Blast furnace zinc control

With the increasing recycling of galvanised steels into steel converters and ever increasing environmental restrictions and costs to dump waste dusts and sludges, increased management of the quantity of zinc in both the input and output materials is required to efficiently manage blast furnace operations and costs.

The use of dust cyclones has large benefits with regard to iron recovery from blast furnace gas, but with a hydro-cyclone installation it is possible to separate the blast furnace sludge into a coarse fraction, which contains relatively little zinc, and a fine fraction which contains a much higher concentration of zinc. In this way it is possible to maximise zinc removal capacity from the steel plant and to create an effective 'bleed' for the excess zinc from the plant.

The right combination of dust separation technology and sludge processing optimises the zinc balance and associated cost.

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Size fraction µm	Wt %	Fe %	Zn %	Pb %	Carbon %
>60	34.4	14	0.3	0.04	
30-60	29.5	38	1.5	0.05	
20-30	22.7	44	1.5	0.05	
10-20	4.5	28	0.5	0.11	
5-10	2.6	41	1.1	0.17	
<5	6.3	19	8.6	1.15	
Total	**100**	**35.7**	**1.65**	**0.23**	**29.5**

Table 1 Typical composition of blast furnace dust

Blast furnaces produce significant amounts of dust, which leaves the process with the top gas. This dust could be dumped, but it is far more attractive to recycle it through the sinter plant back into the blast furnace as it contains a significant quantity of iron-bearing material. Some of this dust, specifically the fine fractions, contains up to 3% zinc and various concentrations of other heavy metals. The zinc originates from the iron ore, but also from other recycled iron-bearing waste streams in the steel plant, such as galvanised steel scrap. The zinc ends up in BOF off-gas dusts and is recycled into the sinter plant as these dusts are rich in iron and other valuable elements.

Typically, the dust production by a blast furnace is between 4 and 8kg/THM. For a large furnace producing 10,000t iron/day, this means up to 80t of dry dust per day, which is a significant quantity. This dust typically contains 30-40% iron and can also contain significant amounts of carbon. The zinc concentration is usually in the range 0.4-3.0%.

WHY CONTROL ZINC?

The need to control the zinc input in the blast furnace is twofold: for process operation of the furnace, but mainly cost. The higher the zinc loading, the higher the risk of upsetting the process conditions in the furnace and the longer the time needed to stabilise the situation. These upset conditions also translate into higher costs.

More recycled material means less raw material is required and there are lower dumping costs. Also, the presence of historic waste materials, such as blast furnace and BOF dust and sludge and the need to process these materials, has its impact on the overall zinc balance. Blast furnace operators carefully monitor the operation and cost associated with recycling, and work out a strategy to optimise the cost and performance of the blast furnace. These strategies may differ from site to site.

ZINC INPUT

The zinc input plays a large role in the preparation of the blends for the sinter (or pellet) plant. Only around 20% of the incoming zinc comes from the fresh ores and fluxes, the remainder comes from the recycle streams generated in the process chain all the way to the rolling mills.

ZINC OUTPUT

The zinc output of a blast furnace can be split into two routes: the liquid metal tapped from the furnace, and the dust in the blast furnace gas. Of the total zinc input, around 20% is tapped with the liquid metal (depending on temperature and slag content of the hot metal) and 80% is removed as dust. The dust can be recovered from the gas and then be processed by means of particle size separation or leaching. Separation processes will be described below.

Zinc and lead concentrations vary with dust particle size. The data in *Table 1* represents samples taken at a plant where the furnaces are burdened with 40% sinter and 60% pellets.

Fraction µm	Wt %	Zn %
>76	24	0.15
50-76	12	0.16
31-50	22	0.15
10-31	16	0.29
<10	26	1.4
Total	100	0.7

Table 2 **Typical size fractions in blast furnace dust**

	Typical blast furnace sludge, wt %
Total Fe (oxides)	35-40
Carbon	20-50
CaO	1.6-2.0
SiO_2	2-5
Al_2O_3	2-3
MgO	0.3-.5.0
Zn	0.4-2.0
Pb	0.1-1.3
Cd	0-0.0006
Sum of Cu, Ni, Cr	0.1-0.4
Water	30-40

Table 3 **Blast furnace sludge composition**

Another example from another plant (see *Table 2*) operating on a high sinter percentage gives a similar picture.

DUST RECOVERY

The dust from the blast furnace is normally recovered in two steps. The first is either a gravimetric dust catcher or a tangential cyclone dust catcher and the second step is usually a wet scrubber. It is preferable to recover as much dust as possible in the first step as this dust will be dry and easy to process in the sinter plant. Within the second step the dust is captured in water and the dust is recovered as a sludge. The processing of a sludge is always more difficult and costly than the processing of a dry material.

STEP 1: GRAVIMETRIC DUST CATCHER OR DUST CYCLONE

The limiting factor in the recycling of both dust and sludge is mostly the zinc loading towards the blast furnace. Ideally the dust from the gravimetric dust catcher or dust cyclone is recycled straight away and therefore should be low in zinc. Gravimetric dust catchers have a typical dust recovery rate of 50%, while dust cyclones have a typical recovery rate of 85%. Both of these fractions are low in zinc. Since the cyclone's dust removal efficiency is highest for the largest particles and the majority of the zinc is found in the particles smaller than 5µm, designing and adjusting the cyclone for even higher efficiencies – which is possible – will only add more zinc to the recovered dust. This would undermine the cyclone's advantage of being able to recycle 85% of the dust straight away as opposed to the dust catcher's 50%.

STEP 2: WET SCRUBBER

After the gravimetric dust catcher or dust cyclone there is normally a two-stage wet scrubber. In the first stage, the gas is sprayed with water to humidify it and remove a large portion of the dust. In the second stage, consisting of a venturi or annular gap scrubber, very intense contact between gas, dust and water takes place, resulting in an overall dust removal efficiency of over 99.9%. This means that in the second stage almost all the dust is now captured in water. After settling and de-watering, a wet sludge remains. Recycling this sludge requires processing in order to limit the zinc input for the blast furnace. Processing sludge from a blast furnace with a dust catcher can recover significant amounts of iron and carbon units, whereas processing sludge from a blast furnace with a dust cyclone is less beneficial, but could still be economical in some cases.

As the highest zinc concentration is found mainly in the very fine fraction of the sludge, the most practical solution is to separate the very fine fractions from the bulk of the sludge. The coarse fraction containing less than 0.15-0.20% zinc can then be recycled to the sinter plant; the fine fraction containing 2-4% zinc can be de-watered using a filter press or equivalent and dumped or stored for further upgrading and may be recycled later.

CHARACTERISATION OF BLAST FURNACE SLUDGE

The typical composition range of blast furnace sludge is given in *Table 3*.

The particle size is fine with 30% having a size below 30µm and 60% below 60µm. The composition and the particle size distribution is highly dependent on the burdening materials (pellets, sinter, lump), how the furnace is operated, and if coal injection or other fuel injection is used and at what rate. Carbon is visible as coke fines, but can also be found as char or as Boudouard carbon. Also, the design and efficiency of the gas cleaning system play a role. Large differences in the physical properties of the sludge have been found in practice. The sludge from the thickener basin of the blast furnace water treatment system consists of approximately 30% solids and 70% water after dewatering.

ALLOWABLE ZINC LOADING

The zinc load to the blast furnace is normally limited to 120-190g/THM. Higher zinc loads can result in an ▷

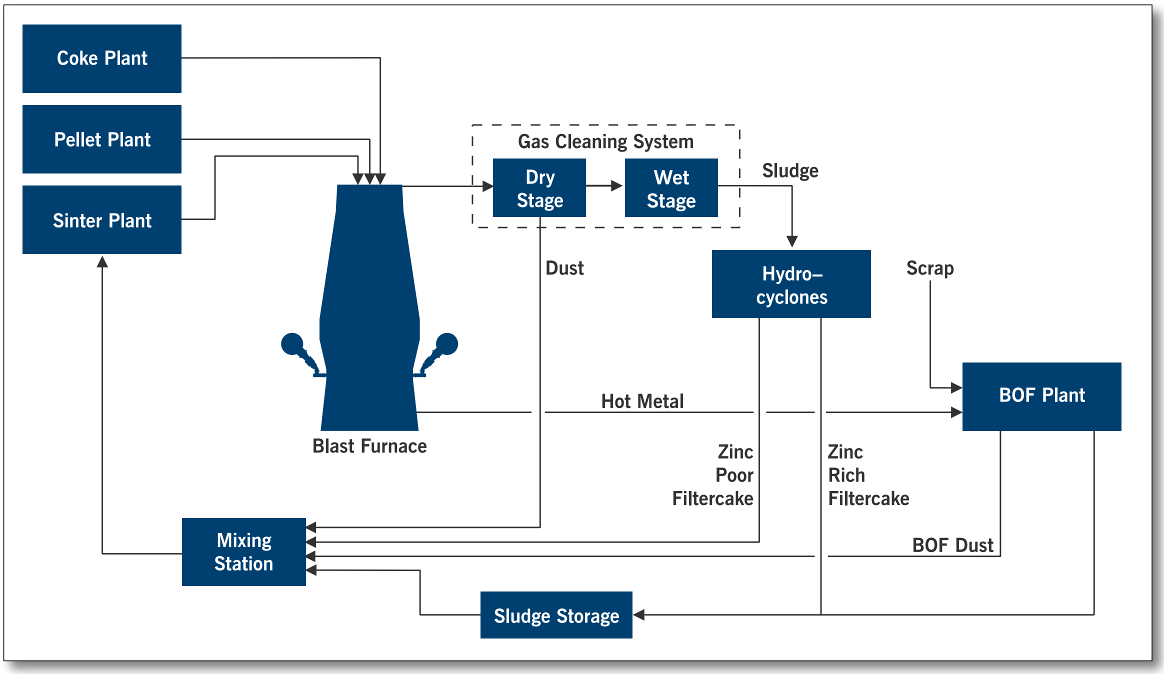

Fig 1 **Zinc flow in an integrated steel plant with the application of hydro-cyclones**

Zinc flow (g/ tHM)	Dust catcher and hydro-cyclone	Dust cyclone
From blast furnace to gas cleaning plant	130	130
Recycled from dry stage to sinter plant	10	86
Zinc available in wet stage	120	44
From hydro-cyclone to dump	76	n/a
Recycled from hydro-cyclone to sinter plant	44	n/a

Table 4 **Zinc balance comparison. Dust catcher combined with hydro-cyclone vs dust cyclone without hydro-cyclone**

irregular process, damage the refractories (specifically in the hearth), and cause release of unhealthy fumes during tapping. In recent years, better control of the blast furnace process, higher quality refractories and improved cast house ventilation have enabled blast furnace operators to gradually increase the zinc loading from 120g/THM in the 1990s up to 190g/THM today. Increasing the zinc content has increased the amount of recycled dust, and so reduced the amount of sludge being dumped.

However, in the future it is likely that dumping will become increasingly restricted, caused by ever more stringent environmental requirements. Specifically, the concentration of heavy metals in the waste material and scrap will require special precautions for safe dumping, which can become quite costly. In most steel plants in Western Europe, the dumping cost of zinc-rich blast furnace dust or sludge may, in many places, well exceed the costs associated with the loss of iron units.

SLUDGE TREATMENT

Over the years, processes have been developed to separate the zinc (and other heavy metals) from the iron fraction so that recycling of at least the iron fraction could be possible. Pyro-metallurgical and hydro-metallurgical processes focus on the highest purity of the recovered metals, but the relatively small plant size and relatively high cost mostly does not justify the realisation of such a plant at an intergrated blast furnace site. The focus of pyro- and hydro-metallurgy is, therefore, on waste streams that contain high zinc concentrations, such as EAF dust.

The use of hydro-cyclones to split and concentrate the zinc fraction is considered a good option in cases where the sinter plant has room to allow zinc-bearing waste streams into the ore mix. Especially when a gravimetric dust catcher is present, this is a viable solution. The hydrocyclone is capable of separating particles by size. Once separated into two or three streams these streams can be de-watered and the produced cake from each stream with its own zinc content, can be fed to the sinter plant, or discarded, optimising the recycle and minimising the amount of waste material. *Figure 1* illustrates the zinc flow in an integrated steel plant with the application of hydrocyclones. *Table 4* indicates the zinc balance between the gas cleaning plant and the waste dump and sinter plant. It compares the situation for a gravimetric dust catcher combined with a hydro-cyclone installation with the situation where only a dust cyclone is applied. It is based on a 130g/tHM zinc flow from the blast furnace to the gas cleaning plant.

THE HYDRO-CYCLONE PRINCIPLE

Hydro-cyclones are well known from the mining and petrochemical industries and are available in a large variety of shapes, sizes and materials. A few examples are shown in *Figure 2*. The key selection criterion is the d50 value which represents the particle size of which 50% ends up in the underflow, in other words particles of this size have an equal chance of ending in the overflow or the underflow. In practice, the d50 value must be at least 3-4 times lower than the maximum particle size that can be accepted in the overflow. If, for instance, all particles smaller than 30µm must end up in the overflow, the d50 value must be at least 10µm. This requires a small diameter hydrocyclone, with a relatively long and slender shape, and a high feed pressure.

In practice, it has also been found that it will be increasingly difficult to separate particles smaller than 20µm from a sludge flow by means of hydro-cyclones, specifically if it has low density. Major disturbances could sometimes result from carbon particles which are large but have a low specific mass, and therefore cannot be separated effectively. The feed pressure determines the swirling speed in the cyclone, and is also a determining factor in the optimum operation of the hydro-cyclone.

From experiments it has become clear that the separation point between fine and coarse material must be as sharp as possible, which requires a two-stage or even a three-stage installation. Finding the optimum separation point depends a great deal on the plant-specific particle size distribution of the sludge, and is very much an economic trade off between:

- The maximum allowable zinc load in the blast furnace (the total zinc balance of the plant)
- The value of the recovered and recycled low zinc material from the underflow
- The dumping cost for the zinc-rich cake from the overflow

Fig 2 **Examples of hydro-cyclones**

If, for instance, the dumping cost becomes extremely high, the tendency is to reduce the volume of the zinc-rich cake as much as possible, and allow maximum zinc load in the blast furnace. The cut-off point must be very accurate. If the main aim is to recover the iron-bearing materials and not to worry about the quantity of the zinc-rich cake, the cut-off point can be much coarser. The volume of the materials streams and their respective zinc concentrations will determine the optimisation for each plant.

One of the parameters to monitor is the concentration of polonium, a radioactive element that is also present in blast furnace sludge, and is also within the finest fraction of the dust. Over-concentrating the zinc in a fraction might result in a sludge waste material that can be classified as radioactive waste. Monitoring polonium and Becquerel levels is advised.

CASE: IMPLEMENTATION OF A HYDRO-CYCLONE

At a steel plant in Europe, a research project was started in 1980 to investigate sludge separation and select the optimum hydro-cyclone configuration. The results were very encouraging and also demonstrated that the economic payback time would be less than two years. Initially, in 1984, a two-stage hydro-cyclone arrangement was built with a capacity of 2 x 60,000t sludge (dry basis). This capacity was needed since a large volume of stockpiled sludge had to be treated as well as current production. The results with this installation were very successful. At the end of the 1990s, the possibilities for land filling the zinc-rich cake became increasingly difficult and costly and further optimisation studies were carried out. This resulted in the addition of a third stage cyclone in which the overflow of the second stage cyclone was re-treated, in order to separate the remaining zinc-poor coarse fraction from that stream.

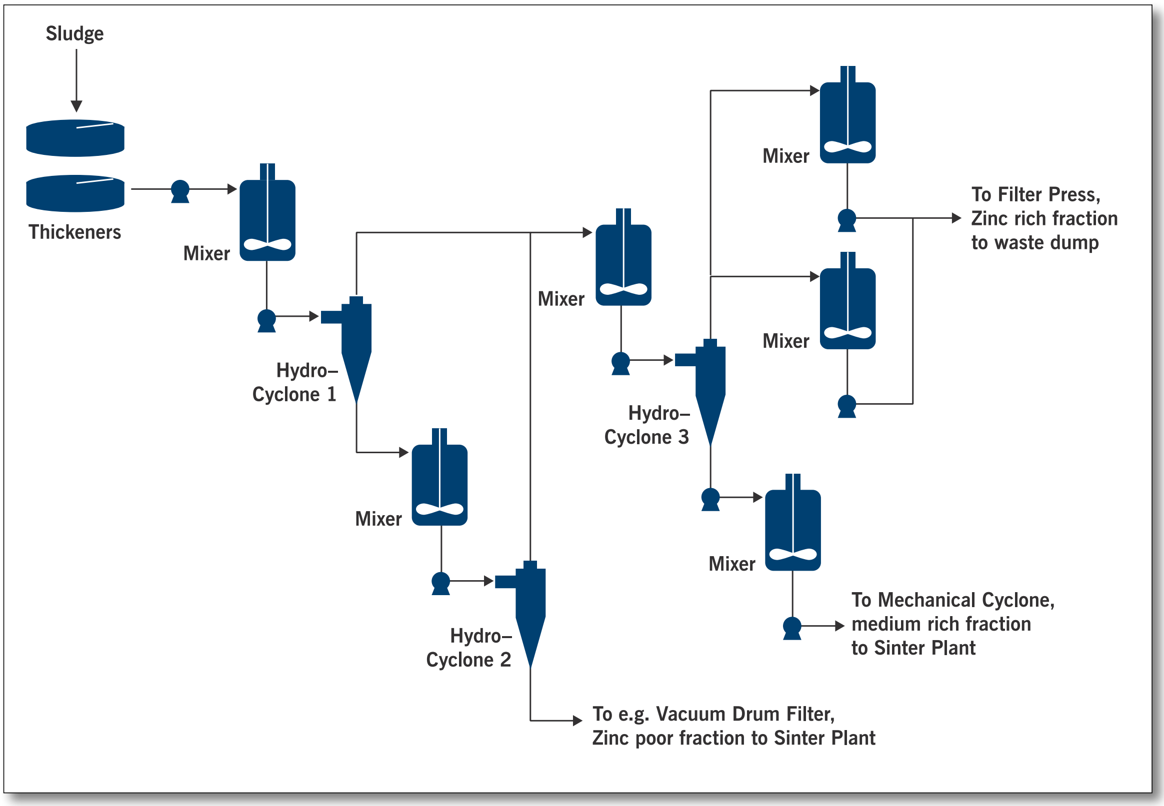

Fig 3 **Flow sheet for a typical three-stage hydro-cyclone installation**

TYPICAL HYDRO-CYCLONE INSTALLATION

The sludge is pumped from the thickener into a mixing tank where its density is optimised for the first stage hydro-cyclone. The overflow is directed to the filter press, and the underflow is treated in a second hydro-cyclone.

Each hydro-cyclone unit has a mixing tank to be able to dilute the sludge to the optimum density and a pump with pressure and flow control, to be able to operate the hydro-cyclone at its optimum working point. The underflow is relatively easy to de-water using a filter press and is recycled to the sinter plant. The overflow is more difficult to de-water, and for this purpose two large filter presses are used.

The addition of a third stage hydro-cyclone creates an additional stream of medium coarse material that also has to be de-watered. The underflow of the third cyclone can be de-watered in a 'decanter' – a horizontal separation centrifuge. *Figure 3* shows the flow sheet for a typical three-stage hydro-cyclone installation (components of and interaction with the water treatment plant is omitted for clarity).

A hydro-cyclone installation can be operated unmanned, with routine maintenance taking place at regular intervals. Typical energy consumption is usually around 16kW/t of treated sludge. Operation can be continuous or during dayshifts only, depending on the available capacity. Starting, stopping and process control is done by PLC.

ZINC BALANCE

The zinc balance will be different for every plant and will not only depend on the natural zinc concentration in the iron ores, but also on the amount of zinc-bearing materials that are recycled in the steel plant, for instance, originating from galvanised scrap, and that show up as an increased zinc concentration in the sinter. Whether a two- or three-stage hydro-cyclone installation is applied has a major influence on the zinc balance. *Table 5* compares the dust and zinc flows before and after the addition of the third stage hydro-cyclone in the case discussed above, which are considered typical. It also shows flows at a site with a single stage installation.

A more specific material balance for a three-stage hydro-cyclone installation is given in *Figure 4*, showing the various input and output streams of the individual hydro-cyclones. The underflow of the third stage, which could be designated medium-rich in zinc, is the typical fraction for managing the zinc flow towards the sinter plant in cases where the total zinc input needs to be brought down. In general, 70-75% of the sludge material can be recycled to the sinter plant (when using three stages) without

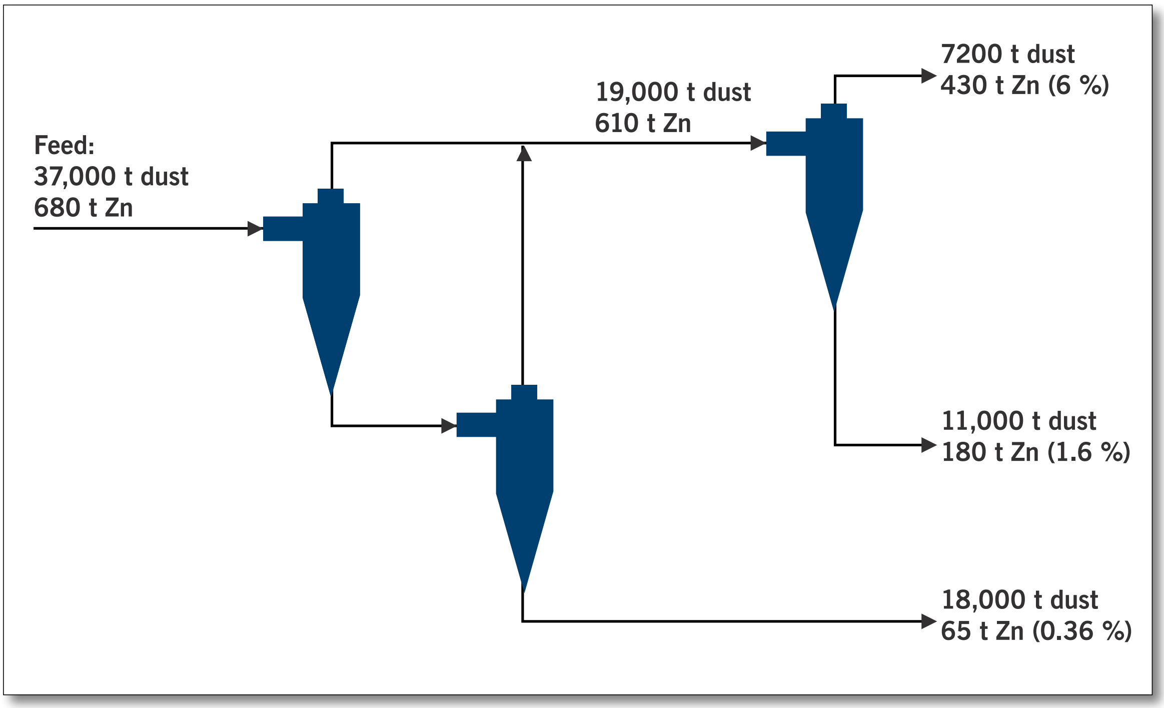

Fig 4 **Material balance for a three-stage hydro-cyclone installation**

upsetting the zinc balance of the steel plant or exceeding the maximum allowed zinc input of the blast furnace.

Increasing the dry dust recovery in the dry stage by means of a (tangential) cyclone dust catcher will justify the installation of fewer hydro-cyclone stages or even lead to a very poor business case for the installation of hydro-cyclones in the first place. An extreme case is shown in *Table 6*.

The table shows that the recovery of material from the wet scrubber might not be economical when installing a high efficiency (tangential) cyclone dust catcher. ROI for the installation of hydro-cyclones could be longer than five years depending on dumping and raw material costs. Therefore, improving the zinc and waste control of a site via blast furnace dust separation and partitioning needs to be studied in detail to select the most economical solution. Installation of hydro-cyclones is most beneficial in case of high dust loadings in the wet scrubber in combination with high zinc loadings.

CONCLUSIONS

- Zinc control on the input and output is required to manage blast furnace operation and optimise cost and environmental impact.
- There are two economical solutions to recover iron and carbon units: first, a dust cyclone where the non-separated dust is discharged and second, a hydro-cyclone unit which is combined with a (less efficient) gravimetrical dust catcher.

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	One-stage (plant A)	**Two-stage (plant B 1984)**	**Three-stage (plant B 1999)**
Dust from blast furnace (t)	24,000	37,000	37,000
Zinc from blast furnace (t)	860	680	680
Dust to waste dump (t)	16,800	19,000	7,200
Dust recycled (t)	7,200	18,000	29,000
Amount recycled %	30	49	78

Table 5 **Zinc balances for one-, two- and three-stage hydro-cyclone installations**

Dust, t/ yr (zinc, t/ yr)	Dust catcher and hydro-cyclone, plant B	Dust cyclone
Feed from blast furnace	74,000 (737)	74,000 (737)
Recovery in dry stage, to sinter plant	37,000 (57)	63,000 (490)
From wet stage to dump	n/a	11,000 (246)
From hydro-cyclone to dump	7200 (430)	n/a
From hydro-cyclone to sinter plant	29,000 (250)	n/a

Table 6 **Dust and zinc balance comparison, dust catcher combined with hydro-cyclone vs dust cyclone without hydro-cyclone**

- With a hydro-cyclone installation it is possible to separate the blast furnace sludge into a coarse fraction, which contains relatively little zinc, and a fine fraction which contains much higher concentrations of zinc.
- With a hydro-cyclone installation it is possible to maximise zinc removal capacity from the steel plant and to create an effective 'bleed' for the excess zinc from the plant.
- At the same time it is possible to reclaim up to 70-75% of iron and carbon-containing waste materials that would otherwise be lost. This material can be recycled to the sinter plant without exceeding the maximum allowable zinc input to the blast furnace.
- So far, an economical method for extraction of zinc from the cake containing <5% zinc has not yet been found. **MS**

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