Image Analysis: Evaluating Particle Shape

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Why Image Analysis?

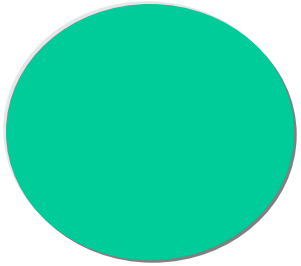
- Verify/Supplement diffraction results (orthogonal technique)
- Replace sieves

- Need shape information, for example due to importance of powder flow

These may have the same size (cross section), but behave very differently.

Why Image Analysis?

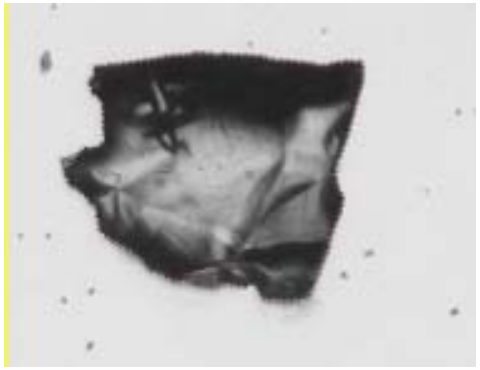
- Crystalline, acicular powders needs more than “equivalent diameter”



We want to characterize a needle by the length (or better, length and width).

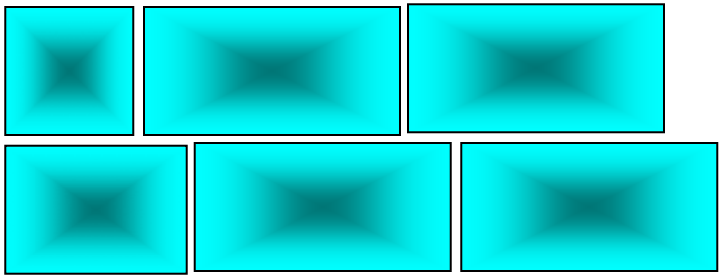
Why Image Analysis

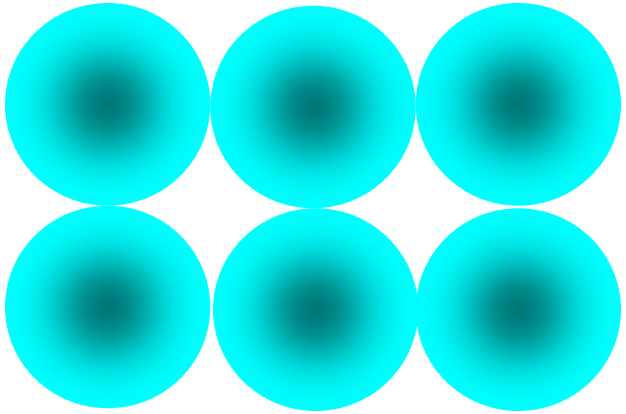
- Pictures: contaminants, identification, degree of agglomeration
- Screen excipients, full morphology
- Root cause of error (tablet batches), combined w/other techniques
- Replace manual microscopy



Why Shape Information?

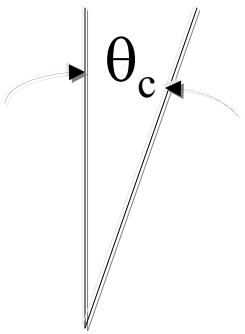
- Evaluating packing
- Evaluate flow of particles
- Evaluate flow around particles
- Retroreflection (optical properties)
- Properties of particles in aggregate (bulk)

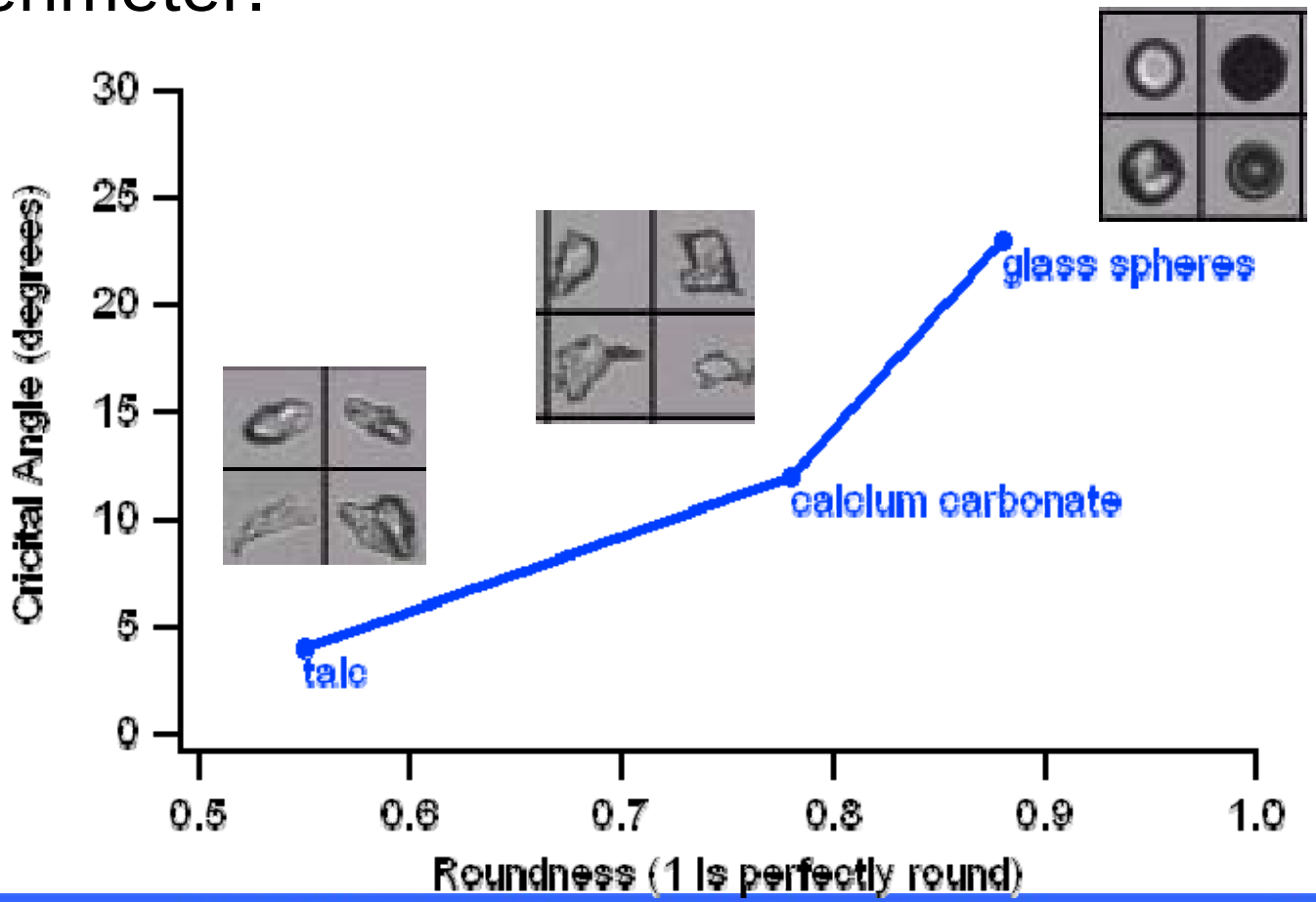




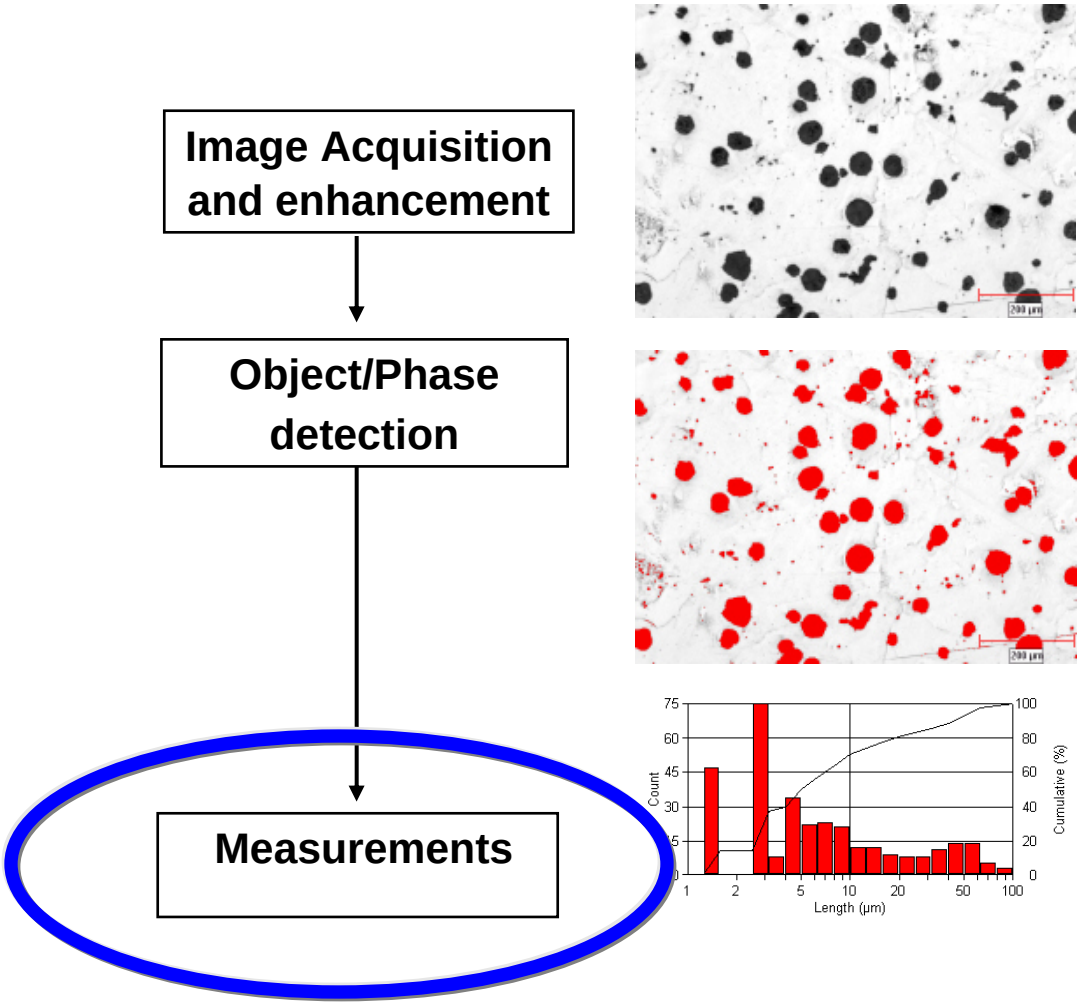
Effect of Shape on Flow

- Yes, I assumed density doesn't matter.
- Roundness is a measure based on particle perimeter.



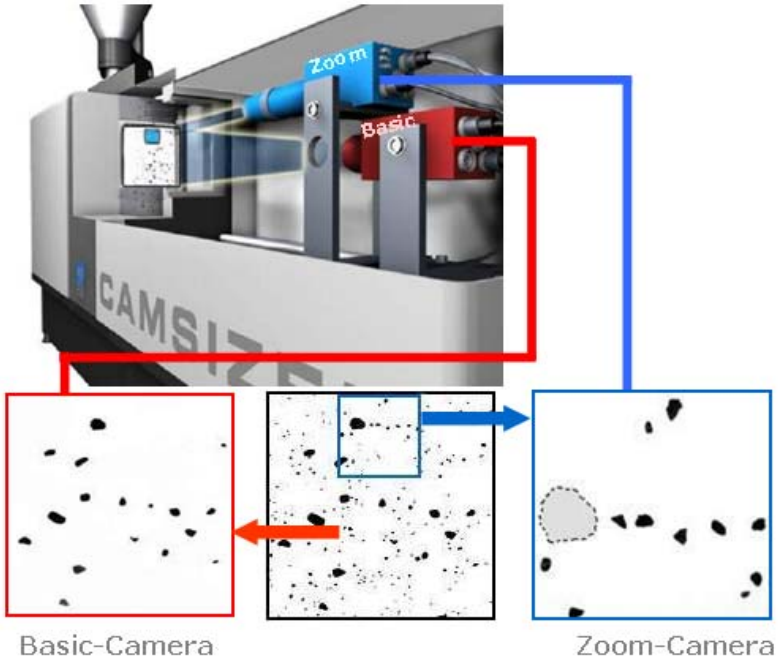


Major Steps in Image Analysis



Two Approaches

Dynamic:
particles flow past camera



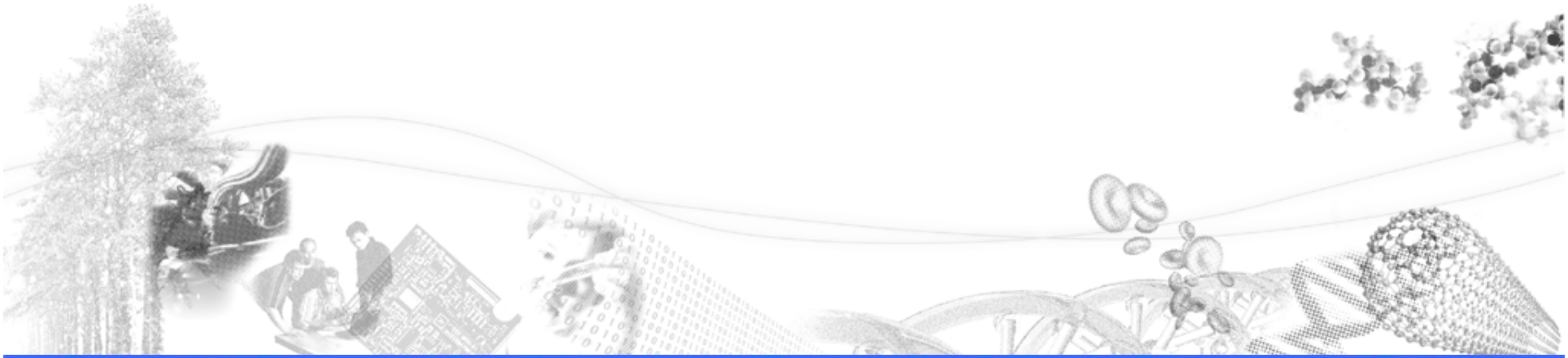
1 – 3000 microns

Static:
particles fixed on slide,
stage moves slide

0.5 – 1000 microns
2000 microns w/1.25 objective

Size Parameters -> Shape Parameters

Shape parameters are often calculated using size measures

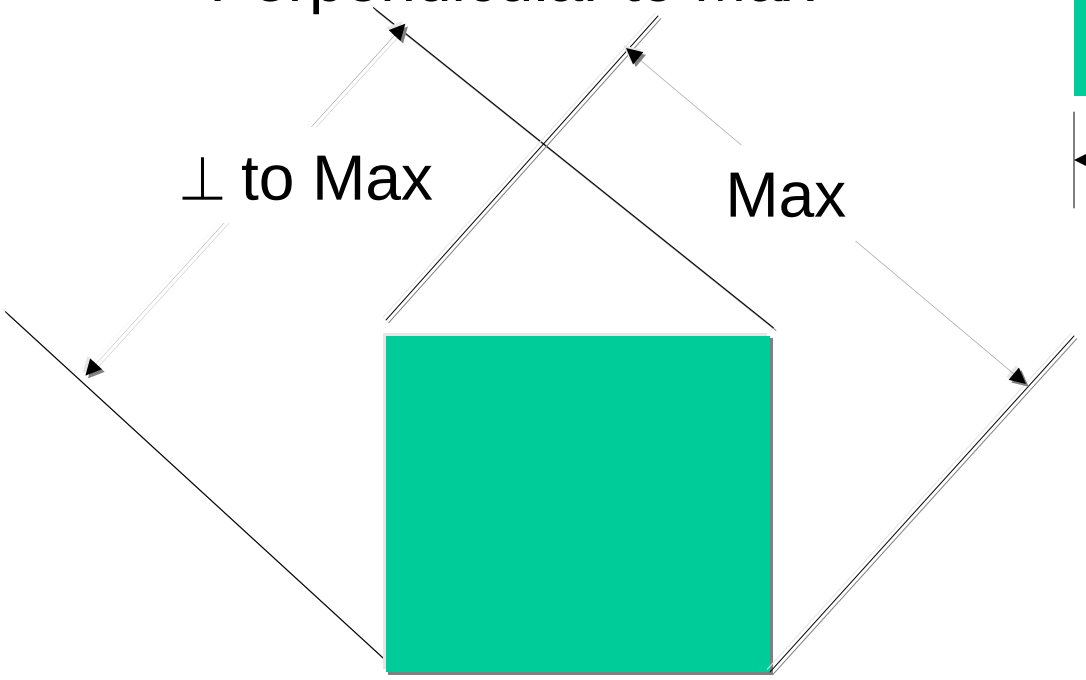


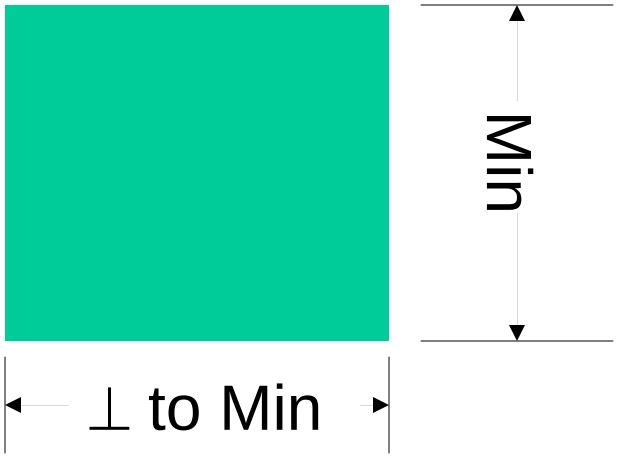
Size Parameters

- Feret
  - Max (length)
  - Perpendicular to Max (width)
  - Min (width)
  - Perpendicular to Min (main length)
- Area
  - Circular Diameter
  - Spherical Diameter
- Perimeter
- Convex Perimeter

Ferets

- Size as measured with a caliper
- Result depends on orientation of caliper
  - Min
  - Max
  - Perpendicular to Min
  - Perpendicular to Max

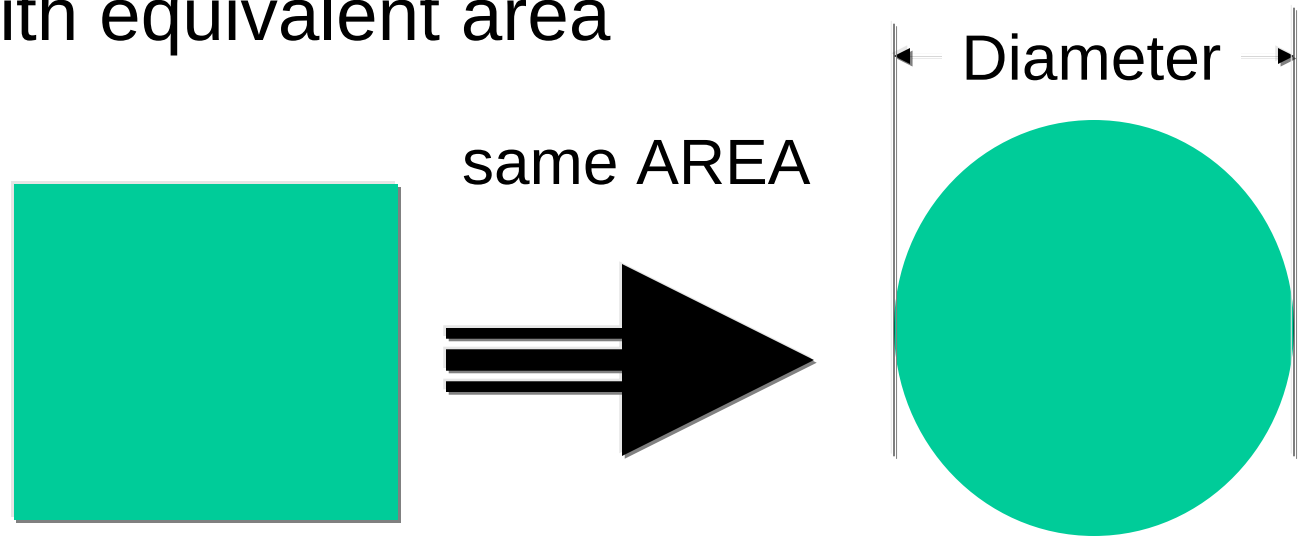




Area (Circular Diameter)

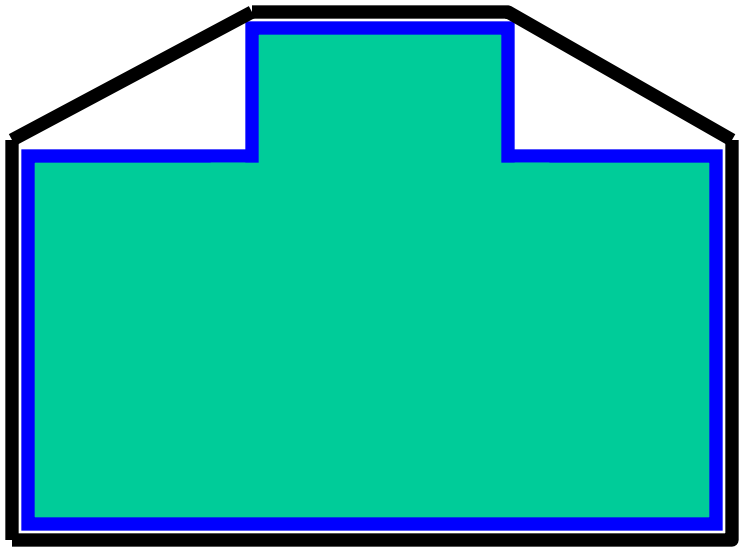
- Count pixels to find area of particle
- Convert to circle with equivalent area

$$2\sqrt{\frac{Area}{\pi}}$$



Perimeter, Convex Perimeter

- Perimeter follows exact contours of object
- Convex perimeter is like a rubber band.



Shape Descriptors

- aspect ratio
- roughness
- roundness
- sphericity

Shape Using a Chart

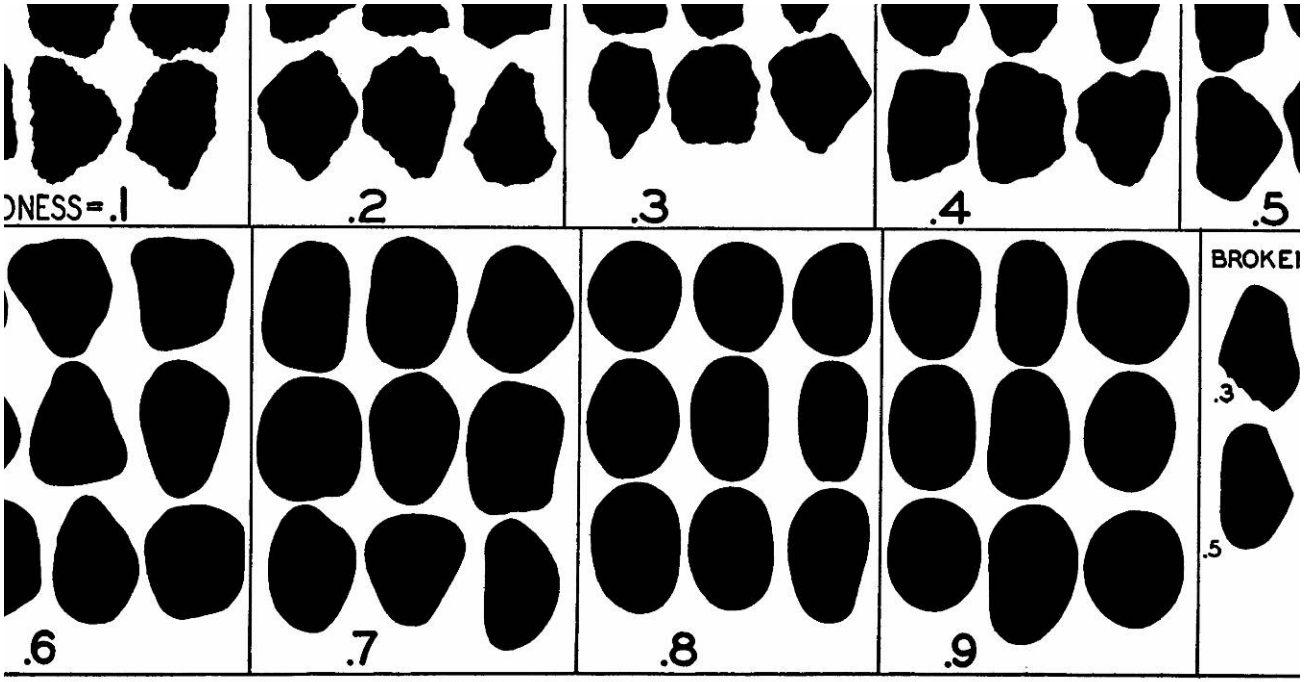


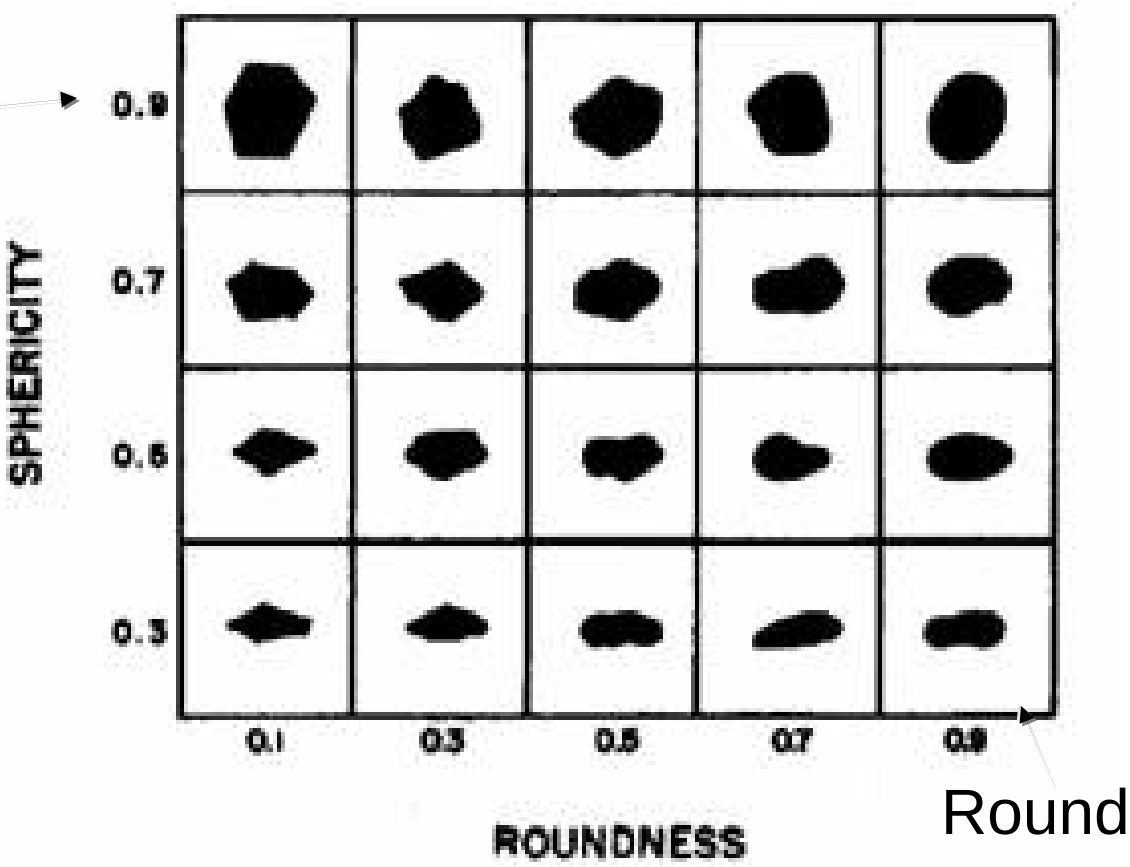
PLATE 1.—Roundness chart for 16–32 mm. pebbles.

Krumbein, Journal of Sedimentary Petrology, vol 11, no 2, pp 64-72, plate 1, August, 1941

A different chart

- Compare particles to a chart like the one below.

Overall shape like a sphere



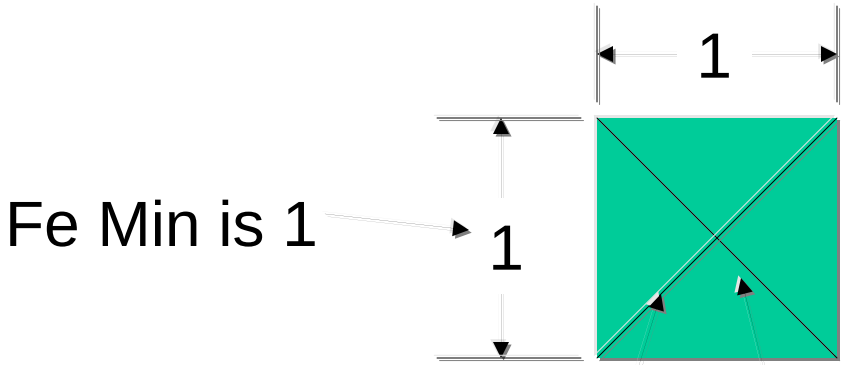
Round corners

Aspect Ratio

- Length of longest Feret over Length of shortest Feret
- Longest Feret over Feret perpendicular to longest Feret
- Feret perpendicular to shortest Feret over shortest Feret
- Or their reciprocal!

- Nice measure of deviation from roundness. Is not profoundly affected by bumps on particle surface.
- Measures “large scale shape”

Aspect ratios of square



Fe Max is diagonal: 1.414

Perp to Fe Max is diagonal: 1.414

Fe Max / Fe Min = 1.414/1 = 1.414

Fe Max / Perp to Fe Max = 1.414/1.414 = 1

Perp to Fe Min / Fe Min = 1/1 = 1

Salt Shape in Aluminum Foam

- NaCl is used to manufacture aluminum foams as a filler. The NaCl is subsequently dissolved away to leave a porous structure.
- The shape and size of the NaCl affects the foam structure and the final properties of the foam.

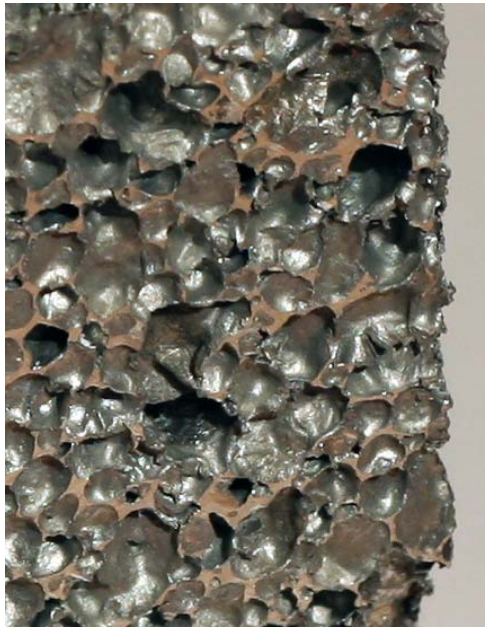


Image courtesy of Wikimedia Commons User Stehfun

C. Gaillard, J. F. Despois and A. Mortensen
Processing of NaCl powders of controlled size and shape for the microstructural tailoring of aluminium foams
Materials Science and Engineering A
Volume 374, Issues 1-2, 15 June 2004, Pages 250-262

NaCl Shape

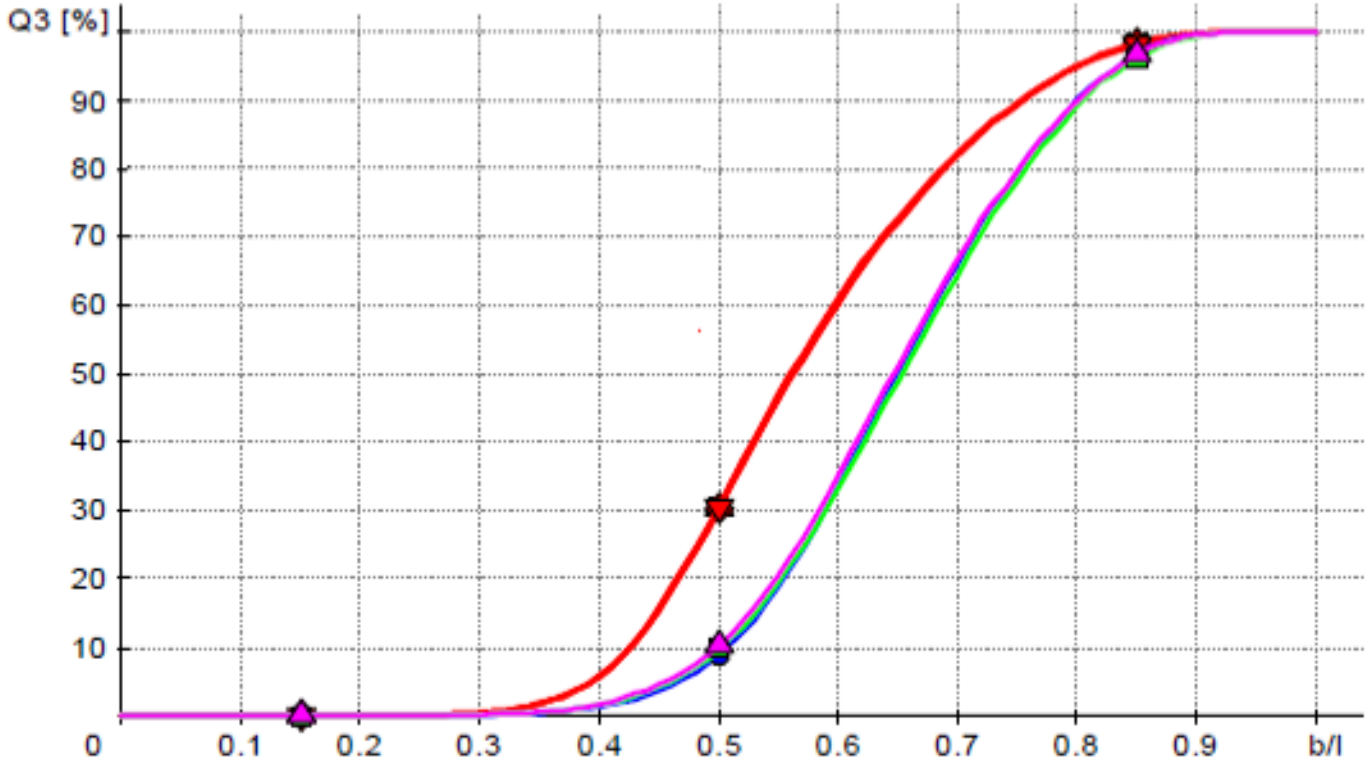
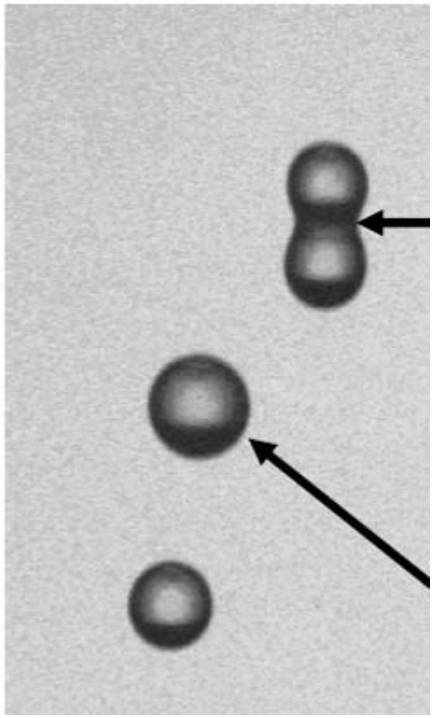


Figure 4: Aspect ratio (width divided by length) for two different salt products.

HORIBA Application Note AN189: size and Shape Analysis of Salt using Dynamic Image Analysis

Glass beads for reflective pavement marking

- Beads must be round to reflect light back to driver.
- Check aspect ratio of each particle, fail if too many particle have a value that is too low.



HORIBA Application Note AN140: Particle size and Shape analysis of glass beads for pavement markings

Acetaminophen (API)

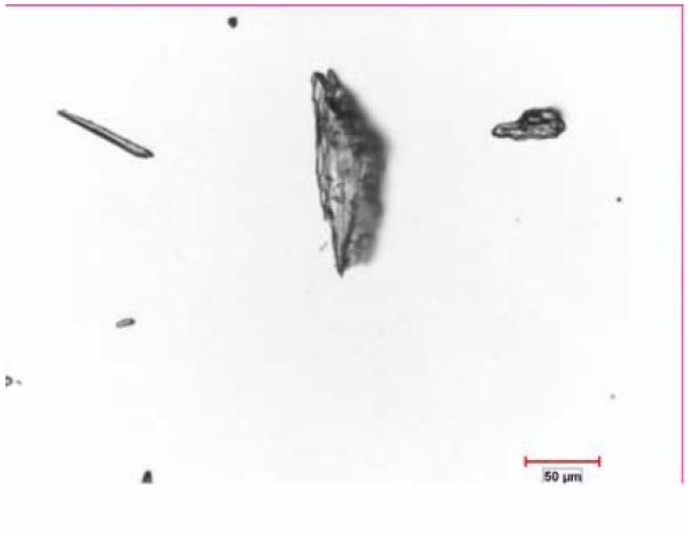
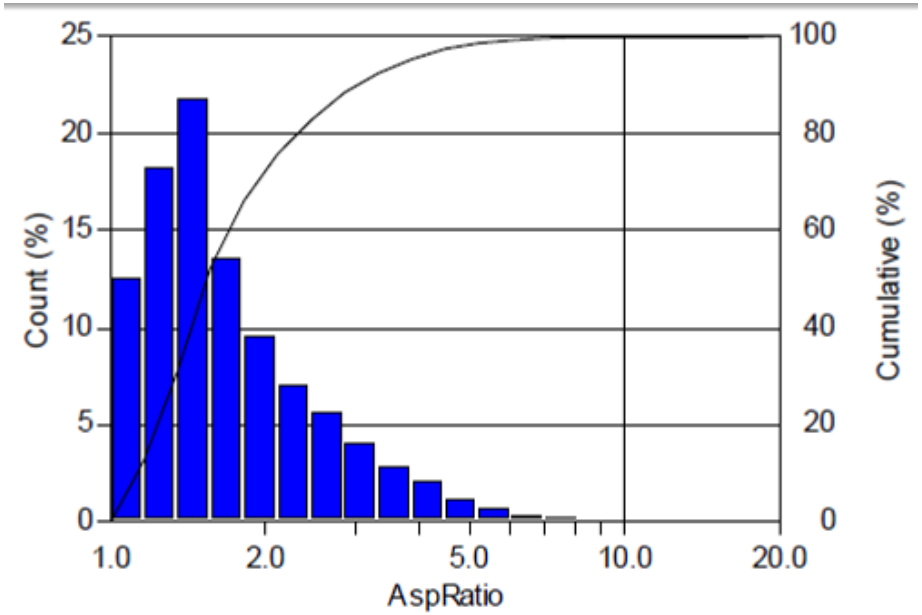


Figure 6: Acetaminophen at 200X

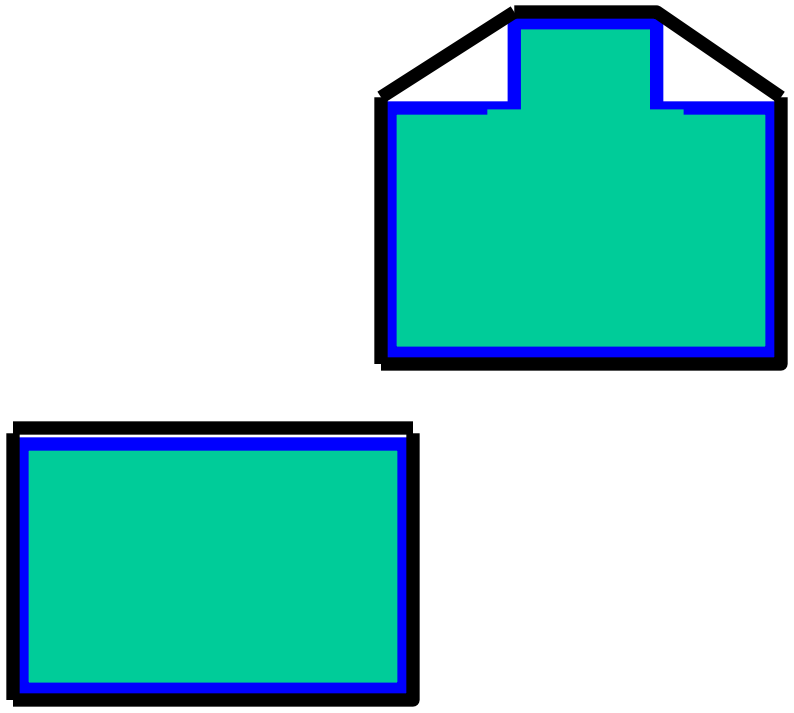


Mean	1.9
Std Dev	1.0
Min	1.0
Max	17.6
Count	11208

Roughness

- Jaggedness of edges
- Short scale. Roughness is sensitive to bumps on surface
- As surface has more concavities, the convex perimeter increases and therefore roughness decreases

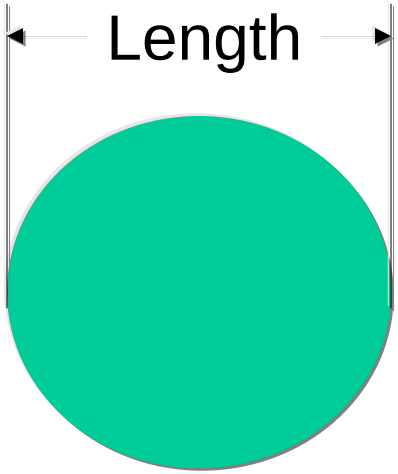
$$\frac{ConvexPerimeter}{Perimeter}$$



Roundness

- As particle becomes circular, value approaches one.

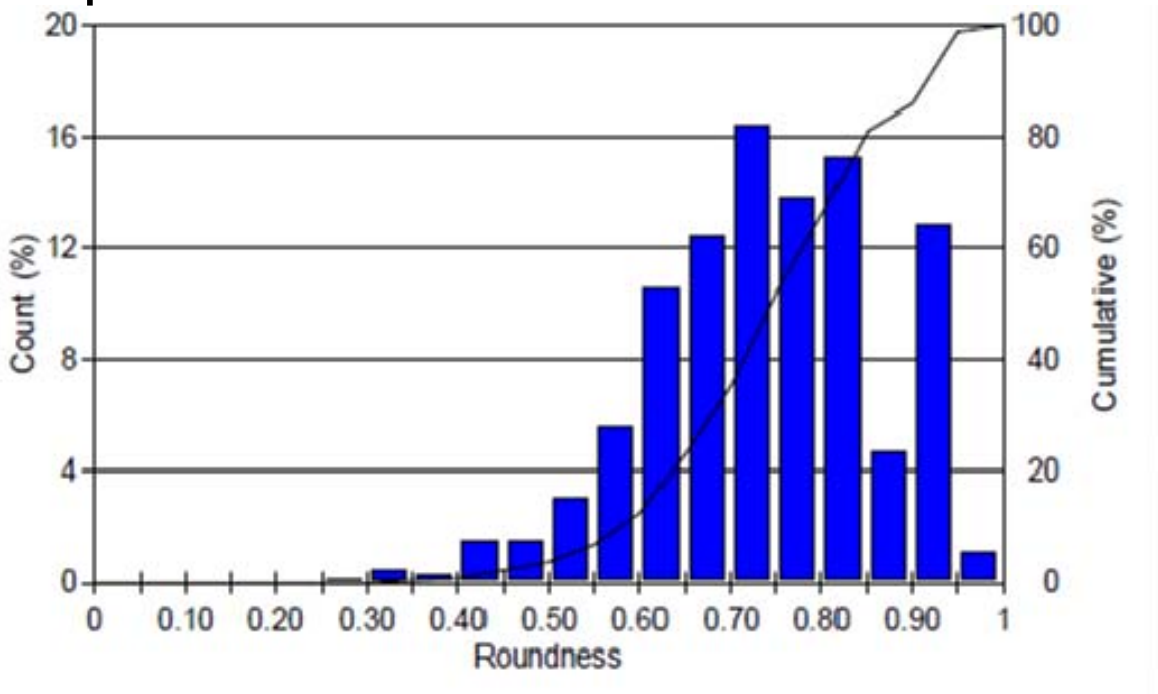
$$\frac{4(Area)}{\pi(Length_{FeMax})^2}$$



Roundness of metal particles

- Metal particles are used for powder metallurgy
- Round particles flow better (e.g., during injection molding) and provide stronger parts

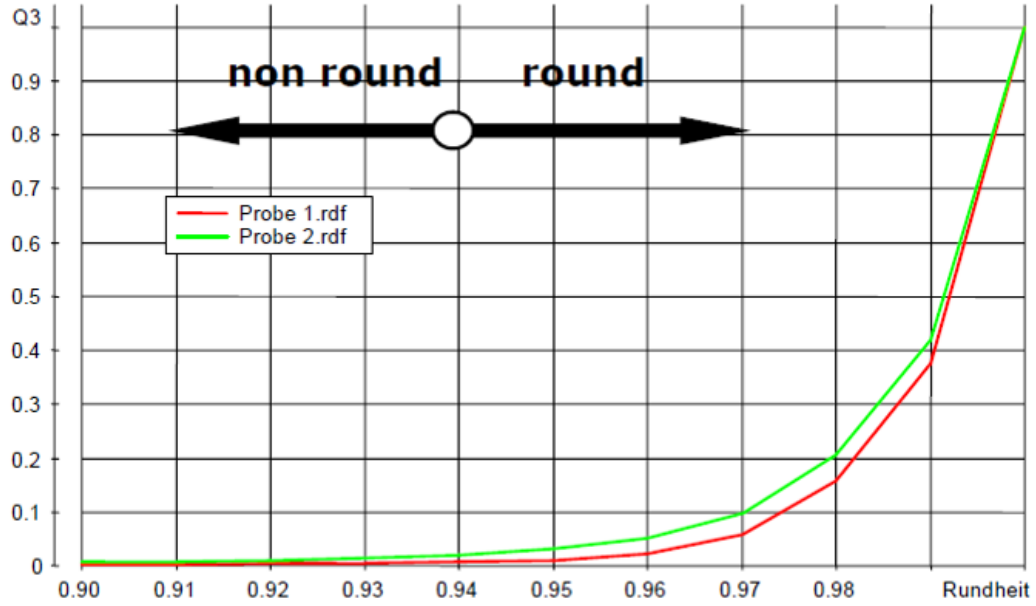
Low quality nickel alloy powder. Note the small fraction of very round particles



HORIBA Application Note AN164: Particle Size and Shape Analysis of Metal Powders

Pharmaceutical Globules

- Spheres from sugar are often used.
- Shape matters for future process steps
  - incorporation or coating of API's
  - Flow through dispensers



HORIBA Application Note AN140: Particle size and Shape analysis of glass beads for pavement markings

Acetaminophen (API)

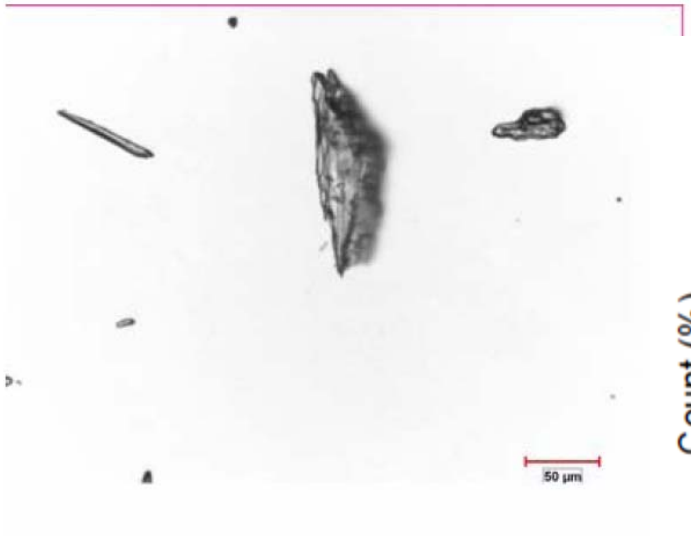
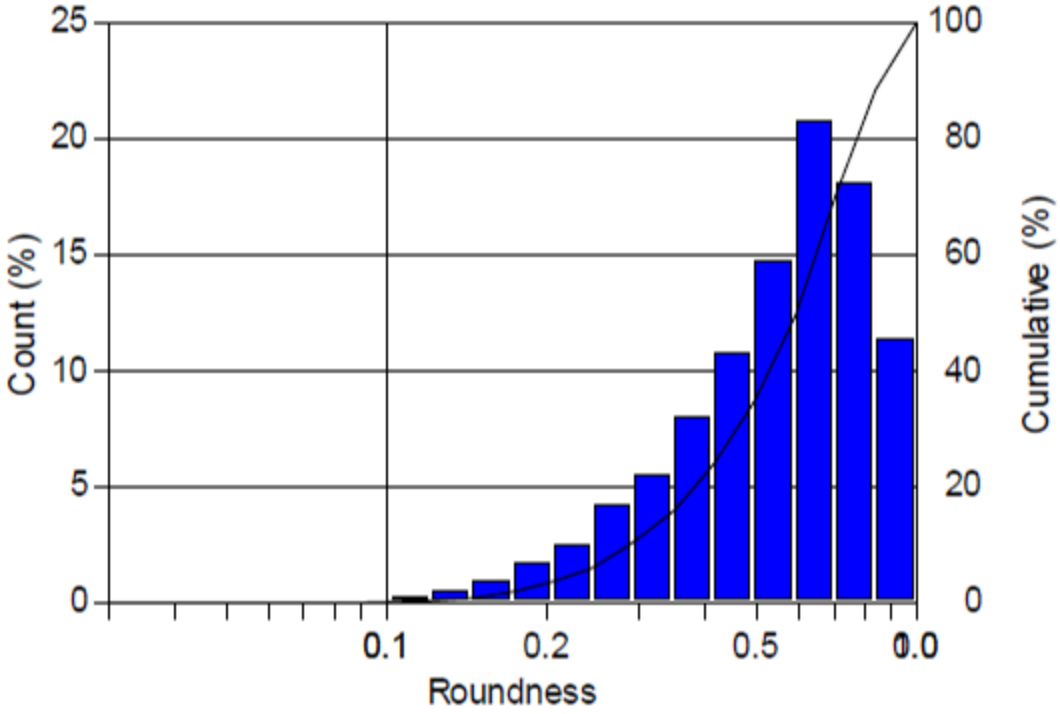


Figure 6: Acetaminophen at 200X



Mean	0.6
Std Dev	0.2
Count	11208
Field Count	400

Sphericity

- As particle becomes spherical, value approaches one.
- More sensitive to small scale bumps that increase perimeter than roundness.

$$\frac{4\pi(Area)}{(Perimeter)^2}$$

Circularity, Sphericity, Perimeter, Diameter

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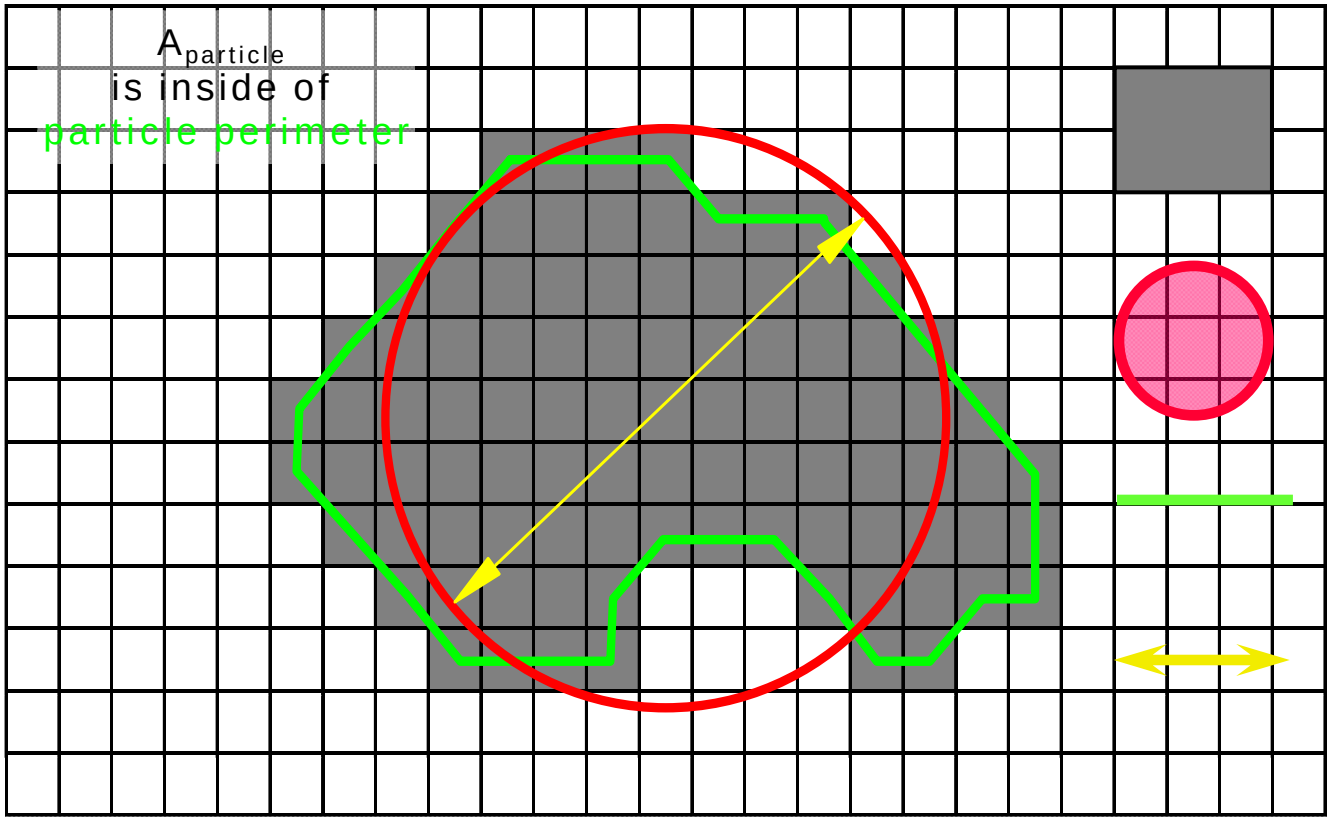
Circularity = perimeter of circle / perimeter of particle

Sphericity = Circularity² = $\frac{4\pi A}{P^2}$



$A_{green} \sim 77$ pixel, $diameter_{red} = 10$ pixel, $perimeter_{green} \sim 38{,}5$ pixel,

circularity $\sim 31/38{,}5 = 0.81$, **sphericity** $= 4 * \pi * 77/(38.5)^2 = 0.81^2 = 0.65$

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Proppants

- Hold open cracks in oils wells to allow oil to flow to well (Hydraulic Fracturing).
- Sand is one example of a proppant
- High roundness and sphericity leads to better permeability.
- ISO/DIS 13503-2 recommended sphericity and roundness of 0.6 or greater, 0.7 for high strength materials.
- Note that these definitions of sphericity and roundness are different from, but related to the one's used in this talk.

Distributions

- Just like size, many particle samples have a distribution of shapes.
- Sometimes a distribution of shapes is desirable. For example, according to the USGA, sand that is highly uniform in size and shape tends to be less stable. Therefore, sand with a variety of grain sizes and shapes is better for use in sand traps.

http://www.usga.org/course_care/articles/construction/bunkers/How-to-Select-the-Best-Sand-for-Your-Bunkers/

Size- & Shape Results

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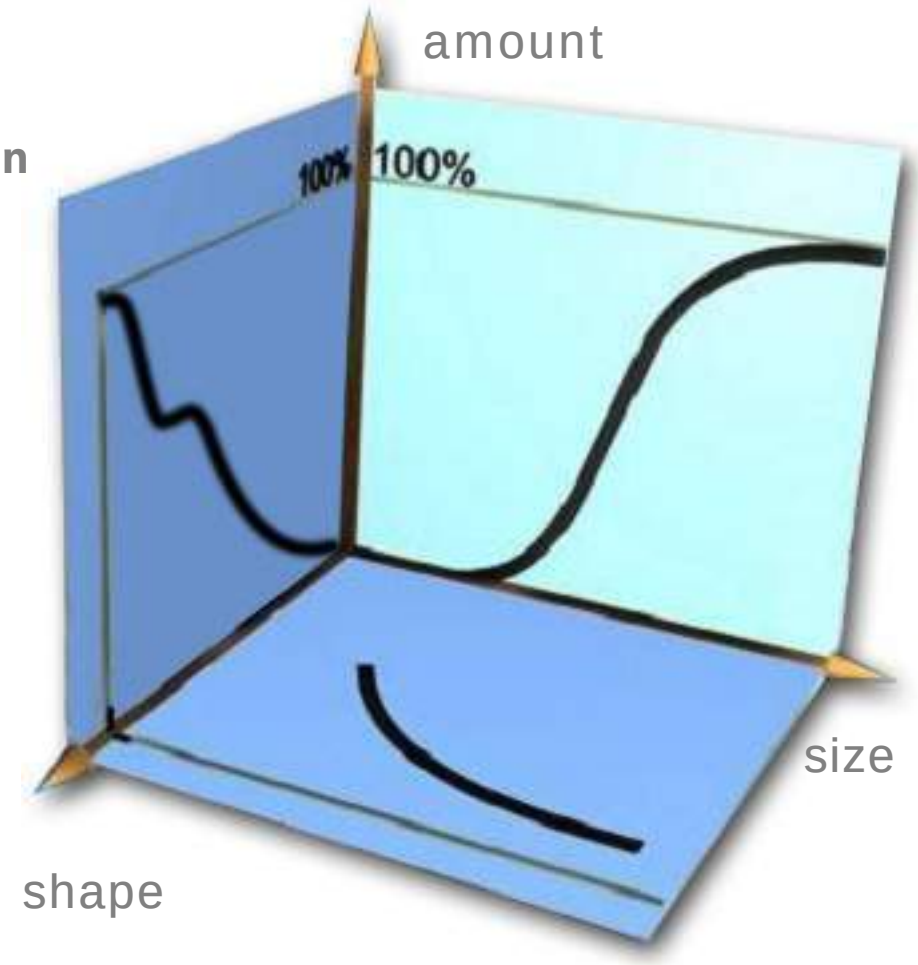
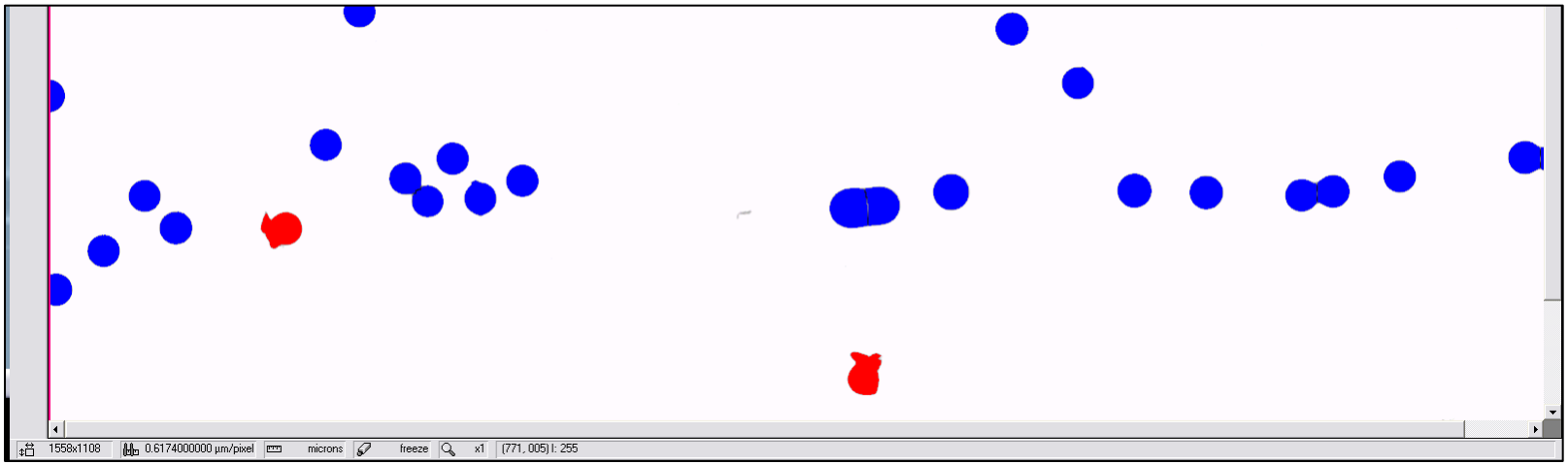
- **size + size distribution**
  - amount by size
- **shape + shape distribution**
  - shape by size
  - amount by shape

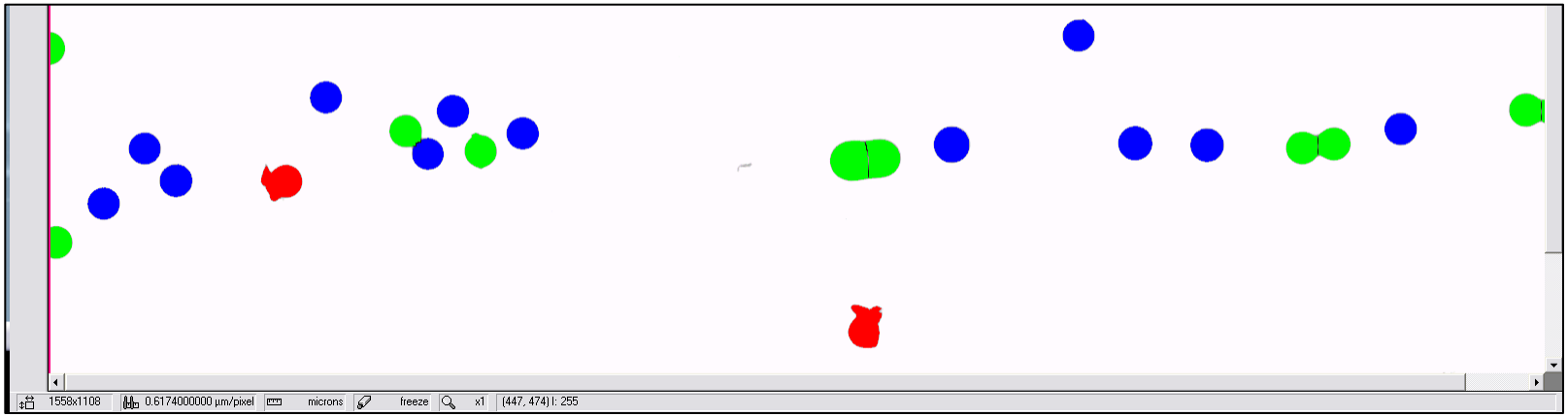


Sorting

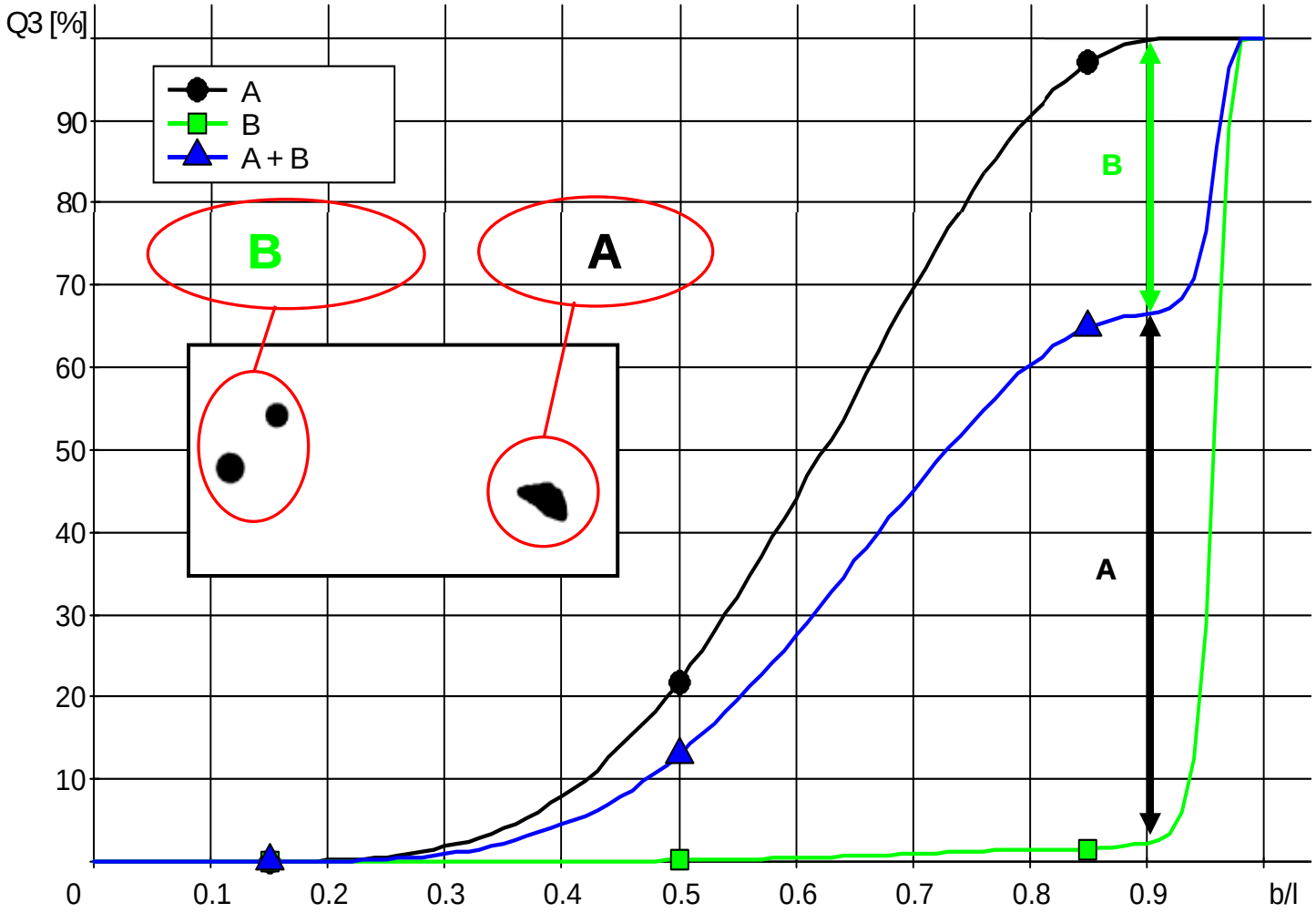
Roughness, “too rough” is red



Roundness, not round enough is green

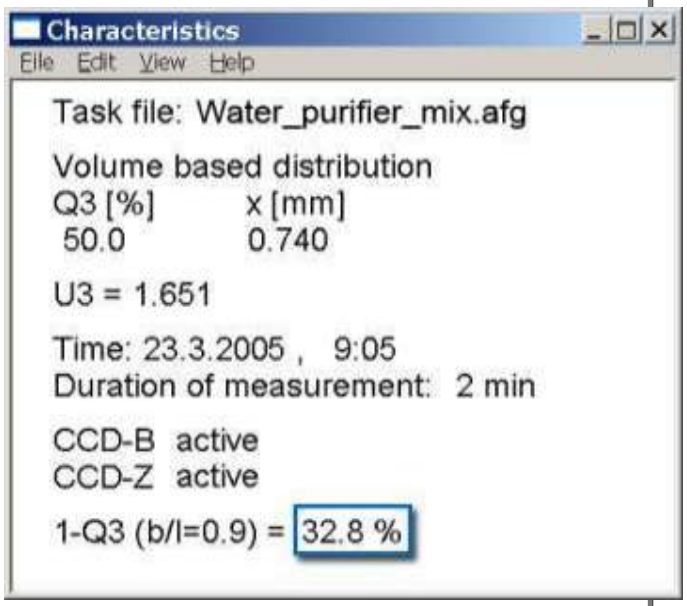


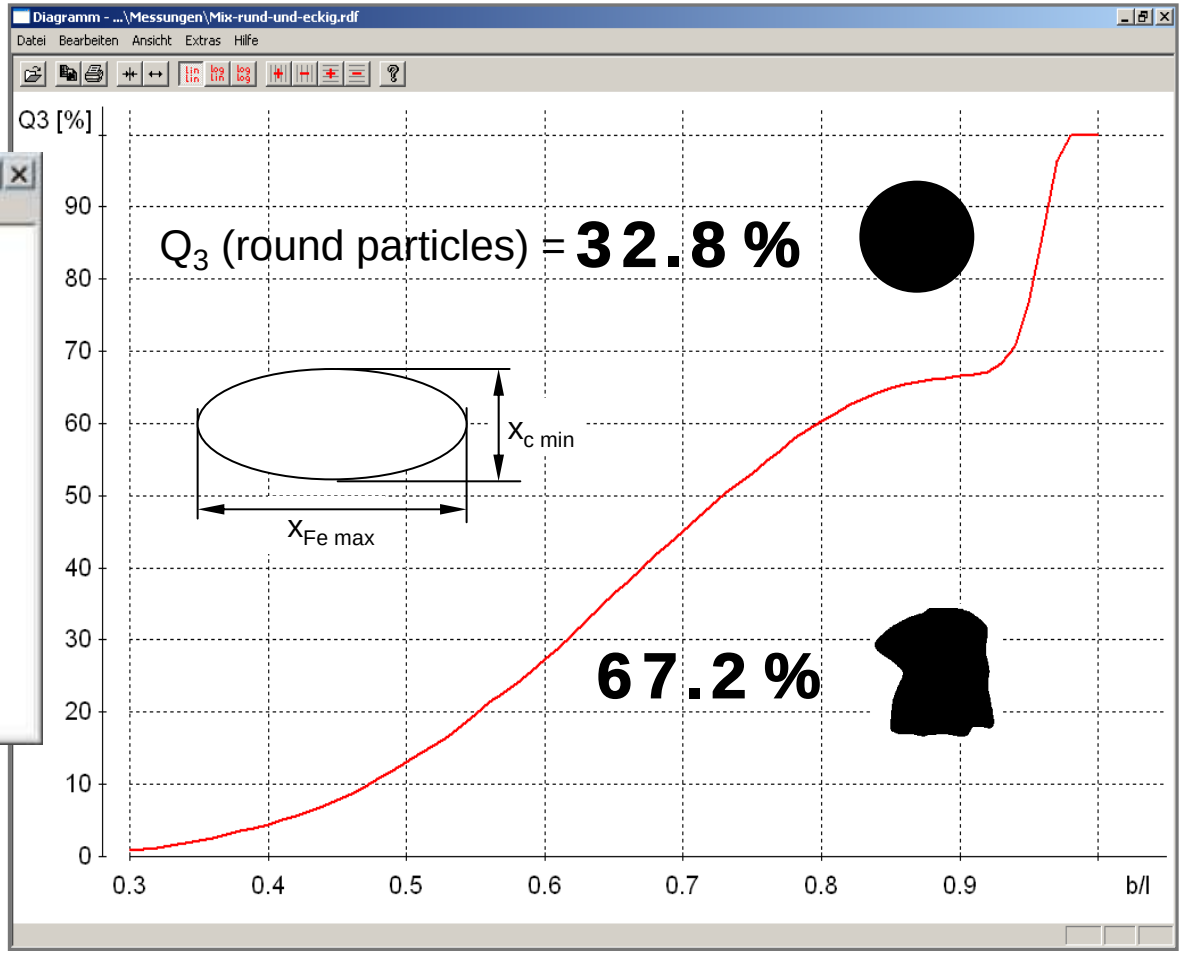
Particle Shape: Amounts in a Mixture



Particle Shape:

Amounts in a Mixture





The HORIBA PSA300

- Turnkey System
  - More time getting results and less time engineering
- Automated
  - Faster
  - Less operator labor
  - Less operator bias
- Powerful Software Features
  - Image Enhancement
  - Particle separation
- Separate Disperser Option
  - More flexible sample preparation

Static or Dynamic Image Analysis?

- Dynamic
  - Broad size distributions (since it is easier to obtain data from a lot of particles)
  - Samples that flow easily (since they must be dropped in front of camera)
  - Samples tumble so sometimes you see more orientations
  - Powders, pellets, granules
- Static
  - Samples that are more difficult to disperse (there are more methods for dispersing the samples)
  - Samples that are more delicate
  - Pastes, sticky particles, suspensions

Conclusions

- Image Analysis is good for
  - Size
  - Shape
  - Supplementing other techniques
- Shape Analysis is the next step beyond size
  - Choice of parameters is very application dependent.

Questions?

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