OXYFINES™ TECHNOLOGY FOR THE RE-MELTING OF FINES, DUST AND SLUDGE

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ABSTRACT

OXYFINES™ is an oxyfuel-based concept for in-plant recycling. It enables the possibility of fines, dust, sludge (without any drying step) and other by-products generated by the steel- and metal-producing industries to be recycled directly back into existing processes or a separate on-site unit. The results from a full-scale installation (20 000 t/a) and pilot-scale trials with dry and wet materials in the steel and ferroalloy industries are presented. The latter include materials arising from ferrosilicon, ferrochrome and silicon manganese production. The concept not only provides a solution to the problems associated with dust and sludge generated in metal production, it also turns these materials into a low-cost raw material which is useful for the same production process, thus replacing some of the raw material input. If required, it could also be used, possibly as an intermediate solution, to convert the dust or sludge into an inert material with a suitable shape. Under some conditions, a directly saleable product could also be obtained. The paper reviews this technology, its status and benefits as wells as its possibilities with regard to application in ferroalloy production.

Keywords*: recycling, fines, dust, sludge, ferroalloys*

1. INTRODUCTION

Large quantities of metalliferous dust are generated by the metallurgical industry. Crushing and screening processes often produce dust. Exhaust gas filters are another major source of metalliferous dust. However, dust from filters often end-up in the wet stage as sludge. Worldwide, it is estimated that at least 50 million tonnes of metalliferous dust and sludge are produced annually and only a fraction of this amount is currently recycled.

The handling and recycling of dust is often difficult and expensive. Public authorities, customers and the public are making ever greater demands on the metallurgical industry to reduce emissions, and this is increasing the need to develop new, more cost-effective ways of dealing with the dust problem. The problem is exacerbated by the obsolescence of some of the existing alternatives. One example is landfills, which are no longer *comme il faut* and will soon be prohibited in some countries. Existing technologies for handling and recycling dust are also expensive. Transportation and treatment often cost hundreds of euros per tonne. In most cases, there is also a lack of technology for recycling sludge generated in metallurgical production.

There are four approaches to solving the dust problem:

- Prevent dust generation. This can be achieved by inerting, which is often the cheapest and best alternative. However, process conditions often mean that inerting cannot be used, at least not as a complete solution to the problem.
- Recycling. There are three options:
  - recycling dust material back into the dust-generating process,
  - recycling into another on-site process, or
  - recycling into a process on another site, possibly in a different sector of the industry.
- Treatment.
- Landfill.

Product flow often goes from treatment to recycling or landfill. An important trend is the increasing pressure being applied by authorities and key customers, which is leading to a change in practice from landfill dumping to treatment and from treatment to recycling, i.e. towards dust prevention. Alternatively, if complete recycling cannot be achieved, the goal is to obtain a product that can be classified as inert material with negligible environmental impact.

It is also interesting to consider the classification of "waste" as it is applied in many places. Waste is classified into the following three types:

- Inert material
- Waste
- Hazardous waste

If "waste" such as dust or sludge can be turned from "hazardous waste" into "waste" or from "waste" into "inert material", it is normally highly favourable from a cost perspective.

2. THE OXYFINES™ TECHNOLOGY

AGA Linde has developed and patented this oxyfuel-based technology. It has been developed to enable the efficient internal recycling of fines, dust and sludge, with the latter (i.e. sludge) being recycled without a drying stage. AGA Linde has developed process concepts for these applications. It is normally an on-site alternative, which can be directly applied to existing processes. It provides a solution to most dust treatment and recycling problems in the metallurgical industry.

The technology is based on the 'waste' materials having known compositions. This generally enables them to be used as a raw material in existing processes, often in the process that generated them. This technology agglomerates particles into solid-state aggregates of a suitable size or creates a liquid product and removes harmful elements and is based on combining injection with oxyfuel technology. It gives a flexible system, where several functions can be combined. The results from work on this technology have been very encouraging. High yields and low levels of oxidation have been achieved. A photograph of the special oxyfuel burner used is shown in Figure 1. This burner has the same features as an oxyfuel burner used to boost production and save electricity in an Electric Arc Furnace (EAF) for scrap-based steel production. The burner can also be used to achieve these benefits. The integrated recycling features are of course unique to the oxyfuel burner used.

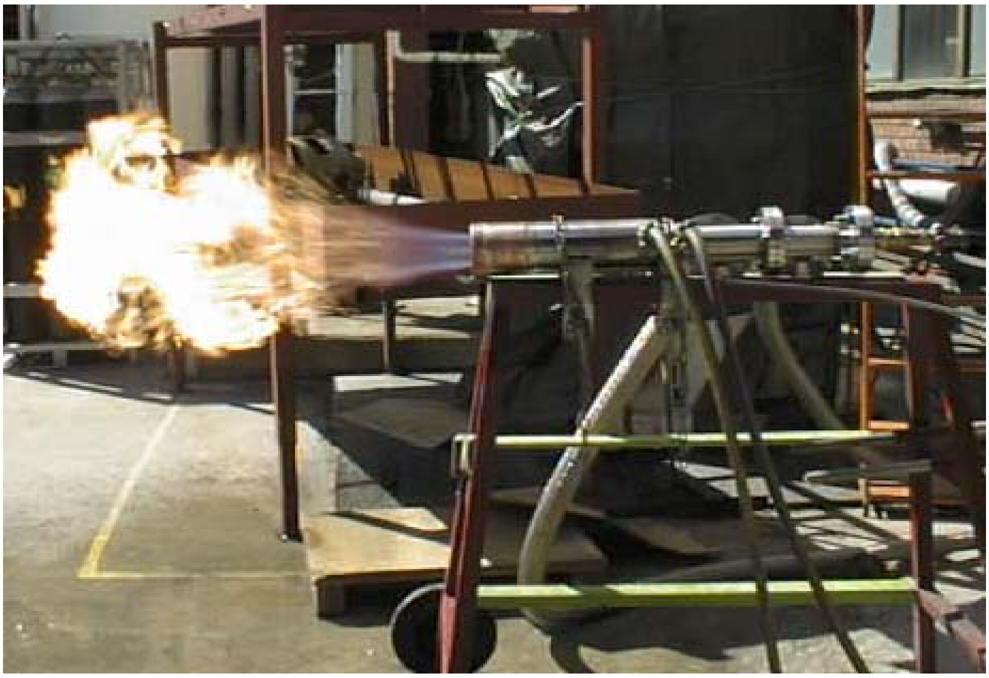

Figure 1. The oxyfuel burner used for fines, dust and sludge re-melting.

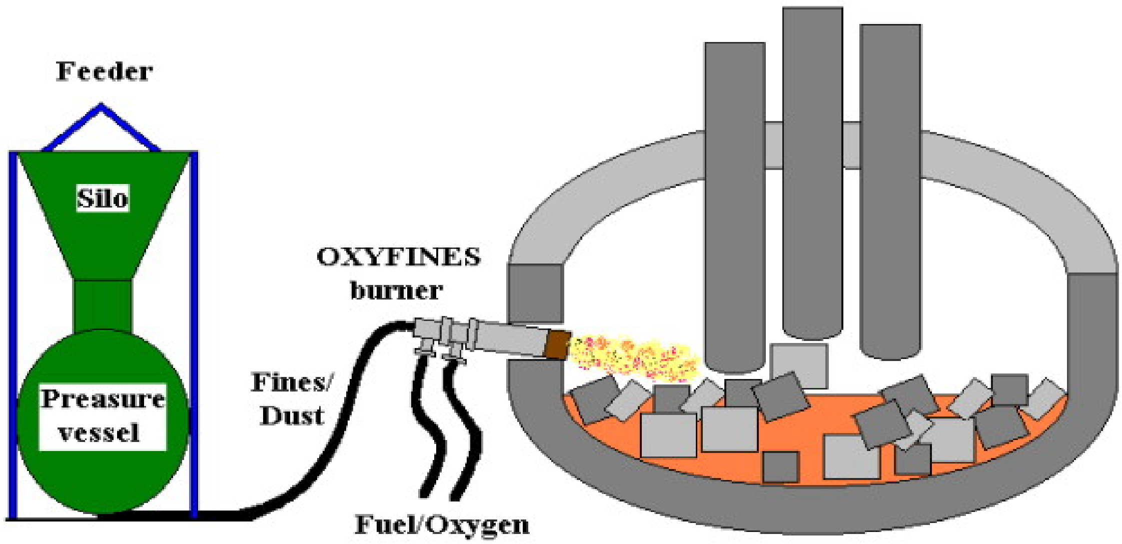

Figure 2. This principle sketch shows how dust or fines can be recycled in to an electric arc furnace using a feeder and oxyfuel technology.

3. TEST RESULTS

The technology has been successfully applied to the recycling of a number of dry and wet materials, including fines, dust and sludge from the production of various ferroalloys, iron powder dust and rejects, dust from carbon and stainless steel production and dust and sludge from blast furnaces and steel-making converters. As recycled materials contain metal, this technology not only provides a solution to the problem of fines, dust and sludge in metal production, as an inert material can be obtained, it also converts these materials into a low-cost raw material that can be used in production and as a substitute for raw material input.

As mentioned above, a special technique can be used to treat wet materials with this technology, with no drying stage prior to pump-feeding of the sludge to the oxyfuel burner. Sludge containing up to 65% water has been "melted" in pilot tests. A key feature is the "atomization" of the sludge to split it into very small droplets.

Figure 3. The photograph on the left shows atomization illustrated by water. On the right is the atomization of sludge, in this case blast furnace sludge containing 48% water.

The technology has been applied to the following materials:

Feed material	Main components (≈ %)	Size distr. (mm)	Test scale
Ferrosilicon dust	Fe 23, Si 75	0.01-0.25; 0.01-3	Pilot
Ferrochromium dust	Cr 50, Fe 35, C 7, Si 4	0.01-1; 0.01-3	Pilot
Molybdenum oxide	MoO_3 90	0.01-1	Pilot
Silicon manganese sludge	MnO 40, SiO_2 30, MgO 10, C 5 (water 60-65)	0.01-0.25	Pilot
Iron powder dust	Fe 87, FeO* 10	0.01-2	Pilot, full
Fly ash	FeO* 20, C 30, V_2O_5 10, NiO 3	0.01-1	Pilot
Stainless steel dust	FeO* 45, CaO 15, Cr_2O_3 17, NiO 3	0.01-2	Full
Blast furnace dust	FeO* 30, C 40, SiO_2 10	0.01-1	Full
Steel converter dust	FeO* 75, CaO 10, SiO_2 1, ZnO 7	0.01-1	Full
Blast furnace sludge	FeO* 45, C 35, SiO_2 5 (water 25-40)	0.01-1	Pilot
Steel converter sludge	FeO* 75, CaO 4, ZnO 6, PbO 0.5 (water 50-60)	0.01-1	Pilot

FeO* = $1.2865(Fe_{tot}-Fe_{met})$

Some of these tests are discussed further below.

3.1 Ferrosilicon dust

The recycling of ferrosilicon fines and dust has been tested in a pilot trial at a feeding rate of about 300 kg/h. The majority of the input material was less than 2mm in size. The results show that fine dust can be accumulated into granulates and fed back into the production process. The yield of granulates or melt to ferrosilicon fines was 95% or higher. The degree of oxidation was shown to be surprisingly low, as the product contained only about 3% oxygen.

Figure 4. Photograph taken during the first pilot-scale trials with processing of ferrosilicon fines and dust. Here, a blend of liquid product and agglomerates is coming out of the taphole.

3.2 Ferrochromium dust

This dust is generated by the crushing operation. It originates either from the finest fraction from the jaw crushers or dust collected in the dust removal system. Pilot tests were carried out at a dust-feeding rate of 500 kg/h. The oxide content of the product was very low; the FeCr yield (product vs. feed dust) exceeded 95%. The operating practice used and the carbon content of the dust may have played a role in achieving these low oxide levels. During the pilot trials, tests were carried out on molybdenum oxide fines feeding both separately and in combination with the ferrochromium recycling (15/85).

Figure 5. The processing of dust with oxyfuel technology, “before and after” photographs. Here, ferrochromium dust at -0.1 mm (left) is recycled and turned into virtually all-metallic agglomerates of 3-8 mm.

3.3 Silicon manganese sludge

Sludge from the production of SiMn has been treated with good results. The sludge was fed to the system using a variable pump at a rate of 300 kg/h. The water content was 60-65%. Inside the reactor, the water was evaporated and the dry substance was melted. The liquid product obtained was tapped continuously and contained 45% MnO, 35% SiO_2 and reduced levels of zinc and alkalines. It should be possible to beneficially recycle this product back into the original SiMn production process.

Figure 6. Pilot-scale trials with silicon manganese sludge containing >60% water. The sludge is pumped into the system and a liquid product is continuously tapped from the reactor.

3.4 Iron powder dust

After pilot testing using mainly iron powder rejects, full-scale injection and melting was successfully carried out in a 50t EAF at Höganäs AB in Halmstad, Sweden. The dust-feeding rate was up to 3.5 tph. The results show that the recycled dust is well suited for use as a substitute for raw materials such as scrap and alloys and that there was no burning of the iron dust above the bath surface. During the trial, large quantities of very fine filter dust from iron powder production, containing almost pure iron, were recycled into the EAF. The outcome of a 2-day continuous trial was a yield of over 95% of injected dust to molten metal in the bath. Some of the 5% lost was found in the slag, which slightly increased the FeO* content.

3.5 Fly ash

This is a very light and voluminous material and is, for example, produced by oil-fired power stations. The presence of valuable metals such as vanadium and nickel in the dust make it of interest. Fly ash is produced by all oil-fired power stations. However, those using oils from countries such as Venezuela have higher concentrations of elements such as vanadium. In the pilot trial, the fly ash was fed at a rate of 150 kg/h. A product containing 15% V_2O_5 and 5% NiO was achieved even before the process had been optimized.

3.5.1 Blast furnace and steel-making converter dust

Both blast furnace and steel-making converter dust has been successfully treated to recover iron oxide from these materials. The dust is converted into solid lumps, which can be used as a raw material for the blast furnace. Separate full-scale tests at 1-1.5 tph have been carried out for blast furnace and steel-making converter dust. Mixtures of the two dusts have also been tested. The blast furnace dust contains sufficient carbon for the energy to melt both the blast furnace dust itself and the steel-making converter dust at mixing ratios of about 1:2.

3.6 Blast furnace sludge

Sludge treatment requires the use of a special type of oxyfuel burner. It has been successfully applied to blast furnace sludge. The sludge is fed directly to the burner by a variable pump, which operated at 250 kg/h during the trials. During the first stage, sludge is atomized and the water content, which is normally 25-50%, is evaporated in the oxyfuel flame. A few seconds after the sludge is injected, a melt of iron oxide and other components is received from the furnace at 1,300-1,500°C. The melt can be formed into lumps suitable for recycling in the blast furnace. The carbon content of the sludge is sufficient to both heat and melt the sludge. The treatment reduced the zinc input content from 0.9% to 0.03%. During the trials, a product containing 74% FeO*, 7% CaO, 9% SiO_2, 4% Al_2O_3 and 4% MgO was produced. The product therefore has an iron content in excess of 57%, which is equivalent or higher than that found in an average sinter (blast furnace raw material feed).

3.7 Steel-making converter sludge

By blending converter dust with blast furnace dust and water, an artificial sludge with 60% water content was obtained and pumped into the system at a rate of 200 kg/h. The ZnO content in the dry steel-making converter dust was roughly 7%. The ZnO content in the liquid product obtained was 0.7-0.8%. The product also contained approximately 70% FeO* and low concentrations of PbO, Na_2O and K_2O.

3.8 Volatile elements

With 100% oxyfuel combustion, exhaust gas volumes are low and normally less than 1,000 Nm^3 per tonne of dust, assuming complete combustion. Volatile elements in the dust, such as zinc, lead, cadmium, mercury and alkalines, will however be lost with the exhaust gases. As many of the elements that would have a negative effect on the potential use of the product are lost in this way, the product is suitable for use as a raw material. However, the volatile elements can have a negative effect on the exhaust gas treatment system (where they end up as a secondary dust).

Zinc is an important element in this context, particularly in the steel industry. Zinc-coated steel strips are recirculated as scrap to steel-making shops. During the steel-making process, virtually all of this zinc evaporates and adheres to the dust, hence the classification of this dust as hazardous material. It cannot therefore be injected into a blast furnace. Zinc concentrations of around 25% are too low for the dust to be acceptable as a raw material. Zinc producers are only willing to pay for dust with a zinc content of at least 35% Zn. Here, recycling provides a possible means of enriching the zinc content in the dust. Each cycle increases the zinc content in the dust, until bleeding is necessary. This removes the high zinc-content dust from the system to be sent for treatment. On average, the optimum point for bleed-off occurs when the zinc content in the dust has reached about 50%. Preventing the zinc from adhering to the metal bath is dependent on the creation of reducing conditions in the oxyfuel flame and the vessel. The CO concentration plays an important role here. It is therefore possible to remove the zinc from steel-making converter dust and create a product that can be recycled as a raw material.

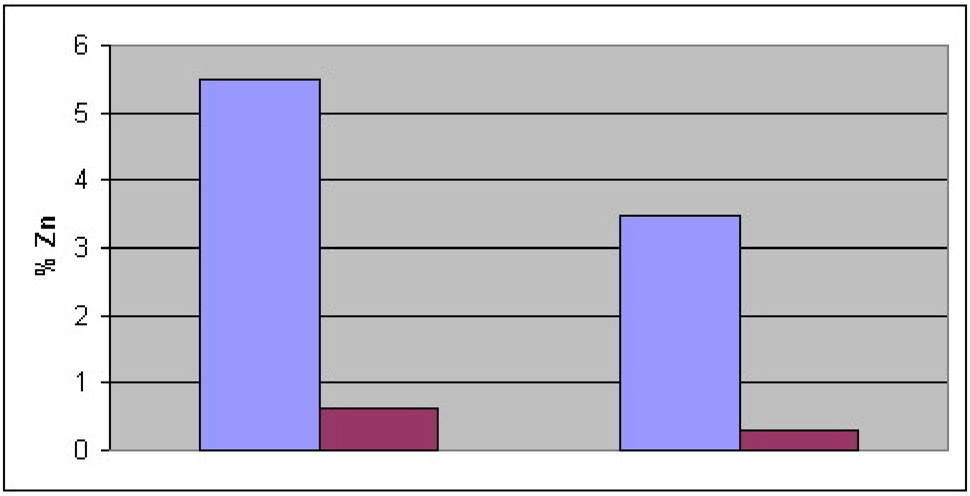

Figure 7. Treatment of steel-making converter dust from two European integrated steel mills with a zinc content of 5.5% and 3.5% respectively. Fed with one-third blast furnace dust. Product zinc content at 0.6% and 0.3% respectively. The zinc removal efficiency obtained was therefore 89-91%.All data is based on average figures for 5-10 samples.

3.9 The situation in the ferroalloy industry

Unlike some other sectors of the metallurgical industry, fines, dust and sludge produced in the ferroalloy industry could frequently be found in a mainly metallic form; this chiefly stems from their origin in crushing and smelting operations under reducing conditions. The “inherent value” could also be higher than many other by-products of this type in the steel and metals industry. This is particularly true for materials that are generated close to the point where the end product is obtained; the alternative value is not very different from the value of the product itself. On the other hand, ferroalloy sites have a production output that is normally much lower than is prevalent in the steel industry, often in the interval 20,000-300,000 t/a. Assuming a combined volume of fines, dust and sludge of one-tenth of the ferroalloy production volume, at the lower end of the interval, situations will of course sometimes occur where investment in a recycling system is barely justified.

An interesting fact is that material from ferroalloy production frequently contains carbon. On recycling, this carbon can be utilized as an energy source for its own melting, thus reducing the need for an external energy supply. Naturally, this carbon also supports a low oxidation of the metal on treatment.

The pilot-scale tests referred to earlier with fines and dust from ferrosilicon and ferromanganese production demonstrated the considerable gains that could be made from using OXYFINES™ as the oxidation of metallic input materials was found to be low. This is basically linked to the concept itself. When fine particles enter the rear end of the flame, their surfaces start to melt. However, due to the strong turbulence inside the flame, they immediately start to collide with each other. When they collide, the particles stick to each other and form larger and larger aggregates until they leave the flame (often by gravity before they reach the “end of the flame”).

Only a small proportion of the original particle is therefore exposed to the risk of oxidation. This risk can also be further reduced by:

- Sub-stoichiometric burner operation;
- Inert or reducing carrying gas;
- Co-injection of a reducing agent; and
- Control of the vessel atmosphere.

In ferroalloy production, the potential for direct recycling into existing processes is less than that for electric steel-making for example. However, if applicable, this concept might bring some interesting features, as unmodified burners could serve three functions:

- As an oxyfuel burner to increase the throughput rate, to decrease the consumption of electricity and electrodes and as an additional energy source in furnace cold spots (more even heat distribution in the furnace).
- For recycling fines, dust or sludge.
- For feeding and melting additives.

Generally speaking, however, the main option when applying this technology to ferroalloy production may be to use a separate vessel. The fines, dust or sludge are then transported via a pneumatic feeding system or pumped from intermediate storage in bins to the oxyfuel burners mounted in the vessel. The product created is then tapped either continuously or intermittently. The liquid product is granulated directly or put to solidify in, for example, a sand bed. The latter option would either involve direct casting into pieces of a suitable size or, more simply, a crushing operation following solidification.

As was the case in some of the tests referred to above, an oxyfuel-based technology would also open up the possibility of converting fines and dust from the final crushing operation into a product. In this case, the total ferroalloy output would increase without affecting the existing production processes upstream.

Another point worth mentioning here, which is linked to the use of ferroalloys in the steel industry, is the possibility of enabling an electric steel–maker, for example, to use this technology for feeding ferroalloys in the form of fines into the steel furnace whilst still obtaining a high yield.

4. INSTALLATION AT FUNDIA WIRE IN FINLAND

An installation applying the OXYFINES™ concept was commissioned in mid-2002 at the small, integrated Fundia Wire steel mill in Finland. The steel output from this mill is just over 500,000 t/a. The installation is designed for recycling blast furnace and steel-making converter dust. The combined capacity is 3 tph, equivalent to about 20,000 t/a. The installation uses a separate flue-gas treatment system. This is mainly due to alkalines in the secondary dust. The results of the operation have been very encouraging. The product obtained, with iron oxide as the main component and reduced levels of elements such as zinc, lead and alkalines, is considered to be an inert material, allowing landfill disposal if necessary. However, it will be used as a raw material in the blast furnace as a substitute for part of the top-charged iron ore feed.

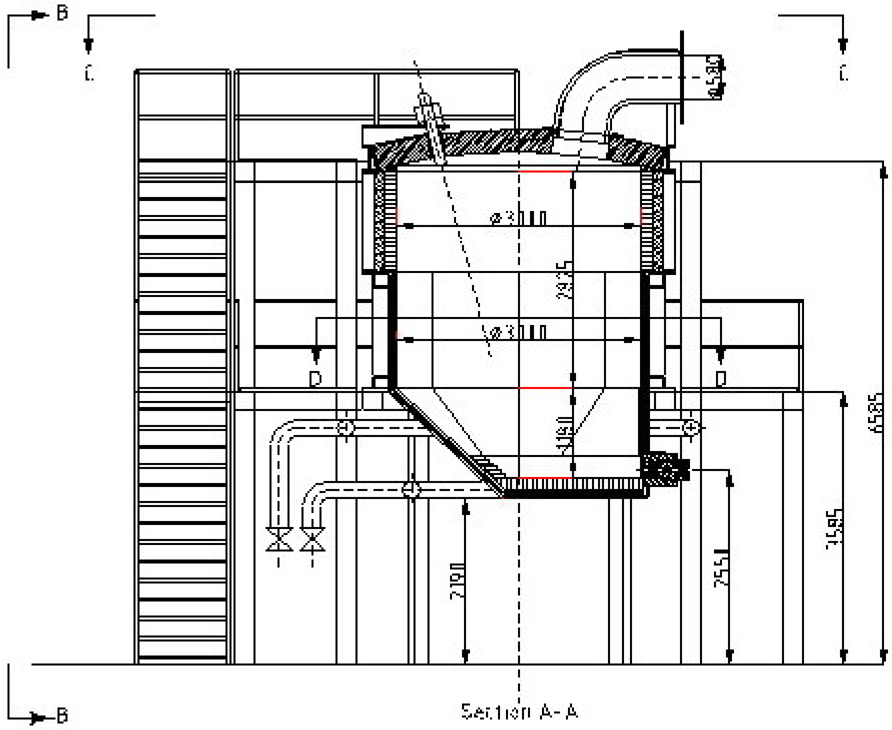

Figure 8. Outline drawing of a facility for the stand-alone treatment of dust and sludge, designed for the combined feeding of 8 tph (60,000 t/a) using four burners, three burners for dust-feeding and one burner for sludge-feeding.

5. VIABILITY AND COMPETING SOLUTIONS

Dust treatment in a separate plant at an outside company is costly; including transportation the cost could be well above 100 EUR/t. For example the use of Waelz kiln technology tends to create costs of that magnitude. Thus in-plant recycling is a preferred way, particularly if the dust contains valuable elements.

To recycle dust and fines into a metallurgical process, injection might be considered. This has been applied at some plants, e.g. some few electric arc furnaces for steel-making. However, this solution has two main drawbacks: the risk of too low yield, and negative impact on the production practice as the energy required for melting the dust is taken from the energy available for melting the scrap – the furnace tap-to-tap time will be prolonged. Another possibility is briquetting, which might also be used for sludge. Briquetting requires substantial investments in a briquetting plant, addition of a suitable binder, and internal transportation and storage logistics. When the briquettes are fed into a metallurgical process, there is a high risk their high temperature properties are not good enough and they easily break up into small pieces that either has a negative impact on the operation (cf. blast furnace) or are carried out by the flue-gas. Additionally, as with injection, feed of briquettes will lead to an increased tap-to-tap time.

When using the herein described technology, those negative effects are avoided. The running cost is mainly dependent on type of material (basically dry or wet) and the cost of oxyfuel energy. If no separate recycling facility needs to be put up, the investment cost is comparatively small, basically only including a feeding system. In this case, the running cost should possibly be found in the range of 30 EUR/t even without including material credits.

6. CONCLUSIONS

There is considerable demand for the increased recycling of fines, dust and sludge in the metallurgical industry. Few solutions are currently available and the solutions that are available are not very competitive. Treatment and disposal costs are high, often 100 EUR/t or more, and there are often no viable alternatives for the disposal of sludge.

OXYFINES™ is an oxyfuel-based technology developed by AGA Linde for in-plant recycling. It allows fines, dust, sludge (with no drying stage) and other by-products to be recycled directly back into existing processes or to a separate on-site unit. The technology has been successfully applied to the recycling of a number of dry and wet materials, including iron powder dust and rejects, fines, dust and sludge from the production of various ferroalloys (ferrosilicon, ferrochrome and silicon manganese), carbon and stainless steel production dust and dust and sludge from blast furnaces and steel-making converters. As the recycled materials contain metals, the technology not only provides a solution to the problems associated with dust- and sludge-generation in metal production, e.g. through the creation of an inert material, it also converts waste materials into a low-cost raw material that can be used in production, substituting raw material input.

The recovery rate has been shown to be very high, 95% or more, and a recycling rate of 3.5 t/h has been shown to be possible. When recycling metallic materials, e.g. in the context of ferroalloys production, oxidation of the material has been shown to be very low, e.g., the product from the feeding of metallic dust and fines from FeSi production contained only about 3% oxygen. It can be used to remove – and enrich in a secondary product – elements such as zinc and lead found in the fines, dust or sludge, thereby generating a product that can be recycled as a raw material, which would otherwise have been impossible, and simultaneously obtain a secondary product with a sales value.

In ferroalloy production, the main alternative would probably be to use a separate vessel for recycling fines, dust and sludge generated in crushing and screening operations and as a by-product from exhaust gas treatment throughout the process chain. There may be considerable potential for recovering these materials in a viable way by applying this technology, particularly where gate fees or "environmental taxes" for dumping are high. However, many of the materials that are generated close to the point where the end product is obtained will themselves have an "inherent value" that could well justify the use of recycling of this kind. The first full-scale installation using OXYFINES™ technology for recycling blast furnace and steel-making converter dust, with a combined capacity of 3 tph, was commissioned in Finland in 2002.