SAMPLING COLUMN

Spear sampling—a bane at all scales

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This column now turns its attention to sampling using a very popular tool, the "sampling spear". There is much good to be said about spear sampling—and only one thing which is bad. But this is bad enough: spear samplers are very, very difficult to get to produce representative samples! The spear sampling principle *can* be made representative, but in most practical situations in which spear sampling is used today it manifestly is *not*. WHY? And more importantly, WHAT can be done about it? This column also turns out to touch on one of TOS' six governing principles: SSI, Sampling Scale Invariance.

Introduction

It is convenient for the present objective to begin by iterating a lesson that was tucked away towards the end of the preceding column, which illustrates a very often used sampler in the laboratory domain, the hand-operated tubular corer (tubular extractor). What is a tubular corer but a (very) small spear designed for forceful insertion in the lot material. This particular sampler is designed so as to allow lot material to be forced into the cylindrical volume as the corer is inserted and forced to greater depths (Figure 1).

The last column laid out in detail WHY the cylindrical corer, used in the one "sample" approach, which is indeed the most often met stipulation, in reality is nothing but grab sampling in disguise (we might call this "cylinder grab sampling"). The singular cylinder extraction approach is in no way able to produce a representative sample of the highly irregular heterogeneity met with in blue cheese—especially if the cylinder is applied in the horizontal direction (left photo). If there is directional spatial heterogeneity in a cheese, it is very likely in the vertical direction, even though this is attempted compensated for by frequent "turning over" of the maturing cheeses. Even though this standard orientation is aiming at reaching all the way to the centre of the lot (a sound objective), there is a marked volumetric *over-sampling* of the lot material closer to the centre relative to the more peripheral locations (see further below).

The illustration of one or two opposing pie-cuts illustrates the *TOS-correct* delineation of a circular lot—and takes it further, by expanding the flat lot completely in the third (vertical) direction.

This is the most fundamental issue for all scales. Even *if* the tubular corer were of the same thickness as the "cheese" in the third, vertical dimension, it would still be at fault. It would still be *over-sampling* in the central locations (Figure 2). The delineating radius vectors must originate at the central vertical axis through the lot, which is not compatible with the

Figure 1. Using a cylindrical coring tool for cheese sampling (left) does not allow a representative sample of the highly irregularly distributed components of a mature blue cheese. Only the two right-most approaches will pass muster as complying with TOS' principles.

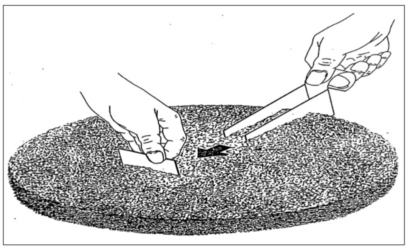

Figure 2. Severe over-sampling of the central parts of the lot; compare illustration above.

geometry of a cylindrical tubular corer (or the scoop illustrated in Figure 1).

The TOS-correct delineation of a spear sampler used in this geometrical context should have been funnel-like, tapering off towards the centre of the lot, but such a geometry violates against a balanced in-flow of material in the corer. Interestingly then (from a TOS perspective), a corer would appear to have to respect two distinctly different geometrical demands, for vertical vs horizontal insertion, respectively. This is, of course, not so interesting for current practice, which does not distinguish between these two *modus operandi*. So, the world is left with a plethora of offerings in the form of "universal corers", none of which able to do correct horizontal coring, but are quite OK for vertical work, so long as they extract a complete core (see further below).

Spear sampling—at all scales

Spear samplers are popular in all walks of science, technology and industry, and at all scales. Spear samplers range in size from the small scale hand-operated tubular extractors used in laboratories, for example in the food and feed industry, certainly not only for cheese as above, but also for minced or mixed meat products, chocolate, butter etc. The main purpose is to extract a sample from the *interior* of the lot material (and only very rarely also with a view of getting a balanced sample w.r.t. the full lot geometry).

Spear samplers are used extensively also in the meso-scale industrial regimen (1–2 m length) for sampling a wide range of products and commodities, e.g. grain, fly ash, coal fines, chemical products, construction materials etc. and are furthermore much deployed in bulk materials handling, e.g. for sampling bulk minerals and concentrates, ores, coal, wood shards (biomass and bioenergy sectors), and "waste" from other industrial processing that contains valuable elements and compounds that can be recovered at a profit (platinum group metals, Rare Earth Elements (REE), gold, silver etc. ranging in scale from jewellery cuttings to industrial recyclates arriving by the truck or railroad load. In many science and technology areas the characteristics of the target material formally *invites* specific spear sampling, e.g. agricultural and environmental sampling, i.e. of soil and peat or in pharma. This state of affairs is widespread indeed, e.g. spear sampling from big bags, from product bags, from railroad cars, from truck loads..., spear sampling almost *ad infinitum* (Figure 3).

All these applications are popular because of the comparative ease with which a column of target material can be extracted. But spear sampling is perhaps mostly popular because of the extremely low capital investment involved, as well as low operator costs. There is actually only one thing wrong with spear samplers in this scenario—**they are very, very difficult to make representative!**

Against this stands TOS' dictum: representative sampling *must* by necessity comply with the Fundamental Sampling Principle (FSP): all *virtual* increments of a lot must have an identical, non-zero, probability to be extracted, which translates: no physical volume of the lot can be allowed to be out-of-reach of the spear (Figure 4).

From current experience with contemporary practices it is obvious that *most* spear sampling violates markedly with the FSP demand illustrated below, because spears only rarely are designed or operated to cover the full depth of the lot in question and thus are idiosyncratic w.r.t. the distribution of spatial heterogeneity in the lot, the distributional heterogeneity, DH_{LOT}. The crucial issue is to be able to recover, completely and without loss, a *full* core length, and in particular the distal bottom part where absolutely no loss is allowed—due to segregation or otherwise. This is the crucial aspect of true spear sampling. Violation of this requirement is the most frequent reason that spear sampling is mostly non-representative (Figure 5).

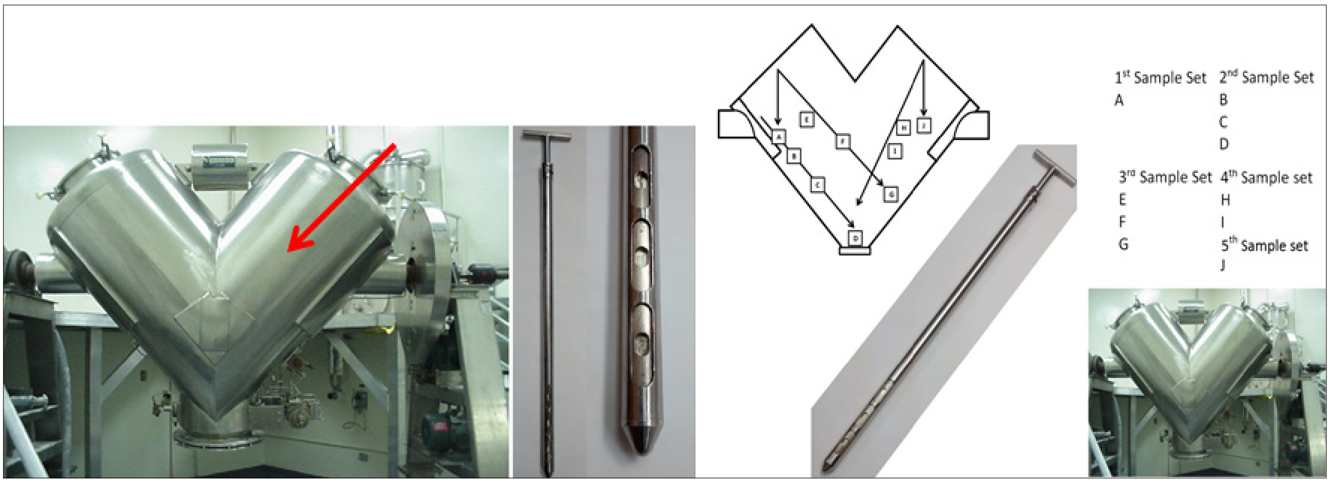

Figure 3. Generic spear sampling in the pharmaceutical industry sector. Although efforts have been made to reduce the increment volume at each designated depth interval (left photo), identical free inflow of material at progressively larger depths is not necessarily obtainable due to differential compaction with depth. Also (right), it is a fallacy that stipulated fixed positions within the V-blender (right) are optimal for all kinds of mixtures met with in pharma. The specific pharma spear sampling scenario is described in detail in Esbensen *et al.*,[1] where also can be found solutions honouring TOS.

Figure 4. Archetypal situation from technology and industry, about to commit one of the world's most blatant violation of "sampling". It is of no interest *which* company, *which* sampler, using *which* protocol, written and approved by *whom*? What is of interest is *only* that spear sampling has absolutely no chance of ever being representative in the scale and typical context shown.

IF a spear sampler should be able to work in a representative fashion, what might be called a "True Spear Sampler" (TSS), it must by design, manufacturing, usage and maintenance be able to mitigate the deficiencies pointed out:

- For a TSS, the sampling depth must *always* be able to cover the full depth of the lot (including the "extra" length needed to connect to the driver/engine).
- The TTS is designed to operate in two *modi*: forced *insertion* or *true coring* (drilling).
- The TSS is designed *always* to recover the complete core, with special focus on the critical bottom part from which no loss is permitted; this demand is *not* negotiable.
- The TSS must allow *all* collected material to be recovered; there must be no material adhering to the inner surface of the sampler.

Any TSS must be tested empirically, under deliberately adverse conditions and with materials comprising at least three components with properties representing mass fluxes and concentrations in typical industrial and technological systems, covering both high, intermediate as well as trace concentrations, see, for example, Petersen *et al.* for description of an extensive experimental design.[2] One of the test components should vary significantly in particle shape, aspect ratio and surface roughness and another (preferentially in trace concentrations only) should be prone to particle bouncing and segregation (spillage). Such test systems should be as difficult to sample as possible, in order constitute realistic worst case scenarios.[2] Such tests must comply with the stipulations of a proper Replication Experiment (RE).[3] Even if a particular TSS is fit-for-purpose and representative for *some* specific materials, it cannot be universally applied to other types of material—*unless* similarly tested empirically by RE. Despite many OEM claims, there is no such thing as a "universal sampler" that will work for all materials… because materials have different inherent heterogeneities.

Conclusions

Observe how analysis of "spear sampling" as a generic sampling process is unhampered by special attention to one or *some* scales only—or to special materials for that matter. The characteristics of spear sampling are principally *identical* at all scales—it is only the physical size of the spear sampling tool that changes so as to match the physical lot size.

Note also, however, that lot heterogeneity will change *independently* of the size of the lot and/or the sampling tool. Material heterogeneity is *not* correlated with lot scale, but *is* correlated with, is indeed a function of, the fragment/grain/particle size and the local-scale arrangements hereof (the lot unit elements) contributing to the constitutional heterogeneity of the lot, CH_{LOT}. Thus spear sampling is a function of the unit sampling volume, the increment volume. In composite sampling the increment volume must of course be set so as to *match* CH_{LOT} (influx openings must exceed 3× the largest particle diameter) etc.

The "spear sampler" is a very good, and therefore a very *bad* example of a very often met with misunderstand-

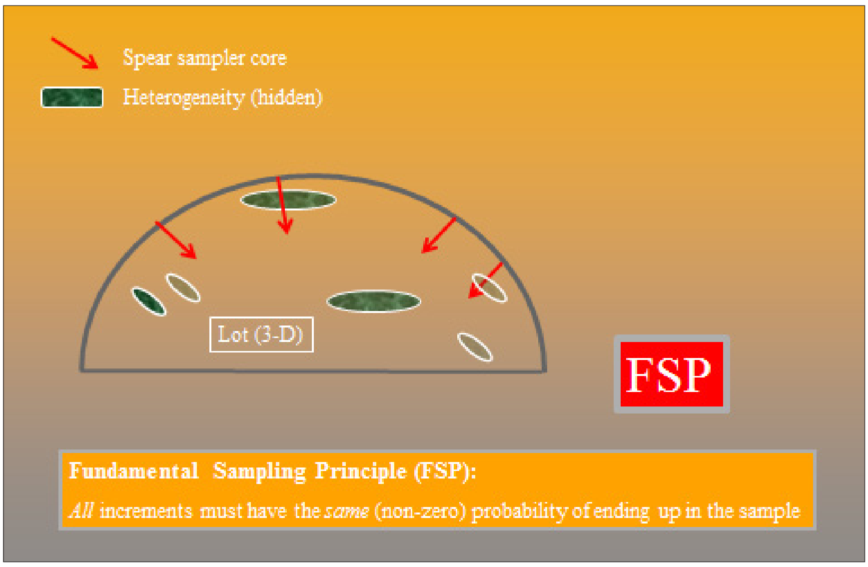

Figure 5. TOS' Fundamental Sampling Principle (FSP): "All virtual increments must have an identical, non-zero, probability to be extracted". Superficial spear sampling (never penetrating to the inner parts of the lot—red arrows) comprises a severe violation of FSP.

ing: one *type* of sampling tool fits all purposes, fits all materials, fit all lots… which it most emphatically does not!

The spear sampler is an example of a perhaps good engineering solution to a problem that unfortunately is not simple and universal: "how to extract a representative sample from the interior of a lot?", but a problem for which understanding of the full complement of features in TOS is necessary, in particular FSP, CH_{LOT}, DH_{LOT}. In order to deal effectively with the latter, DH_{LOT}, it is necessary to understand and acknowledge the imperative of *composite sampling*, i.e. applying a sufficient number, *Q*, of complete top-to-bottom cores of the lot. This is another story already much touched upon in earlier columns (and which needs to be emphasised again below where appropriate).

Representative sampling is *not* about buying a *specific* tool with which to take on all the world's materials, i.e. all the world's manifestations of heterogeneity. This is futile. Despite many OEM claims, there is no such thing as a "universal sampler" that will work for all materials… precisely because materials have different inherent heterogeneities.

Representative sampling is *all* about mastering the necessary and sufficient principles laid down by TOS[3,4] with which then to make rational choices regarding the most appropriate types of sampling tools needed for a specific task, for a specific material.

Incidentally, the above relates directly to one of the six governing principles of TOS, Sampling Scale Invariance (SSI): when designed, operated (and maintained) correctly (unbiased samplers), the spear sampling principle is identical at absolutely all scales.

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