# Sustainable Recycling of Steel Manufacturing Wastewater Treatment Solid Wastes via In-Process Dynamic Separation

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In steel production, wastewater is constantly generated in various unit processes. The wastewater must be treated before the water can be reused internally or released to the environment. Existing wastewater treatment technologies are clean water–oriented, but solid wastes collected in the wastewater treatment processes are generally notorious nuisances that are dirty, full of contaminants and sometimes hazardous. Sustainable recycling of the wastewater treatment solid wastes requires effective separation of beneficial components from undesirable ones. In-process dynamic separation has recently emerged as a promising technology for producing clean, dry and recyclable solid co-products in economic ways while wastewater is being cleaned. ArcelorMittal Global R&D has studied this technology for significantly enhancing recyclability of steel manufacturing wastewater treatment solid wastes.

In steel production, wastewater is constantly generated in various unit processes. The wastewater is generally dirty and has high concentrations of suspended solids and other pollutants. These pollutants must be removed from the wastewater before the water can be internally reused or can be released to the environment. Thanks to the Clean Water Act,[1,2] like any other industry, steel manufacturing processes are accompanied with well-equipped wastewater treatment processes. As a result, the steel industry is not only able to recycle most of the water, but is also able to blow down only a small fraction of the clean water to public waterways.[3,4] However, existing wastewater treatment technologies are clean water–oriented. In current wastewater treatment processes, pollutants are simply transferred from the water into solid wastes through sedimentation, coagulation, flocculation, precipitation and filtration. As a result, while the water becomes clean, the wastewater treatment solid wastes become dirty, full of contaminants and sometimes hazardous.[3–7] How to recycle the wastewater treatment solid wastes remains a challenge in the steel manufacturing processes.

The steel manufacturing wastewater treatment solid wastes are generally rich in iron and/or carbon and/or fluxes (CaO and MgO). Iron, carbon and fluxes are beneficial components needed by the ironmaking and steelmaking processes. However, undesirable components like zinc, alkalis, oil, sulfur, chlorine, etc., in the solid wastes may damage ironmaking and steelmaking equipment, destabilize ironmaking and steelmaking operations, degrade iron and steel qualities, and cause environmental violations if they are returned to the ironmaking and steelmaking processes in excessive amounts.[3,4,8] Therefore, how to produce clean solid wastes with minimal undesirable components is a great challenge for sustainable recycling of the steel manufacturing wastewater treatment solid wastes.

The undesirable components in the steel manufacturing wastewater treatment solid wastes come from several sources. Raw materials like iron ore, coke, coal, fluxes and steel scrap can bring zinc, alkalis, sulfur and chlorine into the steel manufacturing processes. Oil and grease are widely applied in steel production as lubricants and coolants for vehicles, machines, bearings, hydraulic

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lifters and rolling rolls, and they can find ways into wastewater. Alkalis, sulfur and chlorine can also come from chemical compounds added in the wastewater treatment processes.

Separation plays a key role in producing recyclable steel manufacturing wastewater treatment solid wastes. There are three general separation strategies.[9–15] One is to separate the undesirable components from raw materials and to prevent the undesirable components from entering the steel manufacturing processes. This strategy will significantly increase raw material cost for extra strict raw material specifications. In addition, this strategy is unable to prevent oil/grease and alkali-based, sulfur-based and chlorine-based wastewater treatment chemicals from entering the wastewater. The second strategy is to treat the dirty end-of-pipe solid wastes that are already formed and stabilized. Separation of multiple undesirable components from the end-of-pipe wastewater treatment sludge is generally not economical. The third strategy is in-process separation to selectively collect solid particles in the wastewater treatment processes so that undesirable components can be separated from the beneficial components. In-process separation has advantages of lower separation cost, lower energy consumption and less environmental concerns than the other two separation strategies.[9,16,17]

One in-process separation scenario is to selectively collect suspended solid particles from the turbulent wastewater in the early stage of the wastewater treatment processes using dynamic separators.[7,18,19] This technology is under the umbrella of in-process dynamic separation. In the rest of this paper, the technology framework of in-process dynamic separation is described, and then some case studies applying the technology in producing clean, dry and recyclable wastewater treatment solid wastes at ArcelorMittal (now Cleveland-Cliffs) follow.

## Technology Framework

In the steel manufacturing processes, each standalone plant makes only one product, such as sinter from a sinter plant, hot metal from a blast furnace and liquid steel from a basic oxygen furnace. Except the products, any other outputs, including offgas, wastewater and solid residues, are wastes that are not wanted in steel production; the less, the better. The wastes are often called byproducts or co-products.

However, in this article, the meaning of wastes, co-products and byproducts will be differentiated. If waste from a manufacturing process can be directly used as a raw material to replace virgin natural resources or other high-cost raw materials for the process itself or any other processes without requiring further treatment, the waste is regarded as a co-product of the process. Therefore, a co-product is a parallel product to the primary product, and it can be utilized immediately with no negative effects on equipment, operation, product and environment in a process where the co-product is to be applied.

Different from a co-product, a byproduct is waste that cannot be directly used, and which has to be processed first before it can be used to replace virgin natural resources and any other high-cost raw materials in a process. Processing cost, value-in-use and disposal cost will together determine whether a byproduct is recyclable.

As a result, waste is a general term for any output other than the product; a co-product is waste that can be directly utilized and a byproduct is waste that must be treated before it can be used. A co-product is certainly recyclable, but not all byproducts are recyclable. It is desirable to convert byproducts into co-products in the steel manufacturing processes. That is what in-process separation can do.

As mentioned earlier, in-process separation is a strategy to separate co-products from undesirable components in the process while the wastes are being collected. In the steel manufacturing wastewater treatment processes, while the wastewater is flowing from the sources to the wastewater treatment devices, undesirable components are separated from solid co-products. The closer to the wastewater sources, the more separable the undesirable components.

It is well known that undesirable components like zinc and alkalis are normally concentrated in small particle size ranges.[20–23] If a separator is operated in such a way that only large particles above a cutoff size are captured, the separated solids will contain negligible undesirable components and recyclable. Second, some undesirable suspended solids are products of precipitation reactions. If the beneficial suspended solids can be separated before the precipitation reactions take place, those precipitated undesirable components will not contaminate the co-products. Third, as mentioned earlier, some wastewater treatment chemicals contain undesirable components. If the solid co-products are separated from the wastewater before these chemicals are added into the wastewater, the separated solids will be clean and recyclable. Last, since iron-bearing particles are rather heavy, a large amount of water is used to transport these particles into wastewater treatment devices to prevent clogging in the wastewater channels. Therefore, between the wastewater sources and the first wastewater treatment devices, the wastewater is flowing at a rather high speed, about 10 m/second, and is very turbulent. The turbulent water can accelerate the dissolution of the soluble undesirable solid components, can reduce attachment opportunities of undesirable particles to the beneficial solid particles, and can break liquid contaminants, like oil, into small particles. Therefore, the high-speed turbulent wastewater flow is an additional favorable condition for solid co-products to be separated from the undesirable components.

In the existing wastewater treatment processes, settling tanks, thickeners, clarifiers and filters are commonly used. These devices are regarded as static separators since they are characterized by slow motion of the wastewater, minimal disruption to the wastewater and long retention time of the suspended solid particles in the devices. In the static wastewater treatment devices, all aforementioned favorable conditions for co-products to be separated from undesirable components disappear, and hence the existing wastewater treatment processes are unable to fulfill in-process separation to produce clean, dry and recyclable wastewater treatment solid co-products.

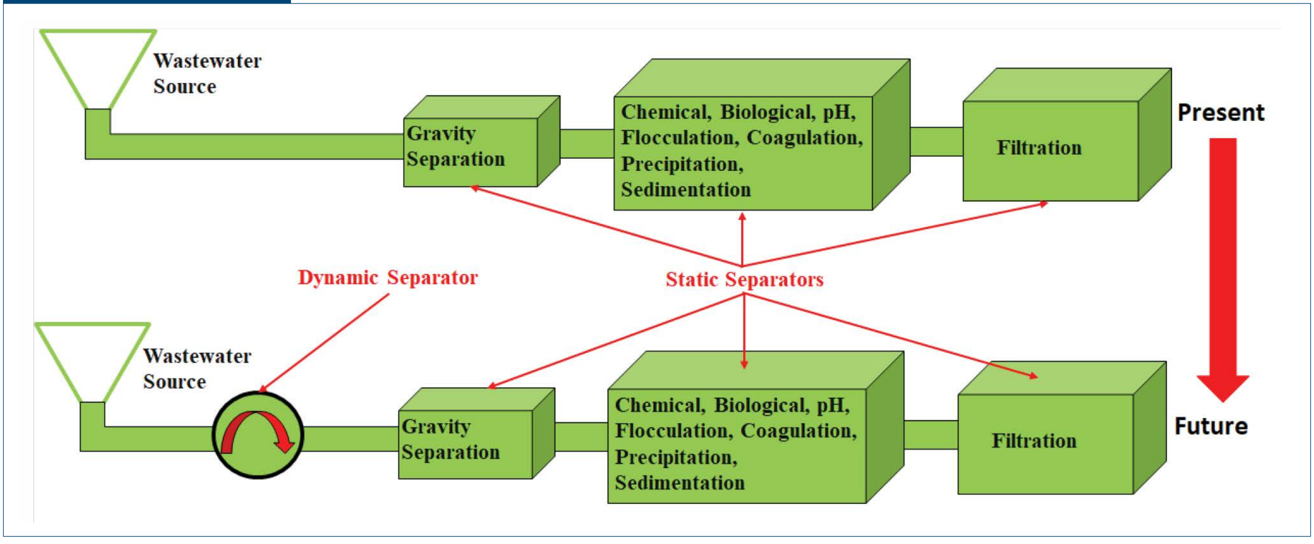
Different from the static separation, dynamic separation will make use of the strong turbulence and the fast motion of the wastewater to separate clean solid particles from the wastewater and from the undesirable components. The dynamic separation is characterized by fast motion and strong turbulence of the wastewater in the separators. In a dynamic separator, the small particles with high concentration of undesirable components, the soluble undesirable components, and the liquid undesirable components will bypass the separator and will not be collected. Therefore, a dynamic separator is capable of producing clean, dry and recyclable wastewater treatment solid wastes in addition to making clean water.

As for dynamic separators, any separating devices can work as long as they can separate suspended solid particles from the wastewater and from the undesirable components in the wastewater by making use of strong turbulence and fast motion of the wastewater. Such separators may include hydrocyclones, magnetic liquid traps, deflective separators and various vortex separators. These dynamic separators are already widely available on the market. However, it has not been well understood how to produce clean, dry and recyclable wastewater treatment solid wastes using these dynamic separators.

The strategy of in-process separation has clarified where and why solid co-products can be produced while solid wastes are being collected. The strategy of dynamic separation has determined how the beneficial components can be separated from the undesirable component when the undesirable components are in a separable status. The marriage of in-process separation with dynamic separation results in the birth of a new technology: in-process dynamic separation. The technology framework of in-process dynamic separation in the wastewater treatment processes is shown schematically in Fig. 1. In the existing steel manufacturing wastewater treatment processes, dynamic separators can be inserted between the wastewater sources and the first wastewater treatment devices, normally gravity separation devices. The closer to the sources, the better the in-process dynamic separation. In addition, in-process dynamic separation can also include conditioning the wastewater so that the undesirable components can become more separable.

It should be noted that the concept of in-process dynamic separation is generic and it can be applied in any other industries and any other processes, such as producing co-products in offgas cleaning, slag treatment, etc. As a result, establishment of the in-process dynamic separation strategy has opened numerous opportunities toward 100% circular manufacturing

Figure 1




*Schematic implication of technology framework of in-process dynamic separation.*

economy. However, the strategy of in-process dynamic separation is strongly dependent on high-efficiency dynamic separators. It is crucial to develop and select a dynamic separator that can fit in a manufacturing process.

## Removal of Grit From BOF Spark Box Wastewater Using a Vortex Concentrator[7]

One of ArcelorMittal USA's (now Cleveland-Cliffs Inc.) basic oxygen furnace (BOF) steelmaking plants is equipped with spark boxes in its BOF offgas cleaning system. A series of water spray nozzles are installed in the spark boxes. While the BOF vessels are running, the spray nozzles inject atomized water to cool the hot offgas. Part of the water evaporates and becomes steam that goes with the BOF offgas. The rest of the water washes the offgas and takes dust particles to the wastewater treatment system.

A block diagram of the spark box wastewater treatment system is shown in Fig. 2. Makeup water is pumped into the second mixing tank so that wastewater with enough flowrate can be pumped and delivered into the settling trailer box without causing clogging issues in the pipelines. The spark box wastewater is top-charged into the trailer box. Grit particles settle onto the bottom of the trailer box, and overflow wastewater takes unsettled solids and flows to the clarifier for further treatment along with other wastewater streams.

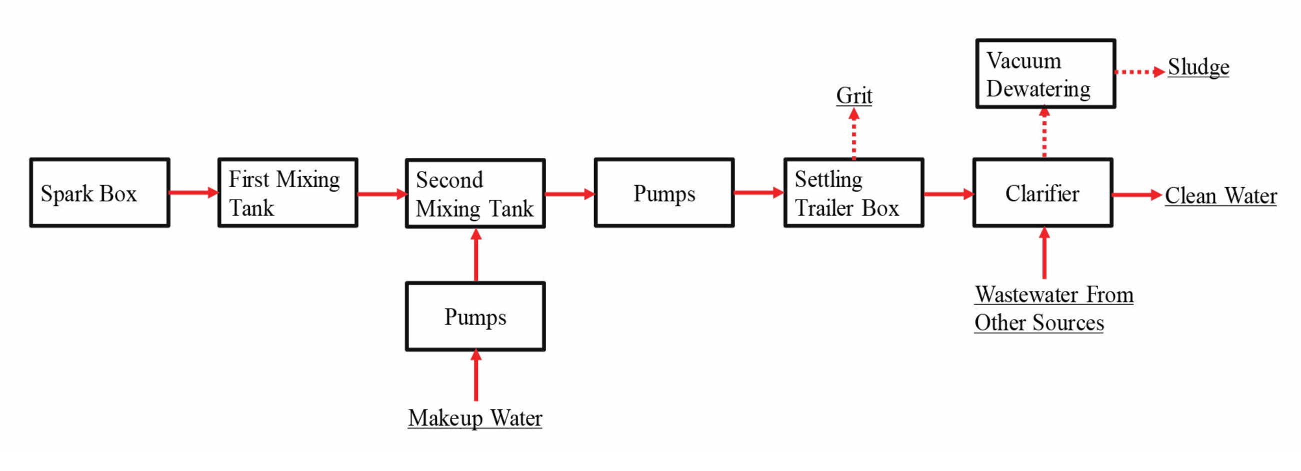
In the existing practice, the trailer box is regularly moved to a drainage site where the slurry in the trailer box is dumped on the ground, and the solids are then pushed and recovered.

This practice has many disadvantages. First, since the trailer box is not an efficient separator, the slurry in the trailer box has a very high water/solid ratio, more than 9 to 1. When the trailer box is being moved to the drainage site, it is wasteful and unsafe to carry a huge amount of water. Second, due to the poor separation efficiency, many solids in the spark box slurry will not be separated and will leave the trailer box with overflow water to the downstream wastewater treatment system. This will result in high wastewater treatment cost and high generation rate of non-recyclable wastewater treatment sludge. Third, when the solids are recovered in the drainage site, the solids are often contaminated with foreign objects on the ground and recyclability of the solids decreases. Fourth, again due to the poor separation efficiency, the trailer box solids contain a high level of zinc. Therefore, it is highly desirable to produce dry solids in-situ with high separation efficiency.

A vortex concentrator coupled with a dewatering classifier was selected for the study of separation of grit from the spark box slurry. A flow diagram of integrating the concentrator with the classifier is shown in Fig. 3. The vortex concentrator was connected to the pipeline right before the existing trailer boxes. The spark box wastewater tangentially entered the concentrator. Suspended solids in the wastewater settled and fell onto the bottom of the concentrator and cleaned water floated up and exited as overflow. Underflow water carried the settled solids and tangentially flew into the classifier chamber. The classifier dewatered and discharged the solids.

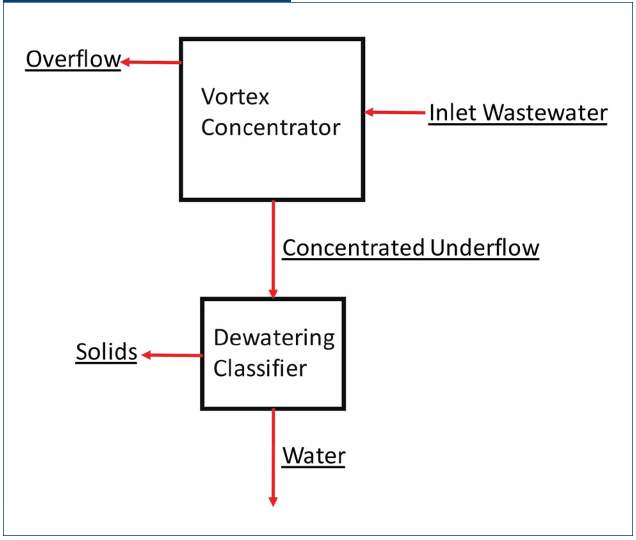
The study was a full-scale industrial trial. The vortex concentrator received all spark box wastewater that had been directed into the trailer box. The influent

Figure 2




*Block diagram of spark box wastewater treatment at an ArcelorMittal USA (now Cleveland-Cliffs Inc.) basic oxygen furnace (BOF) steelmaking plant. Solid arrowed lines represent water flows and dash arrowed lines denote flows of solids.*

Figure 3




*Integration of the test vortex concentrator with the test classifier.*

wastewater and the effluent wastewater were sampled. Concentrations of the total suspended solids in the influent and the effluent samples were analyzed. The separated solids and the solids recovered from the influent samples and the effluent samples were analyzed for size distributions and chemical compositions. The separation efficiency was evaluated using the following formula:

$$\eta = \frac{(S_{in} - S_e)}{S_{in}} \times 100\% \quad \text{(Eq. 1)}$$

where

$\eta$ = separation efficiency in wt.% and
$S_{in}$ and $S_e$ = suspended solid concentrations in the influent and effluent water samples in g/cc (gram of solids per cubic centimeter of water sample).

The trial lasted for 4 days, and spark box wastewater generated in 22 heats was treated with the vortex concentrator. On average, 587 kg of grit was collected for every heat of steel made. Average moisture level in the grit was about 17% by weight. The separation efficiency was between 95% and 98%. Average zinc concentrations in the samples of influent suspended solids, effluent suspended solids and the separated grit were 0.17%, 1.63% and 0.08%, respectively. As a result, the dynamic separation of the suspended solids from the BOF spark box wastewater with the vortex concentrator resulted in rather dry recovered solids, high separation efficiency and significant reduction of zinc in the reclaimed solids. The separated solids discharged from the dewatering classifier to a container are shown in Fig. 4.

## Separation of Mill Scale From Hot Rolling Mill Wastewater Using a Strong Magnet [18,19,24]

A hot strip mill had two scale pits receiving wastewater from the hot rolling process. The #1 pit received wastewater from the reheat furnace discharge ends, the first descaling table and a few roughing mill stands. The #2 pit received wastewater from last a few roughing mill stands, the second descaling table and the finishing mill stands. The wastewater from both pits was combined and pumped to multimedia filtration tanks.

Mill scale that settled in the scale pits was top reclaimed by a clamshell bucket at the #1 pit and by chain scrapers at the #2 pit. The #2 pit had constantly generated oily mill scale that could not be recycled at the sinter plant since the high concentration of oil in the mill scale could cause high-volatile organic compounds (VOC) emissions at the sinter plant and could cause fire in the baghouses of the sinter plant offgas cleaning system. It had been a great challenge to reduce the oil concentration in the mill scale.

A picture of the #2 pit is shown in Fig. 5. The pit consisted of five cells. The first cell had been out of service. The second and third cells received wastewater from finishing flumes #1 and #2, respectively. The roughing flume wastewater split right before the scale pit and flew into cells #4 and #5, respectively. The wastewater in the flumes was moving at a high speed in order to prevent any sedimentation and clogging of mill scale particles in the flumes. There was

Figure 4

*Separated grit discharged from the integrated dynamic separator.*

one chain scraper for each active cell. While the plant was running, the chain scrapers continuously removed mill scale from the scale pit. Trailer boxes were positioned at the discharge ends of the chain scrapers and the chain scrapers discharged mill scale into the trailer boxes.

A 1.1T permanent magnet was chosen for this study. The magnet was mounted on a carbon steel pole and positioned in the flumes. The magnet attracted mill scale particles. The mill scale was recovered and analyzed. At the same time, samples from the trailer boxes were taken and analyzed. In Fig. 6, it is shown that the mill scale was recovered by the 1.1T magnet mounted on a carbon steel pole.

The trial lasted for 3 days. Average oil concentrations in the samples recovered by the magnet and by the chain scrapers are shown in Fig. 7. It is clear that the mill scale samples recovered by in-process dynamic separation using the strong magnet contained significantly lower oil concentrations than the mill scale samples from the existing static separation with sedimentation in the pit and reclamation using the chain scrapers.

## Conclusions

In the existing wastewater treatment processes of steel manufacturing, static separation is the mainstream of separation of suspended solids from the wastewater. Existing wastewater treatment technologies are clean water–oriented, but solid wastes are dirty and are contaminated with various undesirable components. In-process dynamic separation, making use of strong turbulence and fast motion of the wastewater, positioning dynamic separators close to sources of the wastewater and conditioning the wastewater flows before the dynamic

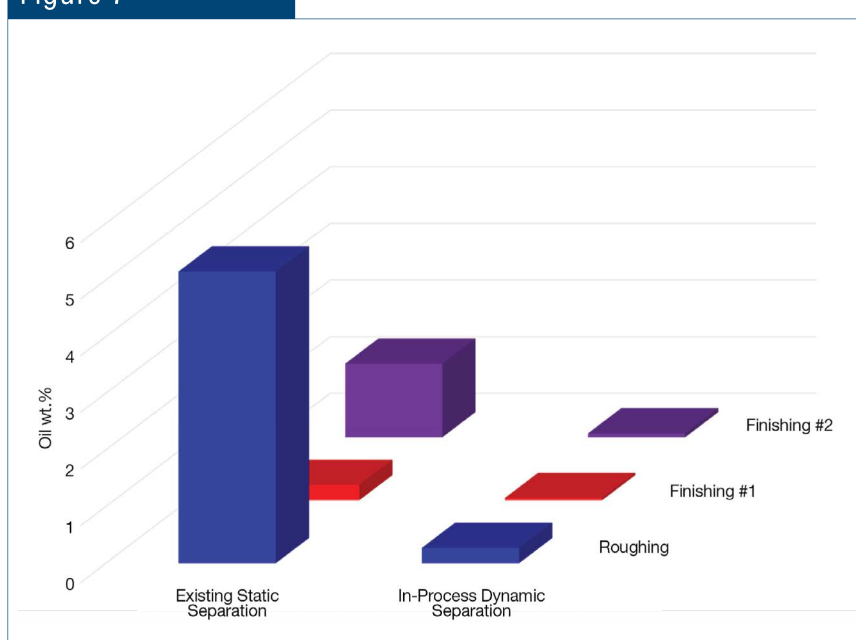
Figure 5


*The #2 scale pit of a hot strip mill.*

Figure 6


*Mill scale recovered by the 1.1T magnet separator mounted on a carbon steel pole.*

Figure 7




*Average oil concentrations in mill scale samples.*

separators, can produce clean, dry and recyclable co-products in the wastewater treatment processes. In the trials of separating grit from BOF spark box wastewater with a vortex concentrator and separating mill scale from hot strip mill wastewater with a strong magnet, clean and dry co-products were produced with significantly low levels of zinc and oil, respectively. It thus has been validated that in-process dynamic separation can produce clean, dry and recyclable wastewater treatment solid wastes in the wastewater treatment processes of steel manufacturing.

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