Experimental testing of 1/3 scale model sampler for horizontally ducted particulate material streams

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Research motivation

• Sampling of particulate materials in vertical flow streams, especially falling streams and stationary lots enjoy plenty of successful TOS-correct solutions, but no fully satisfactory sampler has been presented for the 1-D case of forcefully ducted horizontal particulate material streams.

• Horizontal pneumatic transportation systems are used in very many industries, but currently no satisfactory possibility exists to evaluate material characteristics from this process location because of no satisfactory sampling system.

• Successful development of a sampler for this scenario should allow to obtain representative samples and thus prepare the way for analytical results “on the fly”. A universal sampler can not be expected for all material and lot types however.

• The present R&D foray is specifically oriented towards the power industry, to sample just before burners of pneumatically transported pulverized biomass fuel types (wood chips, wood- and straw pellets etc.).

• First generation results are expected to lead to more general samplers/applications.
Challenges of sampling from horizontally ducted flows

• In horizontally ducted flows, transportation of aggregate material streams must *perforce* cause significant (if not *severe*) gravitative and radial flow segregation.

• Pressurized transportation systems cannot be arbitrarily intersected for extracting increments due to:
  - Pressure loss – extraction from pressurized pipelines.
  - Discharge of material and therefore critical modification of the lot material.
  - A critical prerequisite is that sampling operations should not constrict the material flow in order to minimize the risk of clogging and pressure surges.
  - Sampler must not interfere with transportation flux during “parking” position.
  - Design must respect TOS’ Principle of Sampling Correctness, elimination of all Incorrect Sampling Errors, i.e. no IDE, IEE and IPE.
Current horizontal “sampling procedure” at AMV power plant

• Current procedure causes major Incorrect Sampling Errors: IDE, IEE

Probe extraction “sampler”

Material recovery
Design principles: E-F-sampler

• 1/3 scale model has been designed to fit a horizontal pipeline with a circular cross section with diameter of 80 mm (test rig conditions).

• Direction of ducted material flow does not need to be fixed – the sampling tool (termed “scythe”) can move in both prograde and retrograde directions.

• An electric power source with sufficient over-capacity has been implemented to ensure a completely constant speed. N.B. - only to test run #1.
During sampling operations the sampling arm rotates 180 degrees through the ducted flow stream around a vertical axis.

- Dashed line on the top view shows the parking position of the sampling arm, designed in such way that no disturbances of the source stream can occur while here.

- Sampling arm has been designed with the primary objective of being able to sample the vertical segregation gradient.

- For milled bio-mass materials, experience show that there is only little vertical segregation during dilute flow conditions.
Design principles: E-F-sampler

• The sampling arm has a cross-sectional curved “box” form with parallel sidewalls.

• The opening width as well as the depth of this cutter must accommodate the requirement: width > 3 times the nominal top diameter of the ducted material.

• The outer angle of the cutter blade tip (at least 70 degrees) prevents material not belonging to the delineated increment from ‘climbing’ up along the edges into the cutter.

• The cutter blades are designed to be a complete analogue to parallel cutter blades on conventional falling stream cross-cutters.

• Downward facing outlet chute of the sampling arm is used for extraction of the material into a compositing container. Design specifications call for isokinetic extraction (test run #2).
**Experimental test # 1: Design of experiment**

- Focus of test run #1 has been on **initial technical performance assessment** and on how well sampling correctness can be achieved.

- Aluminate cement has been used as the main test material.

<table>
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<tr>
<th>Density</th>
<th>Particle size distribution</th>
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</thead>
<tbody>
<tr>
<td>3.22 g/cm³</td>
<td>D10</td>
</tr>
<tr>
<td></td>
<td>2 μm</td>
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</tbody>
</table>

- Steel pellets (cylindrical cut-wire pellets) have been added as a spiking material.

<table>
<thead>
<tr>
<th>Density</th>
<th>Particle size distribution</th>
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</thead>
<tbody>
<tr>
<td>&gt; 7.4 g/cm³</td>
<td>~500 μm</td>
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</table>

N.B. Deliberate maximum segregation propensity!
Experimental test run #1: Design of experiment

- Overall rig length: ca. 120m
- Volume of pressure tank: 1m³
Experimental test run# 1: Design of experiment

- Variations of following parameters have been tested:
  - Sampling arm width: 2mm, 7mm, 14mm
  - Sampling frequency
  - Increase of spiking concentration: 5% -> 10%
  - Variation of load: low load (dilute phase), high load (dense phase)
    
    Low load = 7,365 t/h (122,75 kg/min)
    High load = 12,88 t/h (214,66 kg/min)

- For each scenario a composite sample (60 increments) has been extracted, replicated three times.

- For two scenarios initial variograms have been calculated.
Results of test run #1

• 2mm sampling width could not be used in any scenario due to clogging of material.

• No substantial difference in results between low and high load scenarios.

• 14mm sampling arm scenarios result in higher accuracy – but:

• All scenarios result in a bias (10-20% rel.) w.r.t. reference values of 5% and 10%.

Scenario: 10%, 14mm arm width, high load (3 composite samples – 60 increments, repeated on different day).
Results of test run #1

• Variogram for scenarios 5%, low load: 7mm vs. 14mm sampling arm width.

• Increase of sampling arm to 14mm width lowers maximum variance (sill) by around 50%. This is in compliance with expectations from TOS, as the effect of a much more efficient composite sampling.

• Both variograms (7mm and 14mm) show no periodic variations or trends.

N.B. Flat variograms
Explanation for current inaccuracy

• Segregation occurs while filling pressure rig’s sending tank (sic).

  • A substantial amount of material is not falling from the hopper into the pressure tank due to unfavorable silo design (red arrow).

  • The denser steel pellets might be therefore overrepresented in the transported material -> contributing to an explanation for the bias between composite sample and reference sample values.

Testing at this facility has since been discontinued: A new, more versatile testing facility has been selected, allowing also to test on biomass.
• The original construction design of course demands that no material can fall in the opening during parking.

• Due to a mistake in the manufacturing process the sampling arm opening is currently not closed when resting in parking position (sic). **Producer has been duly NOTIFIED!!**

• Experiments with sampler in parking position over the entire test run (no cutting) reveals that around 5-10% of the total composite weight is extracted by this effect.

• Additionally the concentration of the spiking material (high dense steel pellets) in the “specimens” (incorrectly extracted samples) is up to twice as high as the reference value – caused by the heavy segregation in the pipeline. With the result that approx. 7% of the stated (10-20% rel.) bias can be accounted for by this construction fault.

• The “designed” experimental test run #1 deliberately provoking segregation, in combination with this unlucky manufacturer's effect, limited test run #1.
Prospects for Test run #2 [February/March 2012]

• Development of Mark II prototype with the following main modifications:
  • Also 21 mm sampling arm width.
  • New extraction tube/mechanism with closed parking configuration.
  • Varying cutter rotation speed (accelerating and decelerating at the start/stop and with maximum horizontal speed at vertical plane crossing).

• Test phase #2 at different test facility (POSTEC, Porsgrunn, Norway)

• Testing of sampler with biomass (pulverized wood pellets) and similar powders:
  Experimental testing did not correspond well with timing of WCSB5

• Mounting and testing of acoustic sensors for predicting particle size distribution (% of fines).

• Up-scaling of final prototype and full scale implementation at converted coal power plant (combustion of wood and straw pellets), AMV (Denmark), is planned immediately after conclusion of phase #2.
Thank you for your attention!

Full account of the development of the E-F sampler at WCSB6