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THE INFLUENCE OF PRODUCT CHARACTERISTICS AND DOWNSTREAM PROCESS NEEDS, ON SOLUTIONS FOR THE DISTRIBUTION AND STORAGE OF BULK PARTICULATE SOLIDS, BY THE USE OF OCEAN-GOING SHIPPING CONTAINERS (PART 1)

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THE INFLUENCE OF PRODUCT CHARACTERISTICS AND DOWNSTREAM PROCESS NEEDS, ON SOLUTIONS FOR THE DISTRIBUTION AND STORAGE OF BULK PARTICULATE SOLIDS, BY THE USE OF OCEAN-GOING SHIPPING CONTAINERS

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FOREWORD

This paper covers the topic of the use of “lined” ocean-going shipping containers for the distribution and storage of dry particulate solids in bulk, as an alternative to the traditional methods of palletised bags or flexible intermediate containers (big-bags) for distribution and silos for storage. Whilst inland intermodal 30ft containers can be used for storage, this paper does not cover the use of such containers for distribution purposes. Having said this, many of the issues and considerations covered by this paper for the use of ocean-going shipping containers will apply to inland intermodal 30ft containers as well.

The term “lined” container, refers to the solution of lining a shipping container with a inner liner made from either polyethylene or woven fabric (polyethylene or polypropylene), with the addition of a “false bulkhead”. The purpose of this “lining” is to provide a barrier whereby neither the product or the container is being contaminated, thus satisfying both the producer of the product being contained and the shipping line owning the container.

In addition the paper will cover the considerations and decisions to be made in arriving at not only the most cost-effective solution, but the correct solution, taking into account the myriad of handling equipment and safety criteria that need to be considered.

Due the extensive scope of material covered by the subject, the paper is split into three parts:-

1. The Influence of material characteristics on the selection of container and liner.
2. The Influence of material characteristics on the selection of appropriate loading methods and equipment.
3. The influence of material characteristics on the selection of appropriate discharge methods and equipment.

The paper does not cover the aspect of logistics involved in every phase of Parts 2 & 3. This aspect is well covered in papers and guidelines issued by the European Chemical Transport Association (ECTA), based in Brussels.

PART 1 – THE INFLUENCE OF MATERIAL CHARACTERISTICS ON THE SELECTION OF CONTAINER & LINER

MAIN CONSIDERATION FOR THE PRODUCER

Quite often, buyers make such a decision firstly on cost considerations, without fully understanding the possible consequences of such, which in the long-term prove to be the wrong and non-cost effective solution.

This paper tries to show how the particle characteristics of the product being contained and the needs of the downstream process after delivery, can affect the solution decision outcome.

The two predominant questions producers ask when contemplating the concept of using shipping containers to distribute their product in bulk are:-

1. "How do I get my product in to the lined container" and
2. "How does my customer get my product out of the lined container and in to their process"?

Particulate solids come in so many guises and the characteristics of such can and will have an effect on so many aspects of the solution that needs to be arrived at. So let's take each characteristic in turn and what affect they have in considerations and influences that come into play on a given solution.

1. Specific Density:

   This actually plays little part in the overall finding of a solution, other than to give an immediate indication on the weight of the product being contained.

2. Bulk Density:

   This plays a major role in deciding a number of issues in the final solution. These being mainly:-

   2.1 Container size

   There is a range of ocean-going shipping containers to consider when looking to shipment of product in bulk. Below is matrix showing the basic range:-

		20′ container		40′ container		40′ high-cube container		45′ high-cube container	
		imperial	metric	imperial	metric	imperial	metric	imperial	metric
external dimensions	length	20′ 0″	6.096 m	40′ 0″	12.192 m	40′ 0″	12.190 m	45′ 0″	13.716 m
	width	8′ 0″	2.438 m	8′ 0″	2.438 m	8′ 0″	2.438 m	8′ 0″	2.438 m
	height	8′ 6″	2.591 m	8′ 6″	2.591 m	9′ 6″	2.896 m	9′ 6″	2.896 m
interior dimensions	length	18′ 10 5⁄16″	5.758 m	39′ 5 45⁄64″	12.032 m	39′ 4″	12.000 m	44′ 4″	13.556 m
	width	7′ 8 19⁄32″	2.352 m	7′ 8 19⁄32″	2.352 m	7′ 7″	2.311 m	7′ 8 19⁄32″	2.352 m
	height	7′ 9 57⁄64″	2.385 m	7′ 9 57⁄64″	2.385 m	8′ 9″	2.650 m	8′ 9 15⁄16″	2.698 m

volume	1,169 ft^3	33.1 m^3	2,385 ft^3	67.5 m^3	2,660 ft^3	75.3 m^3	3,040 ft^3	86.1 m^3
empty weight	4,850 lb	2,200 kg	8,380 lb	3,800 kg	8,598 lb	3,900 kg	10,580 lb	4,^{3}800 kg

2.2 Payload

Payload is an important criteria for a producer. It can make or break the use of the concept of using ocean-going shipping containers when compared to the intermediate bulk or 25kg bag solution.

For instance in a 20ft container, dependent upon the size of pallets or FIBC's, one can expect to get at least 20 of each in a single 20ft container or at best 22. If therefore each FIBC contains say 1tonne, then a payload of 20 or 22 tonnes can be expected. If each pallet of 25kg bags contains 40 bags, then each pallet will weigh 1000kgs, thus again a 20 – 22 tonnes payload can be achieved. If therefore less than 20 tonne is loaded into a single "lined" container, the concept of using a lined container to ship product in bulk will not provide a cost-effective solution on payload weight per cost of freight. Having said this, this comparison does not take into account other costs associated with both the FIBC and Bag solutions, such as packaging costs, pallet costs, pallet treatment costs and handling costs.

Payload is affected by not only the bulk density of the product, but also by the method of loading, which in turn is influenced by the flow characteristics of the product. Dependent upon the method of loading chosen, i.e. gravity, mechanical or pneumatic, the level of filling efficiency will vary. The matrix below gives a guideline of the different filling efficiency levels based on experience:-

Criteria	20ft	40ft
		
Theoretical volume	33.1 m^3	75.3 m
Practical volume efficiency		
- Gravity inclined	95%	95%
- Mechanical	85%	85%
- Pneumatic	80%	80%

Thus it can be seen by the above figures how the eventual payload can be affected by the method of loading, when one multiplies the volume by the filling efficiency and the bulk density of the product. For example:-

Polymer pellets with a bulk density of 500kgs / m^3 filled by gravity, mechanical means or pneumatic means into a 20ft container.

(i) Gravity:

$33.1m^3 \times 0.95 \times 500 = 15{,}722.5$ kgs

(ii) Mechanical

33.1m^3 x 0.85 x 500 = 14,067.5 kgs

(iii) Pneumatic

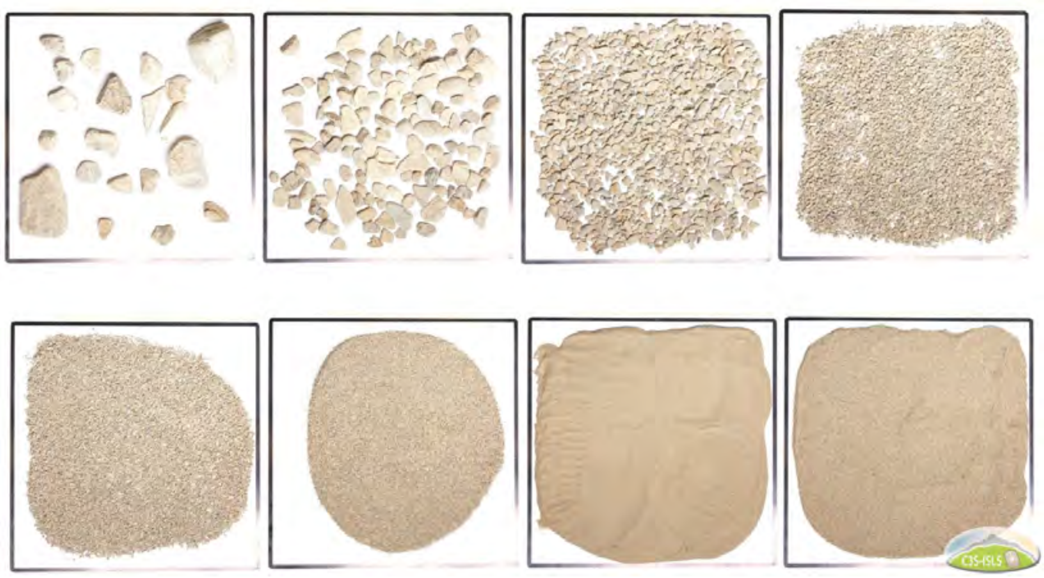
33.1m^3 x 0.80 x 500 = 13,240 kgs

It can be seen by the above example, that a 40ft container with its larger volume capacity would be chosen to maximise the payload. The questions then would be whether (i) are 40ft containers as easily available to the producer as 20ft containers and (ii) what would the comparison hire charges be.

3. Particle Size and Particle Size Distribution (PSD):

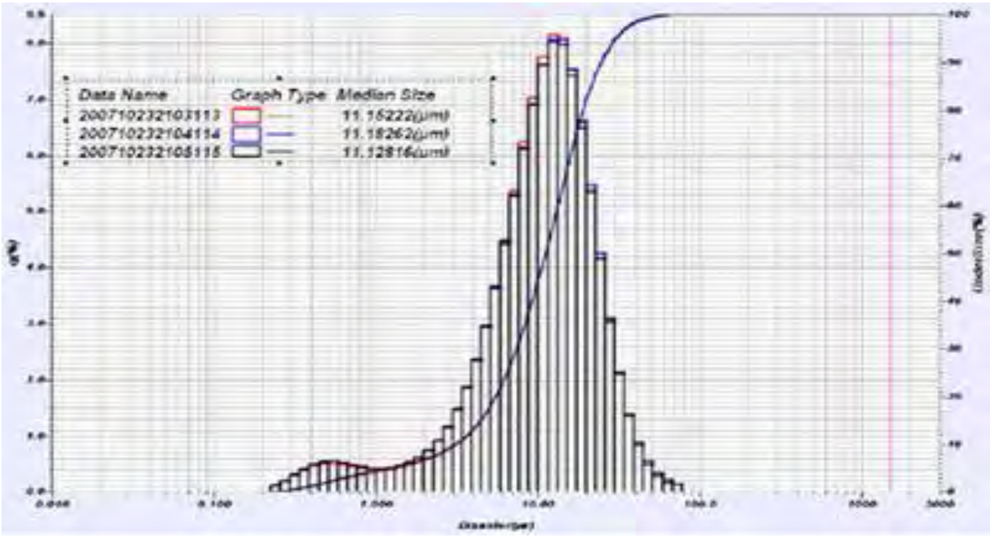
The particle size in any given product varies in any given volume. The size of a particle is usually measured in microns. The distribution of size in any given volume is determined through a multi-layered sieve (see photo below) vibrated for a period of time, to allow the different sized particles to find their appropriate mesh layer.

The quantity found on each mesh layer is then measured against the total to determine the percentage of each size range and to create a resulting graph. Below is a photo of a grain product showing the range of particle size in any given volume.



A PSD graph can give an instant indication to a qualified eye as to whether it is a free-flowing product or a cohesive non free-flowing product.

An example of a PSD analysis of a grade of cement is shown below:-



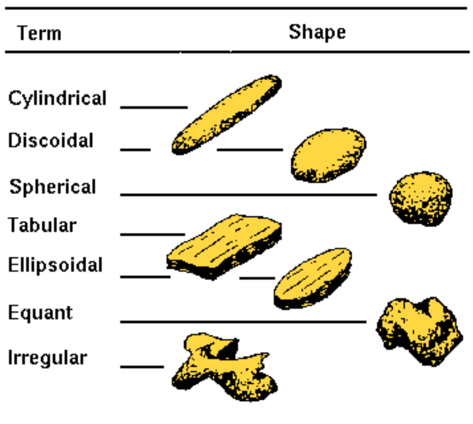
This graph would normally represent a cohesive difficult flow product.

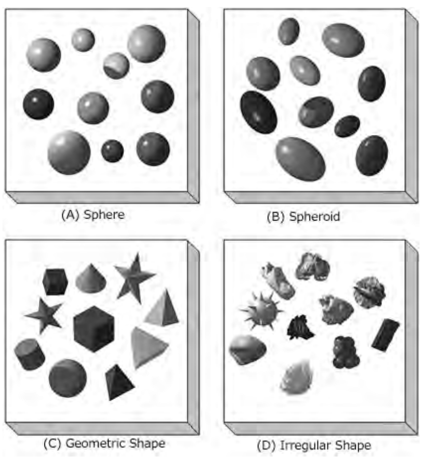
4. Particle Shape:

Encyclopedia.com defines particle shapes as

"Particle shape is defined by the relative dimensions of the long, intermediate, and short axes of the particle. The ratio of intermediate to long diameter and the ratio of short to intermediate diameter is used to define four shape classes. These are: oblate (tabular or disc-shaped forms); prolate (rod-shaped); bladed; and equant (cubic or spherical forms)."

To further explain this, the images below show the main "categories" recognized by most powder handling companies:-



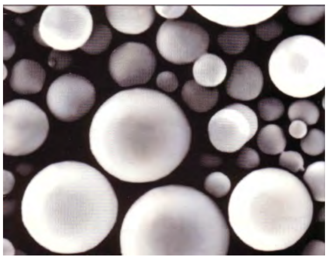


Particle shape and size plays a significant part in the bulk density of a product. The more uniform and cubic the particle shape, the lower amount of gaps there are between the particles and therefore the less amount of gas. Particle shapes can be:-

- Spheroid

- Cube
- Irregular
- Crystalline

The smaller the particle, the finer the product. "Powder" is effectively very small particles of normally regular shape, with very little gap between the particles.



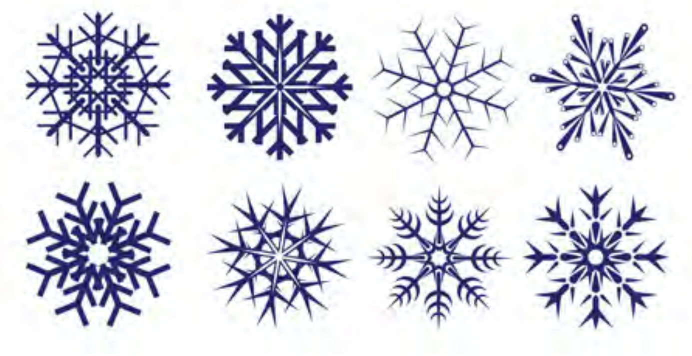
Below are examples of the variety of particle size that can be found with just two products, namely starch and refined sugar respectively:-

Starch		Sugar	
Starch type	Particle size	Sugar type	Particle size
Rice Starch	2µm	Crystal sugar	500-1000 micron
Potato Starch	<100µm	Castor sugar	50-450 micron
Bulk density	640-740 Kg/m³	Bulk density	560 – 800 Kg/m³

Particle size and shape also affects the space between particles and the co-efficient of friction between particles. Imaging hypothetically the comparison of tennis balls and marbles in a given volume if they both had the same specific density. Whilst both are perfect specimens of spheres, because of the respective diameter of each, the gap between each would be different. Thus the total weight of each in the same volume would different as more marbles could be contained in the volume than tennis balls. Also, if fluidisation was to be considered to assist in discharging these products from a loaded lined container, the likelihood would be that neither could be fluidised as the fluidisation gas would in both instances simply pass through the particles without lifting and separating them. If you now consider different particle shapes and sizes, you can see how such differences can affect the decision on the appropriate method of assisting flowability if such assistance was required.

In summary, if the particles are uniform and spherical with no surface cohesion properties, then the product will flow easily. If however, the product is irregular, or of a fine size and of cohesive properties, then it will not flow easily.

Take for example a snowflake. They come in many shapes – see below, but the one common characteristic of them all is the fact that they are "spindly" and when you consider these in 3D, then you can see why when interlocked with each other they are excellent for making snowballs.



So consider other product particles with similar irregular shape when they are assembled into a given volume, why they can be cohesive and prove difficult to flow.

For such products, force has to be exerted in order to get them to flow. Typically force is either provided by

- a mechanical form (e.g. vibration), or
- a sonic form or
- a fluidisation technique.

Whilst sometimes one of these forms of energy appear to be the correct method, it can leave to other problems. Mechanical vibration for instance can lead to compaction of certain products and exacerbate the problem of not flowing, whilst fluidisation can lead to flow control issues. There is no straight forward answer or a one-size fits all solution. Each product must be looked at in isolation and tested for the best method. These issues apply just as much to a container being used for storage as for bulk shipment distribution.

5. Moisture content properties:

Moisture will have a significant influence on the flowability of a product. For a number of products, moisture can be inherent in the product as well as on the surface of the particle. In some products, i.e. white refined granulated sugar for instance, the inherent moisture can “migrate” during transportation to the surface, thus adding to the likelihood of particles agglomerating.

Here is a photo showing the effect of this moisture migration on granulated sugar. As can be seen, severe agglomeration has occurred. This causes major problems for discharging a lined container, not only from a product quality point of view, but more importantly from a operational safety point of view.

In addition to moisture being possibly present in the product itself, an even bigger potential problem is moisture being inside the liner before the product is loaded. In order to fit a liner correctly inside a container before loading, air has to be introduced into the folded liner in order to be able to hang it and fix it to the container lashing points. If a polyethylene film liner is used (recommended for fine powders), then on removal and unfolding from its packaging, static adhesion will be experienced between the inner surfaces of the liner. The method by which this is reduced to allow the hanging to take place, is to introduce air into the liner. In carrying out this procedure, ambient air at the fitting location will enter the liner and if this ambient air is laden with moisture, such as in tropical locations where high humidity can be experienced, then moist air is being put into the liner and will mix with the product on loading, thus adding moisture to the product. This needs to be avoided, so loading in a clean temperature controlled area for moisture sensitive products is the ideal, but if this is not possible, then a process or replacing the moist air inside the liner with clean dry air prior to loading is advisable.

6. Particle Hardness:

In certain downstream processes to the intake of raw materials, the quality and condition in which the material enters the process has a direct consequence to the performance and quality of the resulting process and therefore the condition of the material at this point is critical. In such circumstances, it is quite common for the receiving company to put exacting conditions on the supplier of the material to meet certain criteria.

For example:-

6.1 Plastic pellets into an extrusion or injection moulding process:
The choice of conveying technology either into a lined shipping container or from the container into a receiving silo for either PE or PP pellets, can have drastic effect on the downstream extrusion or injection moulding process, if a conveying method is chosen which for example either produces “angel hairs” or dust particles.

6.2 Fine Powder into a mixing or blending process:
Whilst fine powder can be beneficial for “distribution” to achieve a better homogeneous mix / blend, it can have a detrimental effect on the “incorporation” time, thus extending mixing / blending cycle times. To counter this, receivers quite often stipulate criteria on the allowable level of “fines” (dust) in the powder being delivered. Likewise if the powder has been pelletised, the receiver may well define a allowable level of damage to be made to the pellets to avoid too high a level of dust being generated.

So for both examples of delivery conditions above, full details on the requirements of the said application is needed in order to choose not only the appropriate concept (i.e. mechanical, pneumatic or gravity), but which type of equipment solution in each concept.

7. Explosion properties:
   Some materials being contained and shipped in lined containers, can be of an explosive nature if the right mix of ingredients (fuel, oxygen and ignition source) is present. A number of materials such as sugar and flour being distributed in bulk in lined shipping containers can be explosive. The material dust provides the “fuel” source, and the air inside the liner provides the “oxygen” source. The missing ingredient (ignition source) can be provided by the very material the liners are manufactured from. Liners are either made form polypropylene fabric, possible coated with polyethylene, or polyethylene film. Both materials have static as a property from their manufacturing process. This static can in certain circumstance be higher in energy that the energy level required to ignite a explosive mix level of material dust and oxygen. This is more true of polyethylene film than polypropylene facric, but never-the-less true of the latter as well.

   To counter this potential risk, the supplier of liners should put forward liners made from a material which provides a lower level of energy than that which would cause a ignition level.

   Thus the fineness of materials can affect the packaging solution being provided.

8. Drag forces:

   Particle to particle friction has a major influence in the flowability of materials from a lined container. Containers are manufactured from steel with vertical flat-face corrugation on the sidewalls. The roof is also made from such steel, where the corrugations run across the roof rather than along the length of the container. The floors are normally constructed out of wooden panelling. All these in themselves provide a degree of drag on the surfaces of the liner along with the drag forces of the contained material itself to the surfaces of the liner when either loading at a tilt or during discharge. Such forces can have a drastic and dangerous result when loading or discharging is carried out by inexperienced operators, as can be seen by the photos below.

   The decision on which material a liner should be manufactured from is influenced by the frictional force a given material has on the surface of the inside of the liner. Polyethylene film has a smoother surface property than woven polypropylene, even when coated or laminated, but this higher slip factor can also be detrimental. A fine balance is therefore needed between drag forces, which prevent dangerously easy flow of material against a sluggish slip causing poor discharge or loading.

Wolfson Centre of the University of Greenwich (http://www.gre.ac.uk/engsci/research/groups/wolfsoncentre/home) offer courses on a number of particle solids handling technology, one of which is research into the effect of particle to particle friction and particle to surfaces friction.

9. Abrasive characterisation:

   Many materials by the very nature of their particle form and hardness can have an abrasive affect on the surfaces they are with contact with. With regard to the use of lined shipping containers, this characterisation has a major influence on the decision on what material the liners should be manufactured from and what thickness (in the case of polyethylene film) and what weight (in the case of woven polypropylene fabric) is chosen for the respective application. This is the responsibility of the liner supplier to put forward the correct fit-for-purpose solution.

10. Hygroscopic characterisation:

    Hygroscopy is the phenomenon of attracting and holding water molecules from the surrounding environment, which is usually at normal or room temperature. This is achieved through either absorption or adsorption with the absorbing or adsorbing substance becoming physically changed somewhat.

    A number of materials are hydroscopic, thus again the correct choice of material from which liners should be made is crucial to the success of the application. Generally, polyethylene film provides a better WVTR (water vapour transmission rate) than woven polypropylene, merely because of the very nature of manufacture. Polyethylene film is manufactured from a 360 ° extrusion process, which ensures that the liner has no porosity or seams, whereas woven polypropylene fabric is manufactured in sheets and liners are made by stitching together panels to form four sides and two ends. By the very nature of the fabric being woven also produces a porous fabric, which can be reduced by either lamination or coating, but does not result in as good a surface resistance to moisture as extruded polyethylene film.

11. Corrosive characterisation:

A **corrosive substance** is one that will destroy and damage other substances with which it comes into contact. Generally any such materials which are corrosive in nature are not suitable to be considered for bulk distribution in lined containers, as they would attach the liner material.