres. ISBN-10: 0387335137, ISBN-13: 978-0387335131 (2008).]

1-OBJECTIVE

The objectives of this experiment:

-Learning solid handling properties of solid food materials (particles)

-Bulk density (hectoliter-weight) of solid food materials (particles)

-Angle of repose of solid food materials (particles)

-Sliding angle of solid food materials (particles)

-Silo discharge rate/capacity of solid food materials (particles)

-Mixing of solid food materials (particles)

-Size reduction and energy requirement for milling

-Pneumatic conveying

-Ball milling

2-INTRODUCTION

The characteristics of the flow of solid materials are relevant to many process industries, particularly in the handling of powders, pellets, crystals and aggregates.

In food industry; sugar, salt, flour, grains, legumes, semolina, bulgur, coffee, cacao, pudding, ready-soup mix, nuts and baby soup etc. use these kinds of properties for storage (in silo; as silo design), conveyor design, package design, pipe/duct design, equipment design etc.

3-THEORY

3.1. BULK DENSITY (HECTOLITER WEIGTH)

The purpose is to determine the bulk density (ρ_b) (kg/m^3) (weight/volume) of various solids and to examine the influence of particle size on bulk density. Bulk density as volume part includes the voids between particles.

As a note, moisture content, smoothness and compaction effect the bulk density.

Density is defined as the weight of a unit volume of any material but bulk density takes account of the natural **voids** between individual solid particles. Bulk density is, therefore, dependent on the size of the particles relative to the consequent interstitial volume.

!!!Bulk density depends on; particle size, moisture content, shape of particles, smoothness of particle surface, compactness and sphericity of particles etc. (all effect the void volume).

Compaction is the packing together of the particles of material by the expulsion of airstrikes which, therefore, influences the bulk density of the material.

Similarly the moisture content (m.c.) of a material will affect the bulk density due to much increase in swelling volume of particle.

!!!

IF; Particle size (dp) ↓ ➔ Surface area ↑ ➔Void ↑ ➔ Volume ↑ ➔ Bulk density (ρ_b) ↓

(Example: $(\rho_b)_{flour} < (\rho_b)_{wheat}$; Therefore flour needs bigger silo/package volume than wheat due to increase in volume)

IF; Smoothness ↑ ➔ Void ↓ ➔ Volume ↓ ➔ Bulk density (ρ_b) ↑

IF; m.c. ↑ ➔ Swelling Volume of particle ↑ ➔ Bulk density (ρ_b) ↓ **(Example: Rice pilaf)**

3.2. ANGLE OF REPOSE AND SLIDING ANGLE

The purpose of both experiments are to determine the angle of repose and sliding angle for a variety of materials and to examine the influence of particle size on the both angles.

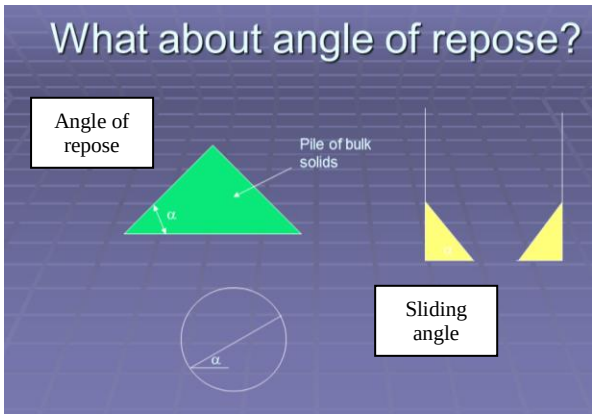
The angle of repose (AR) of any material is the steepest possible angle with the horizontal at which the material will stand when piled.

The sliding angle (SA) is sliding angle of particles from a surface. It is used to determine the pipe angle in plant design (from upper floor to bottom floor to transfer of product by pipe) and silo conical part angle. It is important for equipment design.

!!!Both angles depend on; particle size, adhesiveness, moisture content, shape of particles, smoothness of particle surface, compactness and sphericity of particles etc.

!!! If;
m.c. ↑ ➔ AR ↑, SA↑
Smoothness ↑ ➔ AR ↓, SA↓
Particle size ↓ ➔ Surface area ↑ ➔Friction ↑ ➔ AR ↑

!!! Angle of repose (AR) and Sliding angle (SA) are very important properties for the design the machineries, silo and piping system for solid food products (in flour, semolina, wheat, bulgur factories or for any solid particle food products, the design of pipe to convey the product from one floor to another down floor, you need to know this value. Also, bin, hopper and silo are designed by using these values). In open area storage of wheat or any particular food, you can use the AR to find the quantity. In silo, top pile (top conical pile) is determined by Angle of Repose; bottom conical part of silo is determined by sliding angle (to calculate volume and top part, and angle to discharge product from bottom of silo).

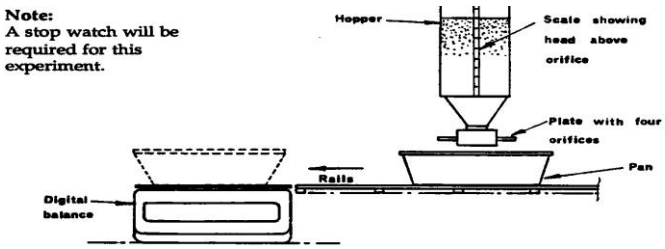


Angle of repose instrument

3.3. SILO/HOPPER/BIN/BUNKER DISCHARGE RATE/CAPACITY

The purpose is to determine discharge rate (capacity) of silo/hopper/bin/bunker (or determine discharge orifice diameter to find required discharge capacity of silo/hopper/bin/bunker). Discharge capacity of silo/hopper/bin/bunker depends on the diameter of orifice (discharge hole at bottom).

Additionally, during discharge of silo/hopper/bin/bunker; whether the head of material over the orifice has any effect on the flow rate due to potential energy.



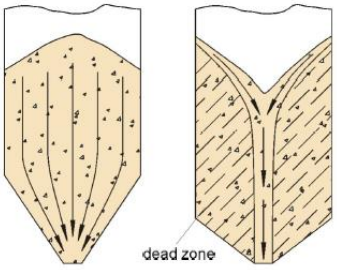


Fig. 6: Mass flow (on the left), funnel flow (on the right)

In general, in silo/hopper/bin/bunker; there are two flow such as **mass flow and funnel flow**. In **mass flow**, particles flow at same velocity in silo (like plug flow), which first-in/first-out from silo/hopper/bin/bunker.

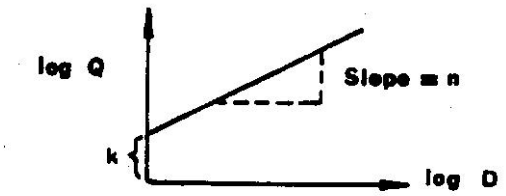
In **funnel flow**, velocity of particles found at center of silo/hopper/bin/bunker is bigger than velocity of particle found at wall of silo/hopper/bin/bunker. Therefore, center is discharge as first, and first-in is NOT first-out.

Generally, the rate of discharge (Q; kg/h or g/sec) is related to the orifice diameter (D; m or cm) by an equation of the form**:**

$$\mathbf{Q = k\ D^n}$$

where k is proportionality constant and n is a power of about 2.5 - 3.0. It is generally found that the head of material over the orifice has no detectable effect on the rate of discharge.

Plotting straight line the calcu1ated discharge rates against the orifice diameter on a log-log basis is used to find n and k values:



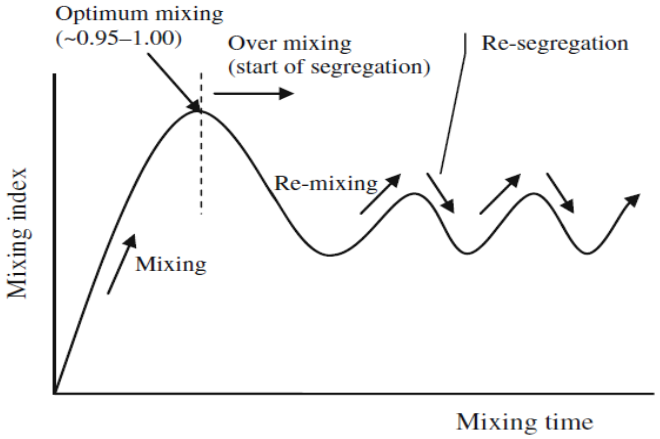
!!!As a note; when n and k are determined experimentally, the required D of silo/hopper/bin/bunker in plant scale at certain flow rate capacity (Q) is calculated.

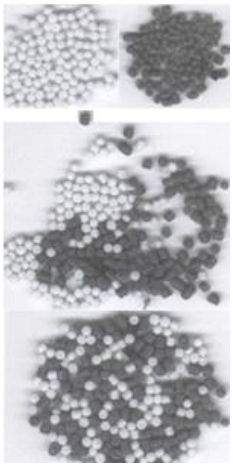
3.4. SOLID/SOLID MIXING (PARTICLE FOOD PRODUCT MIXING)

The aim of this experiment is the learning and experiencing the mixing operation with its principles. Mixing parameters, time, mixing index etc. will be determined and compared.

!!!In industry, solid particular mixing is used in coffee (3 in 1), ready-eat-soup, baby powder food, sweet mixture blends, spice blends, pudding powder blends etc. This experiment is only related to solid/particles mixing.

!!!Long period mixing is NOT a meaning perfect mixing. If optimum mixing time (e.g. at 0.95 m (practical), 1 (theoretical) mixing index) passes, mixture will segregate.





The mixing of solids is a critically important operation in many industries. Mixing is a unit operation in which a relatively uniform mixture is obtained from two or more components. Mixing is the dispersing of components, one throughout the other. It occurs in innumerable instances in the food industry and is probably the most commonly encountered of all process operations. Generally, materials similar in size, shape, and density are able to form the most uniform mixtures. Differences in these properties can also cause unmixing or segregation during mixing or mechanical jiggling of the mixture. To provide good solid mixing the phenomenon to be avoided, or overcome, is the particles tendency to *segregate.* Segregation occurs in competition with mixing and prevents a perfect homogeneous powder blend being obtained. Hence the quality of a powder mixture depends upon the dynamic equilibrium between mixing and segregation, which in turn, depend on the physical and chemical properties of the particles. Segregation occurs when a system contains particles with different sizes, densities, etc. and motion can cause particles to preferentially accumulate into one area over another; e.g. large particles work their way to the top of breakfast cereal - fines are found at the bottom of the packet.

Experience shows that materials with a size greater than 75 μm will segregate readily during mechanical jiggling of the mixture, but those below 10 μm will not segregate appreciably.

Means of overcoming segregation and poor mixing include:

- comminution to smaller sizes
- use of powders with a narrow size distribution
- use of the same volume-average diameter for all components
- granulation
- coating processes
- controlled continuous mixing

It is not possible to achieve a completely uniform mixture of dry powders or particulate solids. The degree of mixing achieved depends on:

- the relative particle size, shape, and density
- the efficiency of the particular mixer for the components being mixed
- the tendency of the materials to aggregate

- the moisture content, surface characteristics, and flow characteristics of each component

The duration of mixing in a process is frequently determined by experimental trials or operator experience. The quality of a blended powder product can be expressed in terms of composition variance, which will decrease over time as a mixing takes place. The most commonly used method to determine blend homogeneity is analysis of "grab or spot" samples. Therefore, I_M (mixing index) is used to determine the optimum mixing time.

3.4.1. Equipment

Selection of mixers must take into account any tendency towards segregation. This may be evaluated form a "heap test", in which a well-mixed material is poured through a funnel to form a heap. If the composition of samples taken from the outside varies significantly from compositions of samples from the centre of the heap, the material is likely to segregate during mixing or later processing.

Batch mixing large quantities (up to 2 tonnes) reduces labour costs but as size goes up so does time to reach desired quality, filling and emptying times per batch. Continuous mixing depends on metering rates, capacity of mixer, axial and radial dispersion performance.

Loading two, or more, components together should reduce batch mixing time, but requires metering or practice.

A brief equipment type description follows.

Mixers can be classed into two groups with respect to segregation:

a) Segregating mixers have mainly diffusive mechanisms, encouraging the movement of individual particles, making segregation more significant. Non-impeller type mixers tend to be of this type.

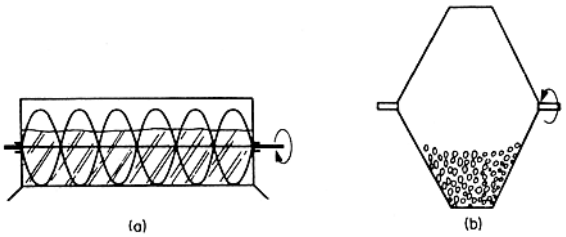
b) Less segregating mixers have mainly convective mixing mechanisms. These are typically impeller types in which blades, screws, screws, ploughs, etc., sweep groups of particles through the mixing zone.

Equipment;

-Tumbler mixers: Easy cleaning and emptying and power consumption and wear are low to moderate. Operating with tumbling the solids inside a revolving vessel; may be fitted with baffles, etc., to assist mixing, or with internal rotating devices to break up agglomerates; operate at speeds up to about 100 rpm (about half the critical speed - at which the centrifugal force on the particles exceeds the pull of gravity); working capacity is about 50 to 60% of volume; best suited to gentle blending of particles with similar physical characteristics, segregation can be a problem; equilibrium is generally reached in about 10 to 15 minutes

-Horizontal trough (screw conveyor) mixers: An agitator mixes material in a trough. Reasonably gentle mixing but with shear and impaction. Not suitable for very cohesive materials. Used for addition of small amounts to larger components, but can be difficult to clean. Consist of semi-cylindrical horizontal vessels in which one or more rotating devices (such as screw conveyors or a ribbon mixer) are located; in a typical ribbon mixer one ribbon moves the material slowly in one direction, while the other moves it quickly in the opposite direction, so there is a net movement of material, and the system can be used as a continuous mixer; particle damage can occur due to the small clearance between the ribbon and the vessel wall, and the mixer has a high power requirement; segregation is less of a problem

-Others: Rotating shapes, Orbiting screw, Pan mixer, Z-blade, Muller or edge runner mill, High speed impeller, Vertical screw mixers, Fluidized bed mixers etc.



(a) Screw/horizontal mixer (b) Tumbler (double-cone) mixer

Three mechanism types are often used to describe mixing performance: *diffusion (diffusive mixing)*, but *not* molecular diffusion - an expanded bed of free flowing material occurs with particles in random movements, *convection (convective mixing)* - when volumes, or regions, of the mix are moved en-masse to different areas, and *shear (shear mixing)*- mixing occurs along the slip planes between regions of particles. The mixer type needs to be right for the material mixed, e.g. cohesive powders are more likely to require shear (and convection) hence blades and ploughs are more appropriate than tumbling.

3.4.1. Mixing of widely different quantities

Mixing is simplest when the quantities that are to be mixed are roughly in the same proportions. In cases where very small quantities of one component have to be blended uniformly into much larger quantities of other components, the mixing is best **split into stages**, keeping the proportions not too far different in each stage.

For example, if it were required to add a component such that its final proportions in relatively small fractions of the product are 50 parts per million, it would be almost hopeless to attempt to mix this in a single stage. A possible method might be to use four mixing stages, starting with the added component in the first of these at about 30:1. In planning the mixing process it would be wise to take analyses through each stage of mixing, but once mixing times had been established it should only be necessary to make check analyses on the final product.
(Ex:Mixing of 1 g product A into 1000 kg product B. Make mixing step by step; 1 g A+1 g B=2 g Total1, then 2 g Total1+1 g product A, then continue like this "step by step or by split into stage")

3.4.2. Calculation

Calculation is based on statistical analysis for the spots. At different time, the spots (samples) are taken and then statistical analysis are made to find I_M and mixing time. If particle sizes of products are different, Screen analysis is used to determine the mixing index. If not, the other techniques are used to separate blended samples (such as chemical analyses, color difference analysis between products etc.).

For screen analysis the following equations are used for calculation (!!!also see example):

1-Number of particle in spot and fraction:

In a sample of uniform particle of diameter D_p the total volume of the particles is (m/ρ_p), where m and ρ_p are the total mass of the sample and the density of the particle, respectively. Since the volume of one particle is V_p. The number of particles in the sample is "n";

$n= [m/ (\rho_p V_p)]$

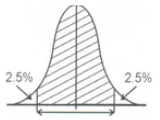
If two products are mixed such as A and B

Fraction (X)= n_A/n_T

where; n_T is total number of particles ($n_T = n_A+n_B$)

2-Standard deviation (σ): provides a satisfactory way of quantifying the extent to which the fractional concentration of a component scatters about its mean value in the various samples. It is given by:

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2} \quad (1) \qquad \bar{x}_m = \frac{1}{N}\sum_{i=1}^{N} x_{i,m} \quad (2)$$



where "σ" is the standard deviation, N is the number of samples taken (i.e. number of spot), x_1, x_2, ... x_n are the fractional compositions of component (in general it can be taken as particle number as fractional) in the 1, 2, ... N samples and "$\bar{x}$ "is the mean/average fractional composition of component (in general it can be taken as particle number as fractional) in the whole mixture (based on initially added amount).
(As a note, Eqn. 1 can be used for max. 30 sample (N<30), for the bigger sample number, Eqn. 1 should be modified as (1/N)).

3-Variances (σ) and Mixing Index (I_M):

Using Eqn. (1) values of **σ** can be calculated from the measured sample compositions, taking the "N" samples (# of spot) at different stages/duration of the mixing operation. Often it is convenient to use σ^2 rather than σ, and σ^2 is known as the variance of the fractional sample compositions from the mean composition (i.e. the *variance* of the mixture). For a perfect mix, σ (or σ^2) would equal zero. Lower standard deviations are found as the uniformity of the mixture increase (σ_∞=0). But σ_∞ =0 cannot be achieved, but in efficient mixers the value becomes very low after a reasonable period.

σ_o^2 = variance at t=0 (initial)
σ_r^2 = variance randomly =σ_o^2/n (n is particle number in spot for any product)

Consider a two-component mixture consisting of "fraction *p* of component A" and "fraction *q* of component B". Summing these in terms of fractional composition of component A and B and remembering that $p + q = 1$.

In the unmixed state (when t=0, added quantity at first to mixer) virtually the samples taken will consist either of pure A or of pure B.

$\boldsymbol{\sigma_o^2}$ = $1/N [pN(1 - p)^2 + (1 - p)N(0 - p)^2]$ (for N samples)
= **p(1 - p)**

When the mixture has been **thoroughly dispersed**, it is assumed that the components are distributed through the volume in accordance with their overall proportions. The probability that any particle picked at random;

$\boldsymbol{\sigma_r^2}$ = $p(1 - p)/n = \boldsymbol{\sigma_o^2/n}$

For example, this might be the mixing of equal-sized particles of sugar and milk powder. The subscripts o and *r* have been used to denote the initial and the random values of σ^2, and inspection of the formulas show that in the mixing process the value of σ^2 has decreased from $p(1 - p)$ to 1/n th of this value. It has been suggested that intermediate values between σ_o^2 and σ_r^2 could be used to show the progress of mixing. Suggestions have been made for a **mixing index**, based on this, for example:

$$I_M = (\sigma_o^2 - \sigma^2)/(\sigma_o^2 - \sigma_r^2)$$

which is so designed that (I_M) goes from 0 to 1 (Note:0.95 (practical), 1 (theoretical) mixing index) during the course of the mixing process.

4-Mixing time and Mixing rate

Once a suitable measure of mixing has been found, it becomes possible to discuss rates of accomplishing mixing. It has been assumed that the mixing index ought to be such that the rate of mixing at any time, under constant working conditions such as in a well-designed mixer working at constant speed, ought to be proportional to the extent of mixing remaining to be done at that time.

In mixing as in other rate processes, the rate is proportional to the driving force. The mixing index I_M is a measure of how far mixing has proceeded toward equilibrium. It has been found that for short mixing times the rate of change of I_M is directly proportional to $1-I_M$.

$$I_M = (\sigma_o^2 - \sigma^2)/(\sigma_o^2 - \sigma_r^2)$$

$$d I_M / dt = \mathbf{k [1 - I_M]}$$

where (I_M) is the mixing index and k is the mixing rate constant, which varies with the type of mixer, conditions (rpm etc.) and the nature of the components and t (s) mixing time, and it can also be used to predict, for example, the **times required to attain a given degree of mixing**. On integrating from $t = 0$ to $t = t$ during which (I_M) goes from 0 to (I_M),

$$[1 - I_M] = e^{-kt}$$

or $(I_M) = 1 - e^{-kt}$ or $\mathbf{\ln (1-I_M) / t = k}$ (Note: t is time at spot taken)

The equilibrium value of I_M is 1 (for the practical application (or for actual value) I_M is taken as 0.95) therefore the driving force for mixing at any time can be considered to be $1-I_M$ with rearranging and integrating between limits

$$t = (1/k) [\ln (1-I_{M,0}) / (1-I_M)]$$

or

$$\mathbf{t_M = \ln (I_M) / k}$$ **(t_M:Optimum mixing time; I_M: <u>at</u> 0.95 or 1)**

As a note the mixing index at zero mixing;

$$I_{M,0} = (n /(n-1))$$

5-Mixer efficiency

The efficiency of a mixer or blender (η_M) has been proposed where

$$\eta_M = (\sigma / \sigma_o)$$

6-Power of mixer power and energy usage

Note: Your equipment is one-phase!!!

P (Power, W or kW) = I (Ampere) * V (Voltage) (one-phase)

P (Power, W or kW) = $\sqrt{3}$ * Cos θ * I (Ampere) * V (Voltage) (Three-phases) E (Energy, Wh or kWh) = P (Power) * t (time)

<u>!!!As a note: Ampere is also measured continuously in industry to prevent the burning/over loading of motor (protection of equipment).</u>

<u>3.5. SIZE REDUCTION AND ENERGY FOR MILLING</u>

Read related Chapter (Size reduction) from Geankoplis Textbook. Especially, equation used for calculations.

<u>3.6. PNEUMATIC CONVEYING</u>

Read related Chapter (Size reduction) from Geankoplis Textbook.

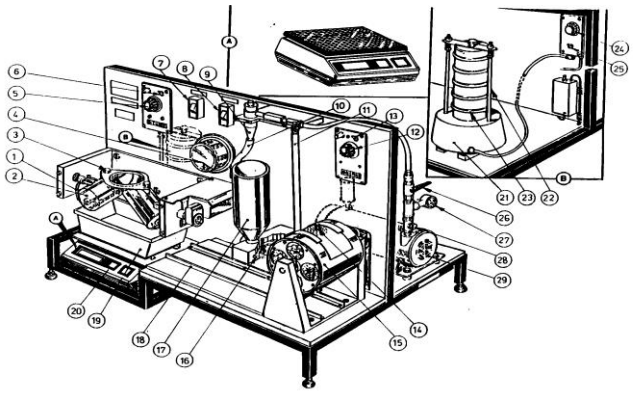
3.7.BALL MILL

Read related Chapter (Size reduction) from Geankoplis Textbook.

4-EXPERIMENTAL/PROCEDURE

Materials:
2 kg semolina+2 kg bulgur (coarse type-pilaf size bulgur)

Equipment:



4.1.BULK DENSITY (HECTOLITER WEIGTH)

Procedure:

1-Graduated cylinder method:

- Fill a graduated measuring cylinder with sample of the material to be tested and determine the weight using the digital balance.
- Compact the material using moderate pressure and top up with more compacted material to fill the cylinder again to the level.

2-Hectoliter-weight apparatus:

Repeat this experiment by using special Hectoliter- weight apparatus.
!!!Calculate kg/m^3 as bulk density. Compare results based on particle size.

4.2. ANGLE OF REPOSE AND SLIDING ANGLE

Procedure:

1-Angle of repose:

- Fill the half of cylindrical apparatus with the sample individually (at the half, use the horizontal line for the filling level). To fill, use a funnel.
- Turn the cylindrical apparatus slowly until the first sliding of the sample. Record this angle for both samples.

!!!Compare the angles based on the particle sizes.

2- Sliding angle:

- Put certain amount of samples on the surface of metal and plastic surface.
- Incline the metal and plastic surface/plates slowly
- Determine first sliding of sample and measure the angle by using miter.

!!!Compare the angles based on the particle sizes.

4.3. SILO/HOPPER/BIN/BUNKER DISCHARGE RATE/CAPACITY AND ORIFICE DIAMETER

Procedure:

a)Determination of "n and k" values:

- Fill the hopper about 2/3rds (until 220 or 250 mm) full with materialOpen the selected orifice (6, 9, 12, 15 mm) and collect the discharged material in the balance pan for a measured period of time (10 sec.). *(!!!Find g/min).*
- The flow should then be stopped and the pan moved along the rail to be weighed on the digital balance. This procedure should be repeated using each of the four different orifices (6, 9, 12, 15 mm) in turn. Each test should use both material and the same initial head of material above the orifice plate.
- *!!!Calculate n and k constant by sketching log (linear) graph.*

b)Determination of flow regime (mass or funnel flow) in silo:

- Fill silo/bin/hopper/bunker with the product.
- Adjust orifice to 15 mm.

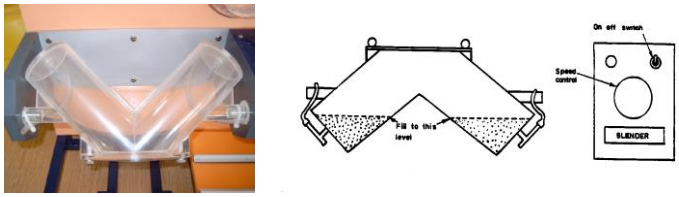
- *!!!Then observe and record flow regimes at top and bottom of silo for separately fine (semolina) and coarse (bulgur) products. What happen?*

4.4. SOLID/SOLID MIXING

Procedure:

Materials: Semolina, bulgur (pilaf size/coarse), timer, graduated cylinder (25 and 250 mL), analytical balance (+/- 0.01 g), sieve (1 mm aperture) (Frame diameter is app. 5 cm, for sample sieving)

Cone type tumbling mixer



V-Shape tumbling mixer

Ribbon type (screw conveyor) mixer

Voltmeter/ Ampermeter

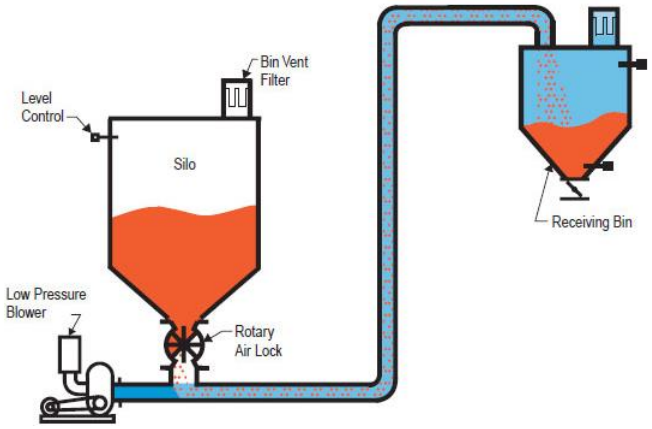
1. Semolina and bulgur are made from wheat. Only, their particle sizes are different.
2. Load the semolina and bulgur into the mixer (obtain quantities from supervisor).
3. Start to the mixing operation at constant rpm (by counting the revolution per minute).
4. Measure the Ampere and Voltage to calculate power and energy..
5. After 1 minutes (t=1 min.), stop the mixing.
6. And then collect nearly equal amounts of spots (spot means sample) from the mixer (if the number of sample increases, the result will be more correct).
7. Firstly, measure their hectolitre-weights (kg/m^3). Record them.
8. Then, sieve them using sieve (1 mm). Weight bulgur and semolina individually. Record them.
9. Continue the mixing operation for the next each 1 minute (t= 2, 3, 4, 5 mins.). Stop mixing at each time, then Repeat Step 7.
10. (Note: Same experiment can be made at different rpm and sample quantities to determine the effect of mixer speed and sample quantities.)

4.5. SIZE REDUCTION AND ENEGRY REQUIREMENT FOR MILLING:

-Mill the product then determine size. After determination of particle size by using screen, make calculation found in Geankoplis textbook.

4.6. PNEUNATIC CONVEYING AND CYCLONE (DEMO)

A pneumatic conveying system transfers powders, granules, and other dry bulk materials through an enclosed horizontal or vertical conveying line. The motive force for this transfer comes from a combination of pressure differential and the flow of air (or another gas) supplied by an air mover, such as a blower or fan. By controlling the pressure or vacuum and the airflow inside the conveying line, the system can successfully convey materials.



In Lab. Equipment:A compressor feeds air to an ejector, to the suction arm of which is connected transparent tubing for particle transport. The outlet of the ejector passes to a glass cyclone. A compressor (29) at the rear of the equipment provides air to an ejector for the purpose of pneumatic conveying. The suction arm of the ejector is connected to a flexible pipe (11) which forms the material intake. The outlet from the ejector passes to a glass cyclone (9) which separates the material from the air. Air is expelled from the top of the cyclone whilst the material is ejected at the base.	

4.7.BALL MILLING AND SIZE REDUCTION (DEMO)

Ball mill: To produce very fine product, inside rotating drum, different sized ball (steel or ceramic) are put, then rotated. Stricking balls to eachother crush the particles. Then screen balls from particles to separate them. It is used in chocolate industry, paste industry, ultrafine product. Power of mill is calculated by using Ritterger, Kink and/or Bond Equations.

In Lab. Equipment:A cylindrical vessel is charged with grinding material, and the comminution history of a batch of granular solids. The charge and rotational speed may be varied. The mill incorporates ceramic spheres of different sizes for the purpose of milling.	

CONCEPT OF REPORT:

QUESTIONS AND CALCULATIONS

A-BULK DENSITY (HECTOLITER WEIGTH)

A1-Calculate bulk densities of bulgur and semolina as kg/m^3?
A2-Which particle has bigger/smaller hectoliter-weight? Why?
A3-What are the practical applications of the hectoliter-weight in the food industry?
A4-What are the relationships of the hectoliter-weight with the particle size, ash and protein contents of the wheat (unprocessed, raw wheat)?
A5-Is there any difference between the results of "graduated cylinder" and "special apparatus"? Why?

B-ANGLE OF REPOSE AND SLIDING ANGLE

B1-Which product (semolina/bulgur) has bigger/smaller angle of repose and sliding angle? Why?
B2-What are the practical applications of the angle of repose and sliding angle in the food industry?
B3-What is the difference in the practice of "angle of repose" and "sliding angle"?
B4-Describe the reason between the difference in the results of plate materials (metal, plastic).

C-SILO/HOPPER/BIN/BUNKER DISCHARGE RATE AND ORIFICE DIAMETER

C1-Sketch the log graph.
C2-Find the k, n values.
C3*-!!!If in your plant, you want to feed your process from silo. The required capacity discharged from the silo is 10 ton/h of bulgur. What is the required orifice (discharge hole) diameter of silo? (use your experimental results).
C4*-!!!By using your experimental results (bulk density, angle of repose, sliding angle), we want to design a silo to store 50 tons of semolina (diameter of silo=3 m). Head space for safety is 10% of total volume. Draw your silo by showing; height of silo (head space, cylindrical part height, conical part height etc.
C5*-!!! Deal with Question C4*; if we want to discharge this silo within 45 minutes, What will be orifice (discharge) diameter?
C6-Which product showed mass and/or funnel flow? Where occurs (at top? Or at bottom of silo?)

D-MIXING OF SOLID PARTICLES

Given:

For bulgur particle (assume sphere);
ρ_p=1.24 x 10^{-3} g/mm^3, D_p= 1.2 mm
For semolina particle (assume sphere);
ρ_p=1.11 x 10^{-3} g/mm^3, D_p= 0.4 mm
Volume of sphere: $V_p = (4/3) * \pi * r^3$

D1-Questions:

D1-Before and after the sieving, you measured the hectolitre-weight. Draw a graph to show change of hectoliter of mixture at 1, 2, 3, 4, 5 minutes for bulgur and semolina (bulk density vs. time)?
D2-What is the importance of ampere?
D3-In mixing, if the amount of one sample (Sample A) (e.g. 1 ton) is higher than another (Sample B) (e.g. 2 g), how can you mix them? (Big difference between quantities).
D4-To analyze the mixture, we used screen analyze to separate and analyze the mixture (based on particle size difference between products). If we have a coffee mix (2 in 1 coffee, like coffee+milk powder) and all have same particle size, How can you analyze the mixture to find the their ratio instead of particle/screen analysis?

D5-Calculate (1) standard deviations, (2) coefficient of variations, (3) hectolitre-weights.
D6-Find k value.
D7-Find mixing indexes
D8-Plot mixing index vs. time.
D9-Calculate mixing time to reach the mixing index to 0.95.
D10-Calculate mixing efficiencies.
D11-Calculate the energy consumptions (at each time intervals) and power of the mixer motor.

E-SIZE REDUCTION AND ENERGY REQUIREMENT FOR MILLING:
E1-What are the particle sizes of sample/product before and after milling operation?
E2-Calculate required energy and/or power value?

RESULT PAPER: (Signed paper will be submitted with the report!!!)
NAME AND NUMBER OF GROUP:……..
Date: ……..
Sign of Instructor: Dr. Mustafa BAYRAM……..

A-ANGLE OF REPOSE

Name of sample	Size (Put X)	Angle of Repose "AR" (°)	Sliding Angle (°) "SA" Metal plate	Plastic plate
Bulgur	Big ( ) or Small ( )			
Semolina	Big ( ) or Small ( )			

B-HECTOLITER WEIGTH

Name of sample	Size (Put X)	HECTOLITER WEIGTH "Using **graduated cylinder**" (kg/m^3) [Don't forget the conversion]	HECTOLITER WEIGTH "using **special apparatus**" (kg/m^3) [Don't forget the conversion]
Bulgur	Big ( ) or Small ( )		
Semolina	Big ( ) or Small ( )		

C-HOPPER (DISCHARGE RATE)

a)Determination of "n and k" values:

Initial head of sample in the hopper =.....mm
Tare of sample box (pan):……..g

		BULGUR		**SEMOLINA**	
ORIFICE DIAMETER (mm)	TIME TAKEN (sec)	WEIGHT OF MATERIAL (g)	FLOW RATE (g/ sec)	WEIGHT OF MATERIAL (g)	FLOW RATE (g/ sec)
6	10				
9	10				
12	10				
15	10				

b)Determination of flow regime (mass or funnel flow) in silo:

Product at D=15 mm orifice diameter	**At top (initial) (Mass or Funnel flow)**	**At bottom (end) (Mass or Funnel flow)**
Bulgur		
Semolina		

D-MIXING OF SOLID PARTICLES

Mixer type: ……. Initial weigth of bulgur:…… Initial weight of semolina:…….	Rpm:……. Voltage:…….. Ampere:…….

Time t (min)	**SPOT 1**			**SPOT 2**		
	Hectoliter weight of mix (kg/m^3)	Weight of bulgur (g)	Weight of semolina (g)	Hectoliter weight of mix (kg/m^3)	Weight of bulgur (g)	Weight of semolina (g)
1						
2						
3						
4						
5						

E-SIZE REDUCTION AND ENERGY REQUIREMENT FOR MILLING

	Write with their units (mm or micrometer)
Initial particle size	
Final particle size	
Time	
Sample weight (g)	

Example for the mixing calculation:

QUESTION: In a pudding mix, powder vanilla (10 g) and powder sugar (60 g) are mixed. Three spots are collected from the mix at 2 and 4 minutes during the mixing operation. Calculate optimum mixing time?

Time (min)	Spot 1		Spot 2		Spot 3	
	Vanilla (gr)	Sugar (gr)	Vanilla (gr)	Sugar (gr)	Vanilla (gr)	Sugar (gr)
2	1.2	7.1	0.9	7.9	1.0	8.1
4	2.8	5.2	3.1	5.2	2.2	5.3

Hint:

For the powder vanilla and sugar (let's both products have same diameter and bulk density):

ρ_p (Particle density) = 0.9 x 10^{-4} g/mm^3; D_p (Particle diameter)=2x10^{-4} mm.

N=Number of spot= 3

1-Product weigth of A and B for calculation

2-Calculate number of particle

n= [m/ (ρ_p V_p)], V_p (volume of particle)= (4/3) * π * r^3, m:weight of the product in Spot

n should be calculated at initial condition (to find p, q, σ_o^2) by using added the sample quantities. Then, at each time internal, "n" should be calculated for each product again.

3-Then, calculate particle fraction of the product (p) by using initial weight of the products

$\sigma_o^2 = p(1 - p)$

4-Then calculate random variance at each time interval

$\sigma_r^2 = p(1 - p)/n = \sigma_o^2/n$,

5-Then, calculate standard deviation and variance at each time interval

Standart deviation= $\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2}$

N=Number of spot= 3

x: Particle fraction at each time for each spot

x^- : Average particle fraction (!!! It is taken from initial samples quantities, because it is target quantity/fraction to reach during mixing, so it can be taken as same with "p" value)

Variance: σ^2

6-Then, calculate Mixing index at each time interval

$I_M = (\sigma_o^2 - \sigma^2)/(\sigma_o^2 - \sigma_r^2)$,

7-Then, calculate k values at each time interval (by taking log)

$[1 - I_M] = e^{-kt}$

8-Then, take average of "k"→ k_{ave}

9-Then, at I_M=0.95 (at optimum mixing index value); calculate t_{mixing} by using;

$[1 - I_M] = e^{-kave*tmixing}$

This t_{mixing} is optimum mixing time.

SOL'N:

1-Product weigth of A and B for calculation

m_A= 10 g A, m_B= 60 g B

N=Number of spot= 3

2-Calculate number of particle

n= [m/ (ρ_p V_p)], V_p (volume of particle)= (4/3) * π * r^3, m:weight of the product in Spot

Initial (t=0) values (based on added samples quantities):

n_A (initial "t=0" number of particle, A)=[10/(0.9x10^{-4}*(4/3*3.14*(2x10^{-4}/2)^3))]= 2.65x10^{+16}

n_B (initial "t=0" number of particle, B)=[60/(0.9x10^{-4}*(4/3*3.14*(2x10^{-4}/2)^3))]= 1.59x10^{+17}

$n_T = n_{A+}n_{B=}$1.857x10^{+17}

3-Then, calculate particle fraction of the product (p) by using initial weight of the products

$\sigma_o^2 = p(1 - p)$

p (initial particle fraction of A)= 2.65x10^{+16} / 1.857x10^{+17} =0.144

q (initial particle fraction of B)= 1.59x10^{+17} / 1.857x10^{+17} =0.856

$\sigma_o^2 = p(1 - p)$=0.144(1-0.144)=0.123

4-Then calculate random variance at each time interval

$\sigma_r^2 = p(1 - p)/n = \sigma_o^2/n$ = 0.123/n (see Table)

For Step 5, 6, 7, 8, 9 follow the following **Table;**

Time (min)		SPOT 1			SPOT 2			SPOT 3			AVERAGE		Total (number of particle) nA(ave)+nB(ave)
		A	B	A+B	A	B	A+B	A	B	A+B	A	B	
2	m(gram)	1.2	7.1	8.3	0.9	7.9	8.8	1	8.1	9.1	1.03	7.70	
	n #	3.18E+15	1.88E+16	2.20E+16	2.39E+15	2.10E+16	2.34E+16	2.65E+15	2.15E+16	2.42E+16	2.74E+15	2.04E+16	2.32E+16
	Particle fraction, $x_{at\ t=2}$	0.145	0.855		0.102	0.898		0.110	0.890		0.119	0.881	
4	m(gram)	2.8	5.2	8	3.1	5.2	8.3	2.2	5.3	7.5	2.70	5.23	
	n #	7.43E+15	1.38E+16	2.12E+16	8.23E+15	1.38E+16	2.2E+16	5.84E+15	1.41E+16	1.99E+16	7.17E+15	1.39E+16	2.11E+16
	Particle Fraction, $x_{at\ t=4}$	0.350	0.650		0.373	0.627		0.293	0.707		0.339	0.661	

Time (min)	σ_o^2 $[\sigma_o^2 = p(1-p)]$	σ_r^2 $[\sigma_r^2=\sigma_o^2/n]$	σ (Take $\bar{x}=p=0.144$) (x for each Spot of one product)	σ^2	Mixing index (I_M)	k	k ave	t mixing (min, at $I_M=0.95$)
2								
	0.123	5.32E-18	0.038	0.0015	0.988	0.0370		
							0.0178	**168.4**
4								
	0.123	5.85E-18	0.417	0.1740	-0.412	-0.0014		