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Coal and coke — Coal preparation plant — Density tracer testing for measuring performances of coal density separators

Charbon et coke — Installation de préparation du charbon — Essais des traceurs de densité pour la mesure des performances des séparateurs de charbon en fonction de la densité

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This document was prepared by Technical Committee ISO/TC 27, *Coal and coke*, Subcommittee SC 1, *Coal preparation: Terminology and performance*.

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Introduction

The objective of this document is to provide the coal preparation industry with an accurate, safe, rapid and site-based method for determining the density partitioning performances of density separators and, to utilize statistical and mathematical procedures to avoid personal biases in fitting partition curves to the observed data. To meet the second objective, this document includes formulae which can be incorporated in a user spreadsheet.

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Coal and coke — Coal preparation plant — Density tracer testing for measuring performances of coal density separators

1 Scope

This document specifies the requirements for testing the performances of coal density separators using density tracers and provides a method for the presentation of test results.

This document is partly based on AS 5213.

This document is applicable to dense medium cyclones (DMCs) and dense medium baths, as follows:

a) for a single separator;

b) for a group of separators where the feed is distributed between them at a point downstream of density tracer insertion;

c) for density tracers of any size; but rarely used for particles with maximum dimension less than 2 mm.

This document also provides guidance for testing the performances of other types of density separators with density tracers.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

AS 2418, *Coal and coke — Glossary of terms*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in AS 2418 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
cut-off time
time which follows the time of last *density tracer* (3.3) *insertion* (3.5) by 5 min plus the greater of *floats transit time* or *sinks transit time*

Note 1 to entry: Floats transit time is the average time in minutes since insertion into a separator feed for particles collected from, or detected in, a separator floats stream. Sinks transit time is the average time in minutes since insertion into a separator feed for particles collected from, or detected in, a separator sinks stream.

3.2
density separator
device for the cleaning of coal, in which particles are separated into two or more streams according to their densities

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3.3
density tracer
non-porous particle of defined shape and density that is not easily broken or abraded

Note 1 to entry: Types include radio frequency identified (RFID) density tracers and non-RFID recoverable density tracers.

3.4
average probable deviation
écart probable moyen
E_{pm}
half of the difference between the densities corresponding to the 75 % and 25 % partition coefficients as obtained from the partition curve

3.5
insertion
placement of a *density tracer* (3.3) into a separator feed stream, typically by dropping into a feed preparation screen oversize launder

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4 Test method

4.1 General

The test method specified in 4.2 to 4.5 covers the following:

a) generation and capture of density tracer test data utilizing either:

1) retrieved, re-usable non-RFID density tracers; or

2) automatically detected RFID density tracers;

b) use of those data to estimate density partition coefficients;

c) presentation of those data and results in tabular and graphical forms;

d) fitting one of two alternative mathematical forms for the partition curve to the density partition coefficients;

e) determination, from the partition curves, of key partitioning criteria.

4.2 Apparatus

4.2.1 Density tracers

For the purposes of this document, density tracers shall have the following properties:

a) shape and dimensions: any that can be fully described in the density tracer test report;

EXAMPLE Cubic, with edge length 13 mm.

b) tolerance on dimensions: 100 % within ±10 % of nominal;

c) nominal densities: any;

d) tolerances on density, for cubic tracers of 8 mm edge length and larger:

1) for nominal relative density (RD) values up to 1,60: 99 % within ±0,006 RD of the nominal value;

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2) for nominal RD values greater than 1,60: 99 % within ±0,011 RD of the nominal value.

e) density designation:

1) non-RFID density tracers: by engraving or colour-coding;

2) RFID density tracers: electronically written to an internal memory chip.

NOTE See Annex A for details of suitable density tracers.

4.2.2 Density tracer retrieval or detection equipment

If a test is to be conducted using non-RFID density tracers, apparatus for use as aids for retrieval shall be suitable for the circumstances (see Annex B).

If a test is to be conducted using RFID density tracers, radio equipment shall be present for retrieval of data from each density tracer in the floats and sinks streams from the density separator(s) (see Annex B).

4.3 Procedure

4.3.1 Density tracer selection

Density tracer selection shall be as follows.

a) Decide on one or more nominal sizes.

b) For each nominal size, decide the nominal densities (guidance is provided in Annex C).

c) For each nominal size, decide the number of density tracers to be used at each nominal density, being:

   1) no less than 30;

   2) equal to the number selected at every other nominal density.

d) Assemble those density tracers.

4.3.2 Insertion of density tracers

The following procedure shall be used for the insertion of density tracers.

a) Decide on the insertion point and required test duration and calculate the required interval between density tracer insertions as the test duration in seconds divided by the total number of density tracers selected.

   NOTE Annex B provides further information on test durations.

b) Ensure that retrieval personnel or detection equipment are in place and activated.

c) Record the time at which the first density tracer was inserted.

d) At approximately the calculated intervals, insert or drop the density tracers into the feed stream of the density separator(s) to be tested (see Figure 1), either manually or using a mechanical dispenser. The density order of density tracer insertions shall be either:

   1) pseudo-random, by mixing the selected density tracers prior to one-by one selection and insertion; or

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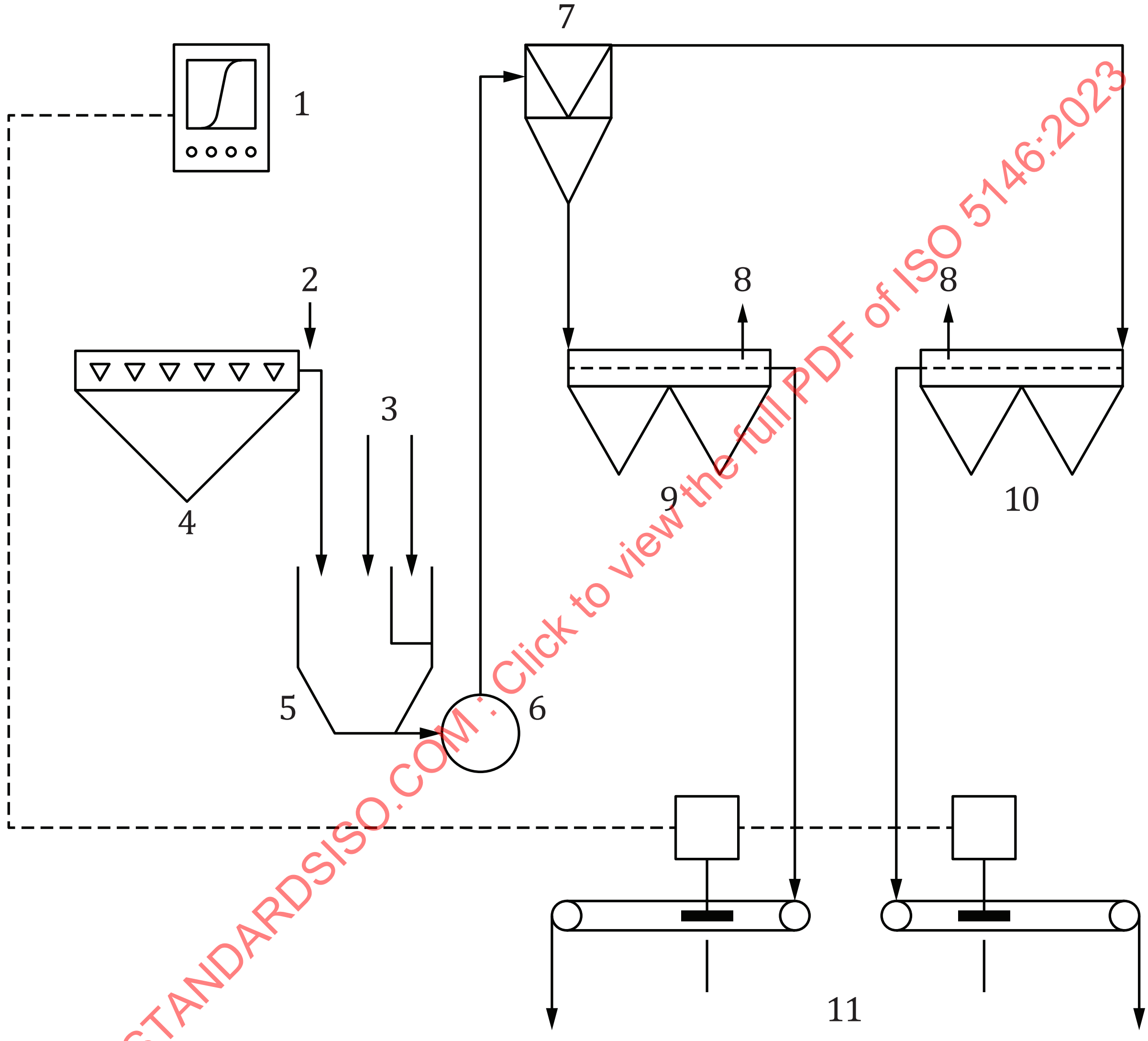
2) following a protocol whereby one density tracer of every selected size and density is inserted, one-by-1, followed by a second density tracer of every selected size and density, etc.

e) Record the time at which the last density tracer was inserted.

Unplanned interruptions to plant feed of up to 10 min duration can be tolerated, but tracer insertion shall be stopped, restarted when feed is resumed and documented.

Figure 1 shows typical locations for the insertion of density tracers and for the retrieval or detection of density tracers.



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Key

1 real-time display of partition curve
2 typically, density tracers would be added here
3 medium
4 de-sliming screen
5 sump or wing tank
6 pump
7 DMC module
8 non-radio density tracers would be retrieved here
9 sinks drain and rinse screen
10 floats drain and rinse screen
11 detectors for radio density tracers

NOTE 1 This is a simplified typical flowsheet showing points of addition and retrieval of density tracers.

NOTE 2 In this case, the separator is a dense medium cyclone.

NOTE 3 For RFID density tracers, alternative locations for detectors are at the drain-and-rinse screens.

Figure 1 — Example of a simplified density separator flowsheet

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4.3.3 Density tracer retrieval or detection and data capture

4.3.3.1 Non-RFID density tracers

The procedure shall be as follows.

a) Retrieve density tracers from the material on the floats drain and rinse screen(s) (see Figure 1) by hand or using a scoop or net or magnets. Place them in one or more containers marked “Floats” (see Figure 1, NOTES 1, 2 and 3).

b) Retrieve density tracers from the material on the sinks drain and rinse screen(s) by hand or using a scoop or net or magnets. Place them in one or more containers marked “Sinks” (see Figure 1, NOTES 1, 2 and 3).

c) Sort the density tracers retrieved from floats before the cut-off time according to their densities and record the number for each density.

d) Sort the density tracers retrieved from sinks before the cut-off time according to their densities and record the number for each density.

In some circuits, screens cannot be readily accessed for density tracer retrieval, and alternative retrieval points should be sought. For example, primary density separator sinks may be fed directly to a secondary density separator without passing a drain-and-rinse screen. In that case, density tracers retrieved from secondary density separator floats and sinks should be reported as primary density separator sinks.

Any density tracers retrieved from the screens after the cut-off time should not be included in the test data.

If the density tracers are to be retrieved by magnets, they should be ferromagnetic.

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4.3.3.2 Automatically detected RFID density tracers

The procedure shall be as follows.

a) Detect and record the densities of RFID density tracers in the floats stream using RFID apparatus located downstream of the density separator (see Figure 1). In some cases, circuit configuration may dictate that two or more detection points are required.

b) Detect and record the densities of RFID density tracers in the sinks stream using RFID apparatus located downstream of the density separator (see Figure 1). In some cases, circuit configuration may dictate that two or more detection points are required.

Any density tracers detected after the cut-off time shall not be included in the test data.

If access to suitable locations for detector placement is limited, alternative locations should be sought. For example, primary density separator sinks may be fed directly to a secondary density separator without passing a conveyor. In that case, density tracers retrieved from both floats and sinks of a secondary density separator should be reported as primary density separator sinks.

4.4 Data processing

4.4.1 Data acceptability

4.4.1.1 Selection of tracer densities

To be acceptable, the selected density tracer densities shall include the following eight RDs from Table 1:

a) the four RDs which are closest to the d_{50};

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b) at least one RD in the range 0,05 to 0,10 lower than the d_{50} (unless the d_{50} is less than 1,31 RD);

c) at least one RD in the range 0,05 to 0,10 higher than the d_{50};

d) at least one RD in the range 0,10 to 0,20 lower than the d_{50} (unless the d_{50} is less than 1,36 RD);

e) at least one RD in the range 0,10 to 0,20 higher than the d_{50}.

See Annex A for more information.

Table 1 — Typical densities and density tolerances of density tracers for coal operations (8 mm and larger)

Nominal density RD units	Tolerance 99 % RD units	Nominal density RD units	Tolerance 99 % RD units	Nominal density RD units	Tolerance 99 % RD units
1,26	±0,006	1,44	±0,006	1,62	±0,011
1,27	±0,006	1,45	±0,006	1,64	±0,011
1,28	±0,006	1,46	±0,006	1,66	±0,011
1,29	±0,006	1,47	±0,006	1,68	±0,011
1,30	±0,006	1,48	±0,006	1,70	±0,011
1,31	±0,006	1,49	±0,006	1,72	±0,011
1,32	±0,006	1,50	±0,006	1,74	±0,011
1,33	±0,006	1,51	±0,006	1,76	±0,011
1,34	±0,006	1,52	±0,006	1,78	±0,011
1,35	±0,006	1,53	±0,006	1,80	±0,011
1,36	±0,006	1,54	±0,006	1,82	±0,011
1,37	±0,006	1,55	±0,006	1,84	±0,011
1,38	±0,006	1,56	±0,006	1,86	±0,011
1,39	±0,006	1,57	±0,006	1,88	±0,011
1,40	±0,006	1,58	±0,006	1,90	±0,011
1,41	±0,006	1,59	±0,006	1,95	±0,011
1,42	±0,006	1,60	±0,006	2,00	±0,011
1,43	±0,006			2,10	±0,011

For density tracers smaller than 8 mm, cubes wider 99 % density tolerances may be accepted, but those tolerances shall be determined and recorded on the density separator performance report.

4.4.1.2 Collection/detection rate

To comply with this document, the collection or detection rate for density tracers over all densities employed shall be not less than 70 %.

NOTE 1 Tracer losses or non-detections influence the fitted curve parameters. For collection/detection rates of 90 % or more, the data acceptability provisions are intended to achieve more than 95 % confidence that, by ignoring those losses or non-detections, the fitted values of:

a) d_{50} will be changed by less than 0,01 RD; and

b) E_{pm} will be changed by less than 25 %.

NOTE 2 For collection/detection rates less than 90 % that confidence level (95 %) is likely to be disproportionately reduced.

NOTE 3 The 25 % confidence level for E_{pm} can also be reduced if E_{pm} falls below about 50 % of the interval between adjacent tracer densities [e.g. below 0,005 (50 % of 0,010 RD)].

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4.4.2 Calculation of partition coefficients

For each density tracer density employed in the test, calculate the observed partition coefficient, as a percentage:

$$P_o = 100 \times \frac{N_s}{(N_s + N_f)} \tag{1}$$

where

P_o is the observed partition coefficient to sinks;

N_s is the number of density tracers collected from or detected in sinks;

N_f is the number of density tracers collected from or detected in floats.

NOTE 1 The numerical factor 100 is used to convert the dimensionless partition coefficient to a percentage, %.

Alternatively, partition coefficients may be expressed in terms of percent to floats. This requires a number of changes in the procedures for calculating partition coefficients and for fitting the partition curves; these are detailed in Annex F.

The conventional procedure for configuring partition curves with the abscissa in terms of percent to sinks detailed in 4.4 to 4.5 shall be used. In case the relevant formulae on Clause 4 are not used, the formulae in Annex F shall be used to configure partition curves in terms of percent to floats.

NOTE 2 Refer to ISO 923 for more information on partition coefficients.

4.4.3 Confidence intervals for partition points

4.4.3.1 Tracer densities

The 95 % confidence intervals for the RFID density tracers described in Table 1 shall be taken as:

a) ±0,005 RD for nominal RDs 1,30 to 1,60;

b) ±0,010 RD for other nominal densities.

4.4.3.2 Partition coefficients

4.4.3.2.1 General

For each selected RD, the lower and upper 95 % binomial confidence limits and the overall confidence interval shall be calculated using Formulae (2) to (4) which are based on the inverse cumulative distribution function for probability, $p_{BETA.INV}$.

4.4.3.2.2 Lower confidence limit, L_{CL}

$$L_{CL} = 100 \times p_{BETA.INV}(0\,0{,}25\,N_s\,(N_f + 1)) \tag{2}$$

with the proviso that if the number collected or detected in sinks is zero, the lower confidence level shall be zero.

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4.4.3.2.3 Upper confidence limit, L_{CU}

$$L_{CU} = 100 \times p_{BETA.INV(0\,0{,}975(N_s+1)\,N_f)} \tag{3}$$

with the proviso that if the number collected or detected in floats is zero, the upper confidence level shall be 100.

4.4.3.2.4 Overall confidence interval, I_{CO}

$$I_{CO} = L_{CU} - L_{CL} \tag{4}$$

NOTE 1 See Reference [2] for more information on confidence limits. Employing a spreadsheet function, and for partition coefficients to sinks, examples of confidence limits for cases where 27 density tracers of one RD are collected or detected are given in Table 2.

Table 2 — Examples of confidence limits

N_s	N_f	Partition coefficient estimate	95 % confidence limits		
			Lower	Upper	Overall
0	27	0,0	0	12,8	12,8
15	12	55,6	35,3	74,5	39,2
27	0	100,0	87,3	100	12,7

NOTE 2 As an example for clarity, for the point represented in the second line of the table:

a) the upper part of the confidence interval will extend from 55,6 % to sinks upward to 74,5 % to sinks;

b) the lower part of the confidence interval will extend from 55,6 % to sinks downward to 35,3 % to sinks.

4.4.4 Two forms of the partition curve

To facilitate objective comparisons of partitioning performances, partition curves shall be constrained within partition coefficient limits of 0 to 100 and fitted using a computer-aided technique to avoid personal biases.

One of two mathematical forms for the partition curve to sinks shall be employed.

a) A 4-parameter form of the logistic function, which incorporates a constant, the natural logarithm of 3 (or 1,098 6), and is known as the Modified Whiten curve[5].

$$P_s = T_0 + \frac{T_1 - T_0}{1 + \exp\left(\frac{\ln(3)}{E_{pm}} \times (X - d)\right)} \tag{5}$$

where

d is the relative density of density tracers associated with one partition coefficient;

P_s is the estimate of the partition coefficient to sinks (in the range 0 to 100) for density tracers of relative density d;

T_0 is the asymptote at $-\infty$ RD (an indicator of bypass of low-RD particles to sinks);

T_1 is the asymptote at $+\infty$ RD (100 − T_1 is an indicator of the bypass of high-RD particles to floats);

X is a parameter relating to the separation density of the partition curve; in cases where T_0 is 0 and T_1 is 100, X becomes equal to d_{50}.

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E_{pm} is one half of the difference between the densities corresponding to the 75 % and 25 % partition coefficients as obtained from the partition curve.

The literature to date appears not to recognize that d_{50} should not appear in Formula (5). The new term X should be used. For known or fitted values of T_0, T_1, X and E_{pm}, d_{50} can be calculated using Formula (6).

$$d_{50} = X - \frac{E_{pm}}{\ln(3)} \times \ln\left(\frac{T_1 - 50}{50 - T_0}\right) \tag{6}$$

NOTE 1 As an aid to computer implementation, linear versions of some formulae are presented in Annex G.

b) A 5-parameter form of the logistic function[3]. This is related to the Modified Whiten curve, but includes terms to cater for the rotational asymmetry exhibited by many sets of partitioning data. Some terms in the two forms are identical or closely related but, for clarity and for consistency with Reference [3], the two formulae use different symbol sets.

$$P_s = D + \frac{A - D}{\left(1 + \left(\frac{d}{C}\right)^B\right)^G} \tag{7}$$

where A, B, C, D, G are parameters which, in concert, fully define the partition curve asymptotes and the curve shape.

NOTE 2 If a data set has been fitted using the 5-parameter logistic curve, the familiar partitioning parameters, T_0, T_1, d_{50} and E_{pm} can be calculated as given in Formulae (8) to (11):

$$T_0 = A \tag{8}$$

$$T_1 = D \tag{9}$$

$$d_{50} = C \times \left(\left(\frac{A - D}{50 - D}\right)^{\frac{1}{G}} - 1\right)^{\frac{1}{B}} \tag{10}$$

$$E_{pm} = \frac{C \times \left(\left(\frac{A - D}{75 - D}\right)^{\frac{1}{G}} - 1\right)^{\frac{1}{B}} - C \times \left(\left(\frac{A - D}{25 - D}\right)^{\frac{1}{G}} - 1\right)^{\frac{1}{B}}}{2} \tag{11}$$

NOTE 3 See Annex E for information on the interpretation of partition curves.

NOTE 4 In any simulation exercise using Formula (7), d_{50} can be increased by increasing the parameter C to $C + \delta C$; but the value of E_{pm} will also change, and that can be considered undesirable. Such undesired change in E_{pm} can be mitigated if the value of B is simultaneously multiplied by $(1 + \delta C \times 0{,}769)$.

4.4.5 Fitting the partition curves

Using the selected formula form, and initial values for the parameters to be fitted (see Table 3), calculate the partition coefficient for each of the density tracer densities employed.

For each predicted partition coefficient, calculate the weighted residual error ε_w as

$$\varepsilon_w = \frac{\hat{P}_s - P_o}{I_{CO}} \tag{12}$$

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where

$\hat{P}_s$ is the partition coefficient to sinks calculated using curve parameters being assessed in the current iteration of the fitting procedure;

I_{CO} is the magnitude of the overall confidence interval for that partition coefficient.

The fitting shall proceed by progressively minimizing the sum of squares of the weighted residual errors by adjusting those of the partition curve parameters which have not been set, using nonlinear optimization. Suitable methods are commonly available as add-ons for standard spreadsheet packages.

Table 3 — Parameters to be adjusted when fitting the partition curves

Recommended initial values and constraints							
Modified Whiten (4 parameters)				**5-parameter logistic** ($B > 0$)			
Parameter	**Initial value**	**Constraints**		**Parameter**	**Initial value**	**Constraints**	
		min.	max.			min.	max.
T_0	0	0	100	A	0	0	100
T_1	100	0	100	B	150	10	500
X	estimate [a]	1,00	4,00	C	estimate [a]	1,00	4,00
E_{pm}	0,010	0,002	0,300	D	100	0	100
				G	1	0,5	10

[a] For X or for C, a suitable initial estimate would be the RD of the lowest-RD tracers which returned an observed partition coefficient > 50 %.

If P_0 for tracers of the lowest RD is zero, set T_0 and A to zero and do not allow the fitting procedure to adjust them. If Po for tracers of the highest RD is 100, set T_1 and D to 100 and do not allow the fitting procedure to adjust them.

4.4.6 Asymmetry factor for 5-parameter logistic

As an indicator of the difference between two partition curves, this document defines a partition curve asymmetry factor, F_a.

$$F_a = \left(\frac{d_{98} - d_{50}}{d_{50} - d_{02}} \right) \tag{13}$$

NOTE 1 In situations where bypass exceeds 2 % (a greater than 2, or D less than 98), F_a is not defined.

NOTE 2 Because the Modified Whiten curve is symmetrical (rotationally, about the d_{50}), its asymmetry factor is always unity.

4.5 Test report

An example density tracer test report is presented in Figure 2. The test report shall include:

a) reference to this document, i.e. ISO 5146:2023;

b) date and time of insertion of the first density tracer (test start time);

c) date and time of test end (cut-off time);

d) density tracer shape and size and whether RFID-detected or manually retrieved;

e) number of density tracers of each density;

f) the overall collection or detection rate;

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g) a table showing, for each density tracer density employed,

   1) the number retrieved from, or detected in, floats;

   2) the number retrieved from, or detected in, sinks;

   3) the total number retrieved or detected;

   4) the calculated partition coefficient (in this case, to sinks);

h) a graph showing:

   1) calculated partition points;

   2) confidence intervals for each partition point for both the tracer density and the partition coefficient; and

   3) a density partition curve (Modified Whiten or 5-parameter logistic) fitted to the partition points, and not extending beyond the range of tracer RDs;

i) partitioning performance parameters determined from both fitted partition curves:

   1) bypass to sinks (T_0) (in many cases the fitted curve shows zero bypass to sinks);

   2) bypass to floats ($100 - T_1$) (in many cases the fitted curve shows zero bypass to floats);

   3) d_{50};

   4) E_{pm};

   5) asymmetry factor F_a [see Formula (13)] if the 5-parameter logistic curve is employed.

A suitable means for computer-aided representation of a partition curve is as follows:

— calculate and plot partition coefficients at RD intervals of 0,01, using no marker.

— use a straight line to join every adjacent pair of partition coefficients (this is sometimes referred to as a “2-D line”).

NOTE See Annex D for a test report template.

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Plant	DENSITY SEPARATOR PERFORMANCE REPORT	Date
XYZ	based on a density tracer test	1-Jan-18

Number of tracers used at every RD? (must be 30 or more)	30	
Collection/detection rate? (must be 70 % or more)	92,7	
Did the density tracer RDs include:		
the 4 closest to the fitted cutpoint?	yes	
one each between 0,05 and 0,10 below and above the cut-point?	yes	(not below if cut-point <1,36)
one each between 0,10 and 0,20 below and above the cut-point?	yes	(not below if cut-point <1,31)
Did the test meet these 5 requirements of ISO 5146?	yes	

Audit ID	Module ID	Feed blend	Start	End
180101/2B	2	33 % B1 / 67 % F3	11:15am	12:04pm

Tracer type, shape and key dimensions mm — For additional classes use additional sheets

RFID cubic 13mm edges

Separator details (including class, manufacturer, model, key dimensions, condition)

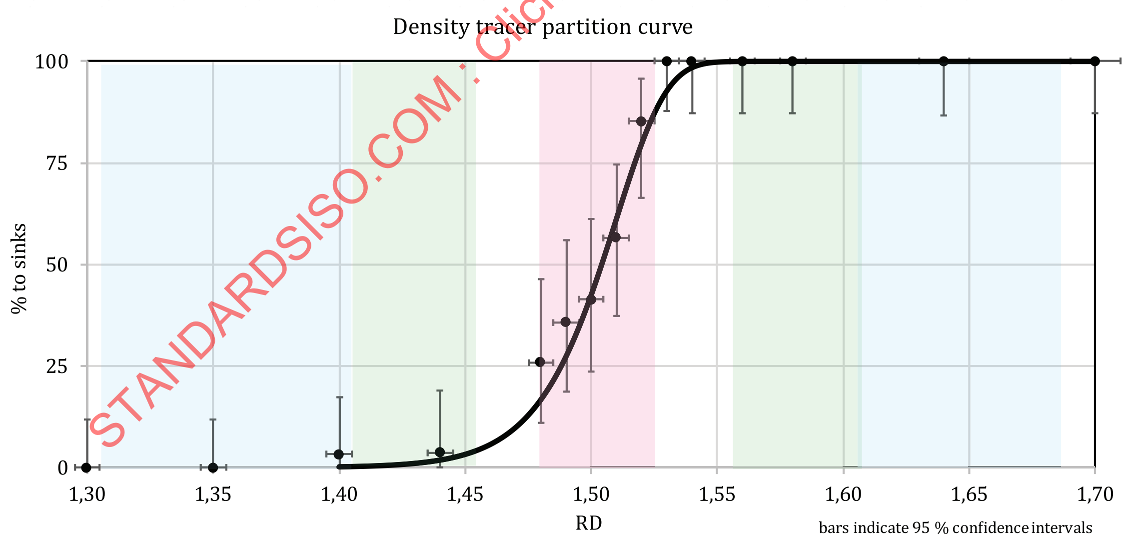
Operating conditions and observations

Other comments

Density tracer results

% to sinks calculated as sinks/(floats+sinks)x100

RD	Collected/detected in: Floats	Sinks	Total	% to sinks
1,30	29	0	29	0
1,35	29	0	29	0
1,40	29	1	30	3
1,44	26	1	27	4
1,48	20	7	27	26
1,49	18	10	28	36
1,50	17	12	29	41
1,51	13	17	30	57
1,52	4	23	27	85
1,53	0	28	28	100
1,54	0	27	27	100
1,56	0	27	27	100
1,58	0	27	27	100
1,64	0	26	26	100
1,70	0	27	27	100
1,80	0	27	27	100



PARTITION CURVE PARAMETERS	Bypass to sinks	Bypass to floats	d_{50}	E_{pm}	Asymmetry factor $(d_{98} - d_{50})/(d_{50} - d_{02})$
5-parameter logistic	0 %	0 %	1,504	0,015	0,549

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NOTE 1 In this case, the 5-parameter logistic curve has been fitted. If the Modified Whiten curve were used the curve and its parameters would be different.

NOTE 2 The example in Figure 2 includes the minimum required data, as well as:

a) optional identifiers for plant, circuit and feed coal,

b) optional colour zones as an aid to checking for acceptable selection of tracer RDs (see 4.4.1.1); the range for each colour zone can be calculated only after the d_{50} has been determined (see 4.4.4),

c) a fitted partition curve with its key performance parameters.

Figure 2 — Example of a density tracer test report

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Annex A
(informative)

Density tracer properties

A.1 Non-RFID density tracers

Typically, non-RFID density tracers are cubic plastic particles that incorporate powdered fillers to give appropriate densities. They may embody properties designed as aids to identify or retrieve density tracers from floats and sinks streams. For example, they can be brightly coloured for manual collection, ferromagnetic for collection by magnets, or luminescent under X-rays for collection by X-ray sorting machines.

Density tracers with an edge length of 8 mm and larger are sometimes manually retrieved from floats and sinks streams. For dense medium cyclones (DMCs), 32 mm cubes are commonly used. They are distinctively and brightly coloured to facilitate retrieval, and the RD is indicated by engraving on each density tracer (see Figure A.1). Available RDs and RD tolerances are shown in Table 1 (see 4.4.1.1).

RD intervals of 0,01 RD units between adjacent density tracer densities are recommended if the d_{50} is expected to be below 1,6 RD.

For smaller density tracers (down to about 2 mm), engraving is not appropriate and RD may be indicated by colour coding (see Figure A.2).

Figure A.1 — 32 mm non-RFID cubic density tracers for manual retrieval, engraved to show RD

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Figure A.2 — Non-RFID cubic density tracers in small sizes, colour-coded for RD

A.2 RFID density tracers

Nominal RD is recorded in a memory chip within the density tracer (see Figure A.3). RD tolerances are the same as those for 32 mm non-RFID density tracers.

Figure A.3 — RFID cubic density tracers in sizes with edge lengths of 32 mm and 13 mm

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Annex B
(informative)

Test duration and aids for density tracer retrieval or detection

B.1 Test duration

The common duration of a density tracer test is approximately one hour.

The upper limit is optional and may be selected to achieve particular objectives.

The lower limit is dictated by the frequency at which density tracers can be retrieved or detected. For a test using a total of 360 density tracers:

a) manual retrieval: approximately 18 min (1 density tracer inserted every 3 s);

b) RFID detection: approximately 6 min (1 density tracer inserted every second).

B.2 Retrieval of re-usable density tracers

Density tracers may be retrieved by hand from the discharge lips of the relevant drain-and-rinse screens. Use of retrieval aids may be considered. Such aids may be in the form of light-weight, long-handled scoops or nets (see Figure B.1) or magnet assemblies.

Excessive losses of non-RFID density tracers can be caused by:

a) use of small density tracers;

b) deep beds of floats or sinks on screens from which tracers are retrieved (the use of larger tracers will help overcome this problem);

c) insufficient personnel;

d) excessively short time interval between insertions of density tracers;

e) retention in the density separator of density tracers and coal (see Reference [6] for more information).

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a) Example of a light-weight weight scoop for manual retrieval of density tracers

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b) Example of a light-weight net for manual retrieval of density tracers

c) Example of use of a light-weight net for manual retrieval of density tracers

Figure B.1 — Examples of aids for manual retrieval of density tracers

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B.3 Detection of RFID density tracers

Typically, RFID density tracer detectors are installed under conveyors (see Figure B.2), downstream of the loading points of floats or sinks from the density separator(s) being tested. A plant which generates primary and secondary floats, as well as sinks, usually requires three detectors.

Alternative locations include the discharge regions of drain-and-rinse screens. In these situations, a separate detector is required for every screen treating floats or sinks from the density separator(s).

RFID systems can incorporate a control centre, which can tune and activate the detectors and display detections and the developing partition curve in real time (see Figure B.3).

A test may be conducted by a single operator.

Excessive non-detections of RFID density tracers can be caused by:

a) communication failures between density tracers and detectors;

b) retention in the density separator of density tracers and coal (see Reference [6] for more information).

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Figure B.2 — RFID density tracer detector located under a conveyor

Figure B.3 — Control station for collation of detections and real-time display of the partition curve

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B.4 Checklist

Prior to a density tracer test, ensure the following are available:

a) a prepared list of required density tracers, and those actual density tracers;

b) sufficient personnel who have been trained in their allotted tasks;

c) free, non-hazardous access to, and adequate lighting at, all points where personnel will work;

d) a camera (if required as an aid for capture of data for manually retrieved re-usable density tracers);

e) an action plan for the event of loss of feed during a density tracer test; this shall include instructions to:

   1) immediately interrupt the insertion of density tracers and record the time;

   2) wait for the re-introduction of feed and record that time;

   3) wait a further period considered sufficient for plant stabilization;

   4) recommence density tracer insertion and record that time.

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Annex C
(informative)

Selection of density tracers

C.1 General

This annex provides guidance in selecting the sizes, densities and numbers of density tracers required to generate a useful partition curve.

C.2 Density tracer size or sizes

C.2.1 Dense medium cyclones

For dense medium cyclones (DMCs), there is usually little difference in partitioning behaviour for particles larger than about 5 mm. Therefore, density tracers of any size from 5 mm to 60 mm or more may be used to approximate the performances of density tracers over that entire range.

The greatest particle-size-related differences in performance relate to the special situations of:

a) retention of near-density particles (more prevalent for larger particles including large density tracers);

b) surging discharge, triggered by retention of near-density coal particles, or floats overload (see Reference [6] for more information).

C.2.2 Dense medium baths

Dense medium baths sometimes have size-related issues caused by damage to "skirts", "rafting" of near-density material or by capture of low-density particles by sinks lifters due to plunging entry of feed. Nevertheless, density tracers of a single size usually give adequate definition of dense medium bath partitioning of all feed particles larger than approximately 15 mm.

C.2.3 Cases where bypass is not expected

To consistently generate suitable data for a reliable partition curve, each test would need to employ all available densities over a wide range (see Figure C.1). Such an approach would be expensive and time-consuming, and the data acceptability provisions of 4.4.1.1 address those problems.

Details of the curve are not known prior to the test. The following can increase confidence that the selection requirements of 4.4.1.1 will be met.

a) Conduct a preliminary test using a small number of density tracers over a wide range of densities and at wide density intervals.

b) Rely on previous test results or on other observations of the circuit, or on rules of thumb, such as:

1) d_{50} for a dense medium cyclone is typically approximately 0,1 RD units higher than the feed medium density; that for a dense medium bath is usually within 0,02 RD of the feed medium density.

2) For a well-operated dense medium cyclone, the entire section of the partition curve where it rises from 0 % to sinks up to 100 % to sinks can usually be encompassed by a tracer density range from d_{50} − 0,06 RD units to d_{50} + 0,06 RD units.

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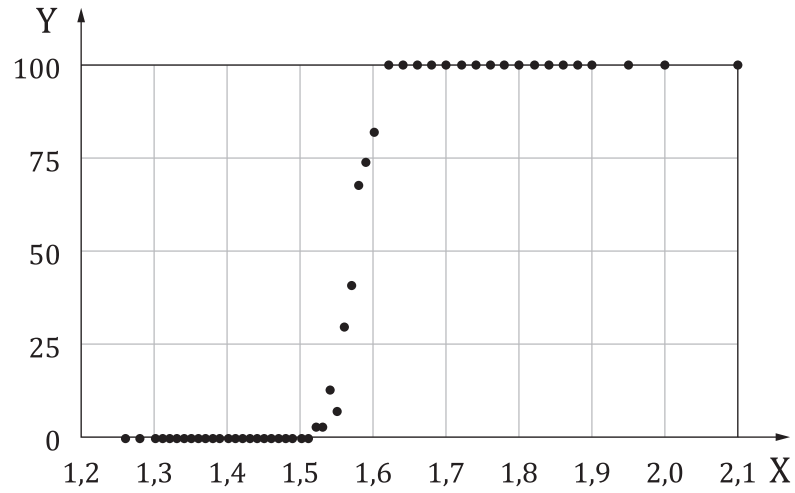

Figure C.1 — Example of tracer density selection covering all densities within a wide range

C.2.4 Cases where bypass is expected

If substantial misplacement by bypass is anticipated (some low-density particles report to sinks or some high-density particles report to floats), it is desirable that such by-pass is defined by selection of additional tracer densities at wide intervals over the affected range (see Figure C.2).

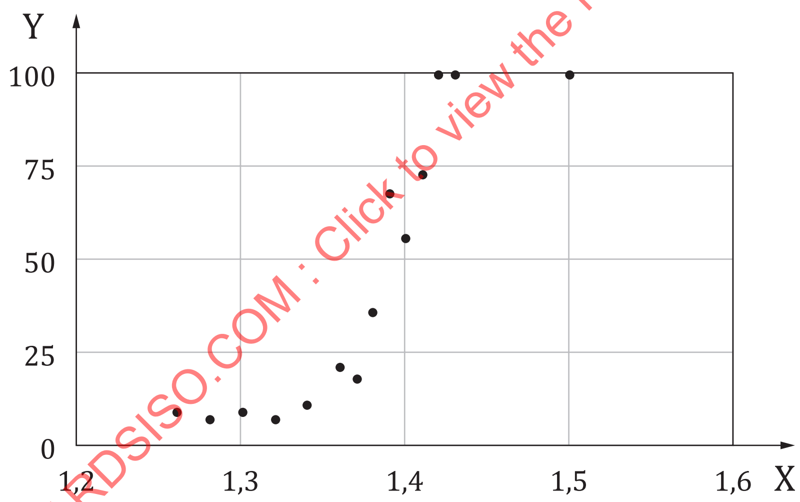

Figure C.2 — Example of a partition curve with good selection of close RDs around d_{50} and with a range of lower RDs to define an anticipated low-density "tail"

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Annex D
(informative)

Density tracer test report template

D.1 General

This annex contains a test report template (see Figure D.1).

For diagnostic and record keeping purposes, it is common to record on the density tracer test report the following information:

a) class and model of density separator(s), plus measurements and observations describing its condition;

b) key operating conditions (some of these may be available from the plant records).

A test report for a dense medium cyclone module may include the following list of recommended parameters to be determined and recorded. This document does not require the following information to be recorded on the test report, but it can be useful for troubleshooting and yield optimization.

See Reference [4] for more information.

D.2 Design variables

The design variables are:

a) cyclone diameter (mm);

b) inlet diameter (mm);

c) spigot diameter (mm);

d) vortex finder diameter (mm);

e) vortex finder length (mm);

f) configuration (e.g. single unit, 2 units off Y-piece);

g) barrel length (mm);

h) cone angle (degrees);

i) brand/manufacturer;

j) type of entry;

k) type of lining;

l) nominal feed rate (wet or dry metric tonnes per hour);

m) spatial relationship between end of involute and bottom of vortex finder;

n) degree of wear (e.g. amount of internal roping profile):

   1) pump-feed or gravity-feed;

   2) magnetite grade.

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D.3 Control variables

The control variables are:

a) pressure (gauge);

b) pressure variation for duration;

c) feed medium relative density;

d) feed medium relative density variation for duration;

e) feed solids flowrate, (wet or dry metric tonnes per hour);

f) feed solids flowrate variation for duration;

g) coal washability characteristics:

  1) yield estimate as a percentage;

  2) feed size distribution (+4 mm and at least 2 fractions between 4 mm and nominal bottom size of DMC feed);

  3) feed blend and variability estimate.

D.4 Operation limiting variable

The operation limiting variable is: volumetric medium: coal ratio.

D.5 Fluid mechanic variables

The fluid mechanic variables are:

a) overflow medium relative density;

b) underflow medium relative density;

c) method of RD measurement;

d) magnetite grade;

e) percentage of magnetics in feed medium.

D.6 Data measurement and presentation

Record medium RD when measurements are made.

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