bulk solids handling Volume 2, Number 2, June 1982

Dedicated to Professor Dr.-Ing. E. Bahke on his 65th birthday

Particle Degradation of ROM Coal and Washery Tailings up to 63 mm Size with Horizontal Hydrotransport

Wolfgang Sold, Germany

Summary

In the hydrotransport of materials with a wide range of particle sizes the degradation of the feed during transport is of paramount importance. The test rig at Bergbau-Forschung has been used to investigate a wide range of material and equipment parameters in their effect on the production of fines. This article reviews the progress of this research and describes some important findings.

1. Introduction

The test rig for hydrotransport at Bergbau-Forschung was installed particularly for handling coarse solid matter up to a maximum particle size of 100 mm. The pipeline in service is of DN 250 type and has a length of 235 m so that ROM coal and washery tailings up to 80 mm granular size can be put through. A pipeline diameter of 350 mm will be installed in a later extension phase. Details of the test rig design and of test performance will not be given here since they were comprehensively dealt with earlier [1, 2, 3].

With the aforesaid wide range of sizes it goes without saying that when investigating the transport behaviour of these solids special emphasis has to be laid on particle degradation. This is because when assessing the economics of hydrotransport the costs of dewatering and water treatment are of critical importance not only with suspensions to be conveyed over long distances, but also with coarse material transported over only short distances. These costs soar with decreasing granular sizes [4] which explains why enrichment of the slurry by fines < 0.63 mm plays an important part. Our main objectives, therefore, were to identify the parameters promoting the formation of fines and to try to find a way of keeping the proportion of fines within acceptable limits for hydrotransport.

Several test series were therefore carried out at Bergbau-Forschung to investigate particle degradation as a function of different parameters.

Dipl.-Ing. Wolfgang Sold, Bergbau-Forschung, D-4300 Essen, Federal Republic of Germany.

Translation of paper delivered at the Conference on Conveying Technology TRANSMATIC 81, September 30—October 2, 1981, organised by the Department of Conveying Technology (Institut für Fördertechnik), University of Karlsruhe, Fed. Rep. of Germany.

2. Difficulties in Reaching Generally Valid Conclusions

Any systematic description of particle degradation during hydrotransport of ROM coal and washery tailings is extraordinarily difficult due to the fact that the results are influenced both by plant-inherent as well as by solids-specific parameters.

The first problems are encountered as soon as one tries to transfer the results obtained from a transport cycle using a rotary pump — as in the case of Bergbau-Forschung — to a different plant of similar design. In this case even when maintaining solids properties and test conditions, the design and rotation speed of the pump impeller, the pipeline diameter or the number of elbows may have a bearing on particle degradation and lead to diverging results.

To this must be added the varying composition of the solids put through. For washery tailings, one has to take into account the mineral structure. Unlike sandstone, the clay minerals may degrade relatively fast [5] in the presence of water and with the mechanical loads prevailing when the material passes through the pump or through the pipeline.

For hydrotransport of raw coal, ash contents, i.e., waste contents, and coal type play an important part. Investigations by other authors show that is primarily the particle strengths of the different coal types which have a critical influence on the disintegration rate [6—11]. Table 1 reviews this work.

The multitude of factors mentioned which have bearing in different ways on the disintegration rate of the solids during hydrotransport even leads to contradictory statements by the authors listed in Table 1. Whereas in references [7] and [11] an increasing disintegration rate with rising slurry speed has been stated, the author in reference [8] has arrived at the opposite result. This shows how difficult it is to evaluate particle degradation either generally or in a mathematical formulation.

The test results obtained by the authors in [7], [8] and [10] have been summarized without any theoretical analysis. The authors in [9] and [11] give an empirical formula for evaluating the disintegration rate.

Trajnis [9] describes the retained matter R on a screen of given mesh width d, after having passed through a transport distance L, by the following exponential expression:

$$R_L^{+d} = R_o^{+d} \cdot e^{-a \cdot d^n (\epsilon \cdot L)^{b-c \cdot \lg d}}$$

Table 1: Experimental investigations on the particle degradation of coal during hydrotransport

Author/ Ref. No.	Shook [6]	Böhme [7]	Pipilen [8]	Trajnis [9]	Lammers [10]	Worster [11]
solids transported	lignite gas flame coal steam coal	ROM lignite (ash: 9—23%)	Pittsburgh seam coal	ROM gas coal ROM steam coal ROM anthracite	Lignite steam coal	coals
Pipeline diameter (mm)	100	125 200	150	150 200 300	95	a) simulation in an annular space with a rotating shell b) 75
Granular size (mm)	< 19	< 40	< 50	< 50 < 50 < 100	< 12.5 < 6.3	a) < 25 b) < 12.5
investigated parameters influencing particle degradation	particle strength; granular distribution in the feed; volume concentration; duration of transport	Transport speed of mix; granular distribution in the feed; transport concentration viscosity of the transport medium	Pump/pipeline; volume concentration; transport speed of mix	Transport distance; particle strength; inter-particle/ friction; volume concentration; transport speed of mix; pipeline diameter	duration of transport; granular distribution in the feed	a) transport speed of mix; transport distance b) rotary pump

where R_0^{+d} and R_L^{+d} are the sieve residues, in percent, on a defined mesh size d both of the feed and of the final product, after a determined distance L. ϵ is the unit of "specific energy expenditure" in $\frac{\text{kWh}}{\text{t} \cdot \text{km}}$, whereas a, n, b and c are dimensionless empirial coefficients depending on the type of coal retained. L is the transport distance in km.

Worster [11] stated a proportionality between the size degradation D and the two parameters, velocity of mix v and transport distance x.

$$D \sim v^3 \cdot x^{1/2}.$$

From this it can be seen that in Worster's experiments the transport velocity was of critical importance for particle degradation.

Shook [6] was the first to try to make his experimental results match with the *theory of grinding rates in milling processes*. He was able to arrive at a fairly satisfactory correlation.

3. Experimental Tests at Bergbau-Forschung

The following parameters influencing particle degradation were investigated in the test series run at Bergbau-Forschung:

a) duration of transport or transport distance
b) transport speed
c) volume concentration
d) granular distribution of the feed
e) number of pump passages of the solid matter
f) constructional design of the pump impeller.

The results are restricted to one type of solids each. Further, some conclusions are based on the results of a few tests only (b, c, and e).

Except for one single experiment all the tests on ROM coal were run with coal (gas flame) from the Lohberg colliery. ROM coal from Gneisenau (steam coal) was used only for test series f. The material for trials on washery tailings was supplied by Consolidation colliery. The results presented here are thus limited to the seam levels worked upon by these few collieries.

To facilitate assessment of the test results, some technical data of the test rig are given:

Cycling distances:	235 m for test series a to d 235 m and 58 m for series e 372 m for series f
Pipeline:	DN 250/steel
Bends:	4 elbows 90° (bending radius 650 mm) 1 bend 180° (bending radius 1,900 mm)
Delivery pump:	Z-wheel pump as produced by KHD, type ROPU. The impeller is equipped with 3 blades. It has a diameter of 825 mm and a free passage of 120 mm.
Specific rotation:	25 min^{-1}

This paper will be limited to consideration of some model-type results of test series b, d, and f since the influence of transport duration, number of pump passages of the solids and volume concentration, on particle degradation have already been reported elsewhere [12].

3.1 The Influence of Transport Velocity on Particle Degradation

Fig. 1 shows the result of two experiments on ROM coal with a grain size between 0 and 63 mm. The velocity of the transport mix amounts to 3.5 m/s for one test and to 5.0 m/s for the second test. Composition of the feed, volume concentration, and the distance over which the solids were transported up to the slurry sampling point, were exactly identical. With respect to fines the granular distributions of the different samples, when considering the accuracy of sieve analysis for varying pulp velocities, do not reveal any discrepancies. The two curves for 3.5 and 5.0 m/s almost coincide.

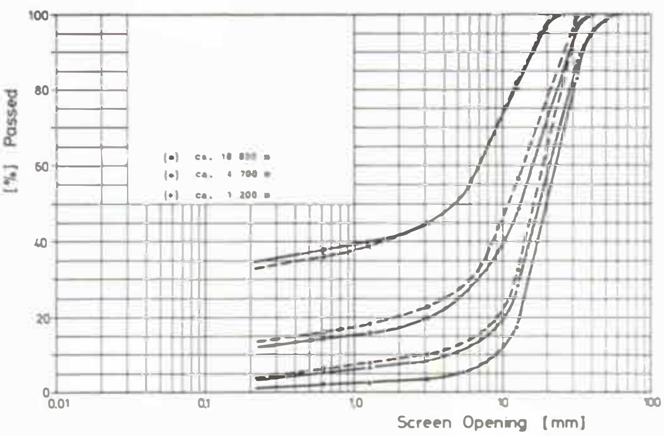

Fig. 1: Influence of the velocity of slurry v on particle degradation. Test with ROM coal between 0 and 63 mm.

solids concentration by volume = 10 %
(•) granular structure of the feed
slurry sample of the transport distance of
(*) approx. 18,800 m
(o) approx. 4,700 m
(+) approx. 1,200 m

The situation is different in the coarse size range between 10 and 63 mm. In this case a clearly faster disintegration rate at higher transport speeds than 3.5 m/s is observed. The disintegration rate decreases gradually between the first and the last slurry sample since the coarse granular fraction decreases with longer transport duration.

This is perhaps the proper moment to say some words on the difficulty of comparing sieve analyses of slurry samples taken from the cycle with samples taken from the material prior to cycling. Due to slippage between carrier medium and solid matter the fines are somewhat over-represented in the analyses of samples taken from the transport cycle, whereas too low volume proportions are found for the coarse granular fraction. This is why, whenever possible, a sample of slurry should be taken immediately when the solids/water mix reaches the sampling equipment for the first time. The granular distribution of such a sample should then be considered as the reference for comparison with the samples taken later in the cycle. One must realize, however, that then the solids have already passed through the pump once and, since sampling is carried out at the end of a cycle, have run through one full cycle length.

3.2 Dependence of Particle Disintegration on the Granular Distribution of the Feed

The two trials on ROM coal of different granular composition in Fig. 2 illustrate very well the dependency of grain disintegration on the grain size of the feed material. The size range with test 1 was between 0 and 31.5 mm, as against 0 to 63 mm for test 2 where, however, the proportion of fines was considerably lower. When one characterizes the granular distribution of the feed by defining a factor K (coarse fraction 12.5—63 mm to fines 0—3.15 mm one obtains from the sieve analysis a K value of 0.1 for test 1 and 2.3 for test 2. The volume concentration is 10 % for both tests. The cycling time until slurry sampling was 30 minutes in both cases.

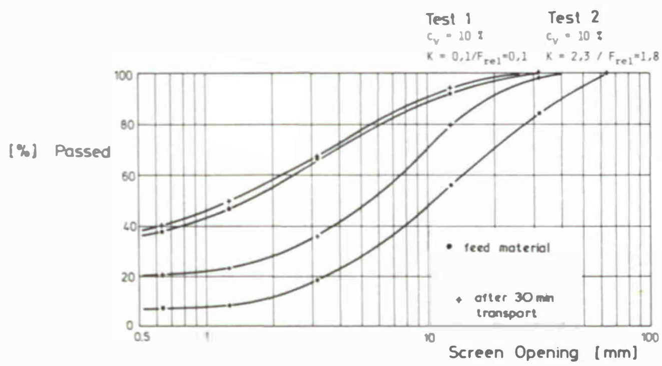

Fig. 2: Influence of varying granular composition K of the feed on particle disintegration.

$$K = \frac{> 12.5 \text{ mm (\% by wt.)}}{< 3.15 \text{ mm (\% by wt.)}}$$

$$F_{rel} = \frac{(< 0.63 \text{ mm } EK) - (< 0.63 \text{ mm } AK)}{< 0.63 \text{ mm } AK}$$

AK = initial granular distribution
EK = final granular distribution

As can be seen from the sieve curves of the two samples after 30 minutes cycling, the disintegration rate of the markedly coarser solids in test 2 is clearly higher. When considering the quantitative increase in the ultra-fine fraction (< 0.63 mm) between the feed and the final product, test 1 shows a 10 % increase against some 180 % for test 2. This *relative increase of fines* in relationship to the initial feed is expressed by the parameter F_{rel}.

An identical relationship between particle degradation and granular size of the feed material can be shown in the hydrotransport of washery tailings. Here again, a coarser feed subjected to hydrotransport leads to a higher percentage of fines in the final material. This result is shown in Fig. 3 for 4 tests on washery tailings within the range 0 to 63 mm. On this diagram has been plotted the relative increase in fines between 2 slurry samples of which the first was taken early during the test after a transport distance of 218 m, whereas the second was taken towards the end after 2100 m. The enrichment in fines (F_{rel} = 1.1 to 4.5) rising with increasing coarse/fines ratio (K = 4.0 to 13.1) of the initial feed is clearly visible.

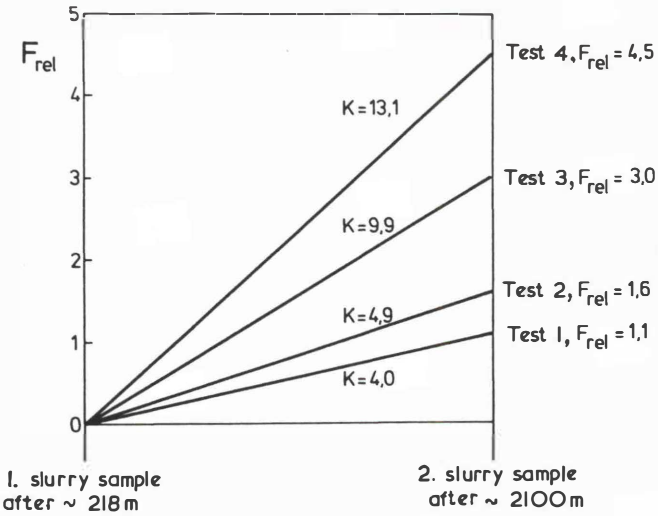

Fig. 3: Relative increase in fines (F_{rel}) between two slurry samples as a function of transport distance and of the coarse fines ratio K of the feed

Solids: Tailings < 63 mm
Velocity of mix: 4.5 m/s
Concentration by volume: 18.5 %

3.3 The Effect of Two Different Rotary Pumps on the Degree of Disintegration of ROM Coal

To investigate the effect of different pump impellers on the particle degradation of ROM coal Bergbau-Forschung ran a total of 8 trials. 4 tests were carried out with the pump installed on the test rig and 4 with a second pump with an impeller of smaller diameter. All the tests were run with ROM coal from Gneisenau colliery. The slurry velocity amounted to 4.5 m/s with a concentration by volume of 20 %.

Table 2 gives details of the pumps:

	Pump no. 1	Pump no. 2
Number of channels	3	3
Specific rotation (min⁻¹)	25	50
Impeller diameter (mm)	825	480
Gap width (mm)	120	100
Rotation (min⁻¹) at v_{Tr} = 4.5 m/s and c_v = 20 %	approx. 550	approx. 1,100

Table 2: Details of design and operational speed of the pump impellers

Figs. 4 and 5 show the results of one trial on each of the pumps. The granular distribution and waste contents of the feed were almost constant in all of the 8 trials. The sieve curves of two slurry samples after a transport distance of 355 and 2,200 m are given.

When comparing the curves one sees a clearly faster solids disintegration in the coarse granular fraction using pump 2, which runs at double the speed. In the fines range, however, hardly any difference is perceivable. The average increase in fines (< 0.63 mm) between the first and second slurry samples for the 4 tests run with pump 2 is even slightly below the result for pump 1.

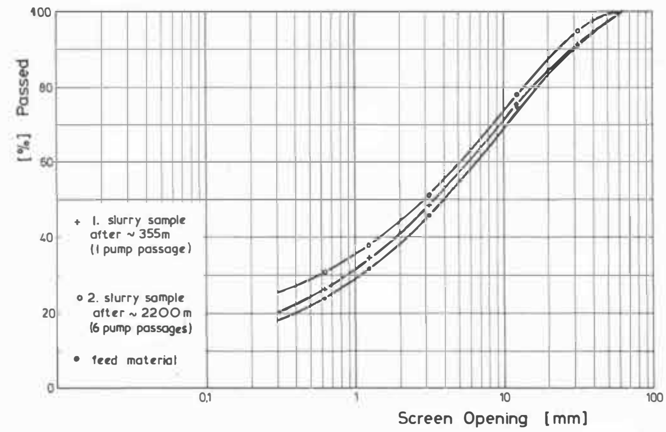

Fig. 4: Particle degradation for conveyance by pump 1
Solids: ROM coal < 63 mm

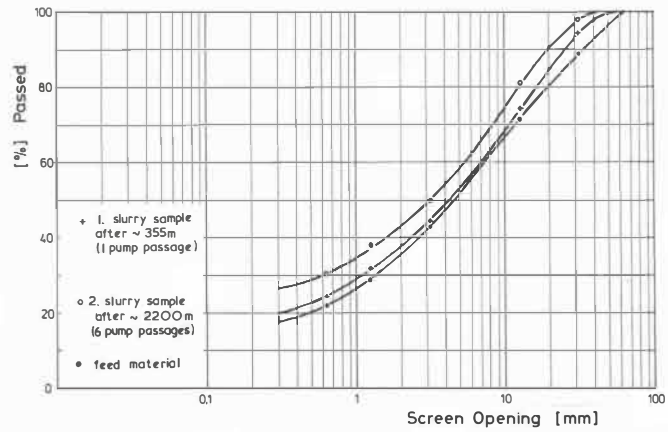

Fig. 5: Particle degradation for conveyance by pump 2
Solids: ROM coal < 63 mm

The average decrease in the coarse range (> 31.5 mm) between the first and the second sample, however, is visibly higher with the faster rotating impeller (decrease from 63.3 % to 49.7 % with pump 1). This behaviour has been plotted in Fig. 6.

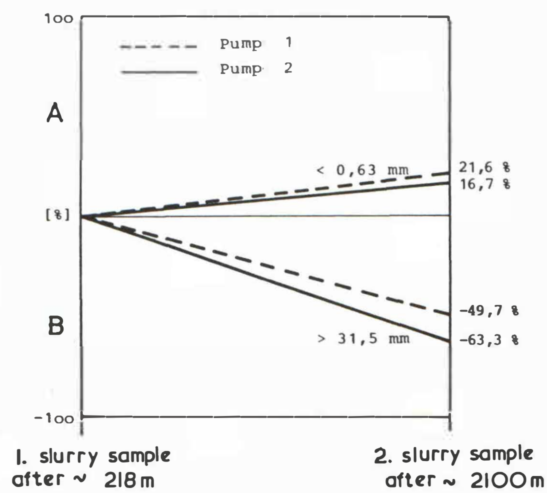

Fig. 6: Average increase in fines and average decrease in the coarse size range with hydrotransport of ROM coal using two different types of pump

A = rise of attrition

B = decrease of coarse particles

The double speed of pump 2 thus seems to manifest itself only in a stronger crushing effect on the coarser fractions, whereas it does not affect the small size range.

The above result reconfirms earlier experience [8, 9, 12] according to which the coarse particles are comminuted mainly by the action of the pump impeller, whereas the cause for the increasing proportion of fines < 0.63 mm depends above all on the duration, or distance, of transport. These two kinds of particle degradation do not however, appear independently; it is established that the coarse particles crushed by the impeller will, through the action of their sharp edges, tend to produce attrition during pipeline transport.

4. Summary

Even though the experiments on particle degradation during hydrotransport of coarse granular fractions are far from being completed as yet, some important statements can already be made. Bearing in mind the enormous technical and financial efforts being invested in the dewatering of small solid particles, the investigations have so far resulted in some interesting findings on fines enrichment of slurry under various operational conditions.

It can be said that with a pipe diameter of DN 250 the slurry speeds selected for the trials, of 3.5 or 5.0 m/s, do not have any measurable influence on the formation of fine attrition matter in the pipeline.

When considering the influence of the rotary pump alone one may say that with all trials run so far any increase of the rotational speed of the impeller brings about a strongly increasing disintegration of the coarse granular fraction.

The coarse/fines ratio K turned out to be a very important solids-specific influential parameter for particle disintegration. The coarser the feed material, the higher will be the disintegration rate during hydrotransport.

From these observations it is clear that there will exist an optimum granular distribution of the feed material for a specific hydrotransport system as well as for a specific type of solid matter. It has to be demonstrated by further experiments whether reproducible results can be expected.

References

[1] Maurer, H., "Test rig of Steinkohlenbergbauverein for transport of lump-size coals; experimental lay-out and methods." 3rd colloquium on pipeline bulk transport, organized by GH Paderborn/Meschede (1978).

[2] Maurer, H., "Application and potentials of hydrotransport in hard coal mining". Transrohr 80. VDI-Berichte No. 371 (1980), pp. 131/37.

[3] Mez, W., "Metrological problems with the test rig for hydrotransport of Bergbau-Forschung". 4th colloquium on pipeline bulk transport, organized by GH Paderborn/Meschede (1980).

[4] Köhling, R., "Solids/liquid cycles in coal preparation plants". 3rd colloquium on pipeline bulk transport, GH Paderborn/Meschede (1978).

[5] Knatz, H., "The behaviour of different rock strata in respect of water". Glückauf-Forschungshefte (1979), vol. 2, pp. 57/62.

[6] Shook, C.A., Haas, D.B., Husband, W.H.W., Small, M., "Degradation of coarse coal particles during hydraulic transport". Hydrotransport 6, paper C1, 26—28.9.1979, Canterbury.

[7] Böhme, F., Ebbecke, K., "Results and problems with experimental trials on hydrotransport of granular size lignite". Neue Bergbautechnik, vol. 6, June 1975, pp. 433/39.

[8] Pipilen, A.P, Weintraub, M., Orning, A.A., "Hydraulic transport of coal". U.S. Bureau of Mines Report of Inv. 6743 (1966).

[9] Trajnis, V.V., "A method of calculating the degradation of coal in pipelines during hydrotransport" (in Russian language). Ugol. No. 9 (1963), pp. 37/41.

[10] Lammers, C.C., Allen, R.R., Donaven, D.J., Wagner, E.O., Parry, V.F., "A study of the feasibility of hydraulic transport of a Texas lignite". U.S. Bureau of Mines Report of Inv. 5404 (1958).

[11] Worster, R.C., Denny, D.F., "Hydraulic transport of solid material in pipes". Proc. Inst. Mech. Engrs. 169 (1955) pp. 563/73.

[12] Maurer, H., Sold, W., "Hydraulic transport of coal and washery tailings up to 63 mm size. — Particle degradation, sampling, and sample treatment". 4th colloquium on pipeline bulk transport, GH Paderborn/Meschede (1980).