

## Conference Paper

# Manganese Ore Thermal Treatment Prior to Smelting

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## Abstract

Partial metallisation of manganese before smelting is challenging but other forms of thermal treatment offer a viable opportunity to reduce the electrical power consumption and increase the productivity of manganese smelters. Manganese ore pre-treatment include the following: pre-heating in a shaft furnace or rotary kiln with furnace off-gas; calcinations in a shaft furnace or rotary kiln; nodulizing; sintering ore fines or pellets in a shaft furnace, travelling grate (linear or carousel configurations), grate-kiln or steel belt sinter plant. These technologies are well-known, but with the exception of travelling grate sintering not commonly used. All these pre-treatment technologies reduce operating cost by a varying degree. At the same time, single unit capacities and capital costs for the options are significantly different. The proposed article addresses the application of the different technologies to different ore types (oxide ore, carbonate ore and pyrolusite ore), technical advantages of each manganese ore pre-treatment technology and the impact of each technology on operating- and capital cost. Operating availability, number of operating units and risks associated with each technology are also discussed in the article.

**Keywords:** manganese ore, sintering, pelletizing, calcination

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## 1. Introduction

Manganese ores (containing more than about 30% manganese) can be broadly categorised as oxides ( $MnO_2$ ,  $Mn_2O_3$ ,  $Mn_3O_4$ ,  $Mn_7SiO_2$  and  $MnFe_2O_4$ ), carbonates ( $MnCO_3$  and  $(Mg,Mn)CO_3$  and silicates (silicate ores are of limited economic importance and are not further considered).

All commercial metallurgical manganese ores may in principle be upgraded by driving off volatiles (moisture and  $CO_2$ ), reducing the amount of excess oxygen (pre-reduction), and improving the size distribution (agglomeration or sintering) to improve

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the performance of the ore during smelting in a submerged arc furnace. The processes that may be considered for upgrading are the following:

1. Calcination in a vertical or rotary kiln to decompose carbonate minerals under oxidizing or mildly reducing conditions. Calcination will mitigate against the release of CO<sub>2</sub> in the SAF but does not serve to agglomeration of fines.
2. Nodulizing of ore fines in a rotary kiln under slightly reducing conditions to decompose carbonate minerals, agglomerate fines and reduce manganese to the divalent oxidation state.
3. Pelletizing of ultrafine ore to provide well-sized feed followed by induration to decompose carbonate minerals.
4. Steel Belt Sintering to eliminate ore fines and remove CO<sub>2</sub> from the ore. If sintering is carried out in a reducing environment similar to traditional sinter plant operation it would also be possible to pre-reduce some manganese to the divalent oxidation state. The extent of pre-reduction should be confirmed by test work and during the operation of the sinter plant.
5. Travelling Grate Sintering to agglomerate ore fines and remove CO<sub>2</sub> from the ore.

## 2. Calcination

Calcination in either a vertical shaft kiln or horizontal rotary kiln offers an elegant solution to decompose carbonate minerals in suitably sized Mn ore. Calcination is applied to limestone, magnesite and dolomite across the world, but it is not commercially used for manganese ores despite the fact that it would metallurgically be possible to do so.

The PFR (parallel flow regenerative) double or triple *shafts kiln* technology was developed by Maerz at the end of the 1960's for production the high quality quicklime at a low fuel rate. In 1990's Cimprogetti modified Maerz' circular double shaft PDF kiln into the Twin-D shaft kiln (Figure 1). These technologies in principal could be adopted for Mn ore calcinations.

Two shafts contain the ore to be calcined. The shafts are alternately charged, and the calcined product is discharged continuously at the bottom of the shafts through the burning cycle. Fuel is supplied to only one of the two shafts at a time, which for that period serves as 'burning' shaft. In the 'non-burning' shaft ore is pre-heated by the combustion gases in preparation for the next 'burning' cycle in that particular shaft.

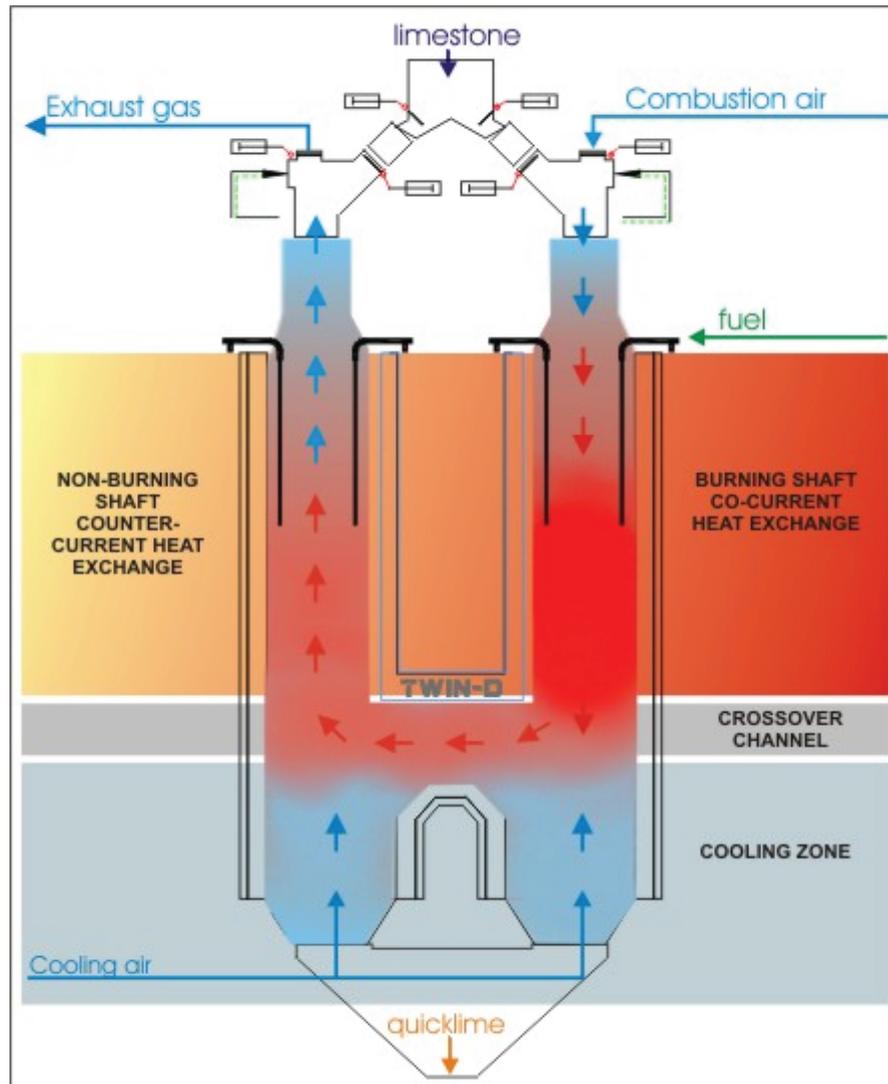


Figure 1: Twin-D shaft kiln.

Each shaft cycles through burning and non-burning periods at intervals of approximately 12 minutes. Cooling air is continuously introduced at the bottom of both shafts to reduce the temperature of the product prior to discharge into the product hopper. PFR kilns can utilize any type of fuel: gaseous, liquid or pulverized solid.

Advantages of calcination in a vertical shaft kiln are as follows: simple plant design and layout; low opex; the ability to use low-cost fuel, no need for binders or additives; no need for secondary ore crushing; low repair and maintenance cost; high thermal efficiency; low off-gas volume and dust load in the off-gas; low electrical energy consumption; no recirculating product stream.

Disadvantages of calcination in a vertical shaft kiln are: not suited for fine ore – the proportion of undersize Mn ore can be as high as 40% of the ROM ore and a vertical kiln calcining process will not be suitable for this material; risk of clinkering if hot-spots

develop in the reactor; limited shelf life of calcine product – ideally, the calciner should be located at the smelter; not commercially proven for manganese ore.

The refractory lined *rotary kiln* is widely used for the calcination of limestone, dolomite, magnesia, and pre-reduction of iron ore, chromite ore pellets, lateritic nickel ores and other applications.

Rotary kiln has 2 zones for preheating and calcination. Unlike the vertical shaft kiln, the calcine is cooled outside the kiln. The preheat zone utilizes hot gases from the calcination zone. The primary burner air and secondary combustion air are pre-heated by the waste gases and the hot calcine. The fuel consumption for the rotary kiln calciner is about 20% higher than that of the vertical shaft kiln due to less efficient heat transfer from the hot gases to the ore and little heat recovery from the hot calcined product.

The kiln is generally lined with alumina bricks. The refractory lining of the horizontal kiln is subjected to intense abrasion by the charge as well as thermo-mechanical shock. Conditions inside the kiln depend on the type of fuel that is used, which, in turn, affects the lining life. An overall lining life of 15 years can be attained but hot zone repairs may be required every second year. Depending on operating conditions a kiln throughput of more than 1,600 tonnes per day can be attained. At an operating factor of 90% this will result in a throughput of about 530,000 tons per year.

In a calcination kiln, temperatures will be controlled below 1300°C to prevent the formation of a liquid binder phase, which will result in ring-formation, clinkering and a shorter campaign life. The calcine composition and shelf life (as determined by free lime presence) is the same as from a vertical kiln. A range of fuels including pulverised solid fuels such as coal, anthracite and coke as well as liquid and gaseous fuels can be used. The burner system generally uses a single burner located along the central axis of the kiln and the feed moves counter to the flow of hot gases in the kiln.

Trials performed in Ukraine and Georgia by MehanobrChermet, Krivoi Rog, Ukraine showed high levels of carbonate Mn ore calcination (98–99%) at temperatures of 900–1100°C. The calcine contained hausmannite (5–8 glaucochroite (30–32%) and the Mn content was upgraded by a factor of 1.4.

The main advantage of calcination in a horizontal rotary kiln over a vertical shaft kiln is an ability to process a wider range of ore sizes with larger fraction of fine material and potentially lower capital cost.

Disadvantages of calcination in a horizontal rotary kiln are: higher operating cost; higher repair and maintenance cost; lower operating factor; higher risk of ring formation; more degradation of the ore during calcining and a higher fraction of undersize

product; higher dust load in the off-gases and their volume; higher electrical energy consumption; lower refractory lining life.

### 3. Agglomeration

Four processes are considered for the agglomeration of Mn ore. These are nodulizing, pelletizing, steel belt sintering and travelling grate sintering. With the exception of pelletizing, agglomeration is carried out at temperatures that are high enough to achieve complete calcination of the carbonate minerals in the ore.

#### 3.1. Nodulizing

Following the concept of cement clinkering, fine manganese ore is reacted in a refractory lined counter-current flow horizontal rotary kiln to produce nodules in which most of the manganese is in the divalent oxidation state. The process was first used in the USA and Norway for the treatment of manganese oxide ore fines and since 1968 by Minera Autlan in Mexico for nodulizing carbonate ore fines. In the case of the Autlan ore liquid formation required for nodulizing takes place at temperatures between 1145 and 1260°C.

The operation of the nodulizing kiln is very similar to that of the rotary calcination kiln except that the maximum flame temperature is significantly higher to form a controlled amount of liquid to bind the nodules at temperatures between 1300 and 1390°C. The liquid phase is necessary to form nodules in the kiln but excessive liquid formation may lead to ring formation, adversely affecting the operating factor and lining life. The optimal ore feed size for the nodulizing process is <12 mm with a median size of 6 mm. Lump solid fuel with a low volatile content is added to ensure the formation of Mn<sup>2+</sup> in the kiln. A nodulizing kiln for Mn ore is approximately 115 m long and 5 m in diameter. Nodules are discharged at a temperature of about 1000°C and cooling takes place outside the kiln. Undersize nodules (< 6 mm) are recycled to the kiln.

Alumina-based refractory lining of a nodulizing kiln is similar to that of a calcining kiln. The throughput of a nodulizing kiln is about 1000 tonnes/day (0.3 million tonnes per year at an operating factor of 85%).

Pulverised solid fuels (coal, anthracite and coke), liquid and gaseous fuels can be used in the kiln. The preference is for a gaseous or atomised liquid fuel that produces easily controllable steady flame with a temperature of 1450–1500°C. The combustion

air has to be pre-heated (by recovering the heat from the waste gases) to ensure the required flame temperature is attained.

Trials performed in Ukraine with carbonate and pyrolusite ores show that nodulizing increases the manganese content of the nodules by 20 to 30%. The physical properties of nodules produced from carbonate ore were inferior to those obtained from pyrolusite ore (the maximum kiln temperature 1220°C might have been too low for adequate liquid formation in the carbonate material). As expected ore granulometry plays an important role in the size distribution of the nodules.

Advantages of nodulizing over calcining in a horizontal kiln are: higher value product (extended shelf life, lower content of manganese in the +3 oxidation state; suitable for undersize ore; extended shelf life of nodules compared with calcine; proven technology for the processing of manganese ore.

Disadvantages of nodulizing over calcining in a horizontal kiln are as follows: need to crush all the ROM ore to < 6mm; higher capital and operating costs; higher repair and maintenance cost; lower operating factor; higher dust load in the off-gases; higher off-gas volume; higher electrical energy consumption; higher risk of crust formation.

### 3.2. Pelletizing

Pelletizing is applied to ultrafine concentrates sized between 35 – 75  $\mu\text{m}$  with a  $d_{50}$  of about 50  $\mu\text{m}$ . The concentrates are typically obtained from wet concentration of milled ore. Gangue minerals are rejected during concentration and the grade of pellet feed is invariably higher than that of the ROM ore. Pelletizing is extensively applied to hematite and magnetite ores in the global iron making industry and for the agglomeration of chromite ore in South Africa and Kazakhstan.

For optimal pelletizing behaviour certain particle properties are preferred. These include water adsorption and absorption capacity, surface roughness, surface area and porosity. Mn ore particles may not meet all the desired criteria, especially with respect to water adsorption capacity and surface roughness (the carbonate minerals in the ore will break along smooth surfaces defined by crystal cleavage planes).

Pelletizing comprises three steps; raw materials preparation, green pellet production and pellet induration. For improved hot strength, pellets are indurated to create solid-state or slag bonds between the particles. Four steps (drying, preheating, firing and cooling) are common to the induration process. Induration could be carried out in a short shaft furnace, travelling grate, grate-kiln or steel belt sintering machines.

### 3.2.1. Short shaft furnace

The short shaft furnace would be very similar to the vertical shaft kiln with an annual capacity of about 500,000 tonnes. The shaft furnace has low technical risk and both the opex and capex are low compared to other induration machines. The hot strength of pellets indurated in a shaft furnace is significantly lower than that of pellets indurated in other types of pelletizing plants. However, these pellets are suitable for use in a submerged arc furnace.

### 3.2.2. Travelling grate induration machine

The travelling grate induration machine (Figure 2) uses the same concepts as the Lurgi travelling grate sinter machine for the agglomeration of undersized iron ore. The capacity of the travelling grate pellet sintering machine is between 3 and 7.5 million tonnes per annum. Natural gas (coke oven gas at integrated mill) or fuel oil are the main sources of energy. Several burners are used to combust the fuel.

The travelling grate is a continuous chain of pallets that form a roller conveyor on which the pellets are evenly distributed. The modern machine utilizes the deep bed technology where the thickness of the protective hearth layer is about 80 mm and the green pellet bed depth is between 420 to 470 mm.

The main advantages of the travelling grate pellet induration machine over the shaft furnace are pellet quality and reduced energy consumption. Technical risk is low.

### 3.2.3. Grate-kiln system

The grate-kiln system consists of a travelling grate, rotary kiln and an annular cooler (Figure 3). The grate-kiln is similar to the travelling grate with the exception that the firing zone is replaced by rotary kiln to improve pellet strength. Improved cooling and lower grate-bars temperature in the pre-heat zone eliminates the need for a protective hearth layer and the depth of the green pellet bed is reduced to about 180 mm to allow faster grate movement. Fuel and electrical energy consumption are claimed to be lower than for the travelling grate. The annular cooler improves heat recovery and brings about a capital saving over the travelling grate.

### 3.2.4. Steel belt pelletizing (sintering)

Steel belt pelletizing is extensively used for sintering of cold pressed metal powder performs and chromate ore pelletizing. The woven or perforated ferritic belt is about 3.0 mm thick, between 3 and 6 m wide and 20 to 50 m in length. Despite the name of 'Steel Belt Sintering' this is a typical pelletizing process with respect to chromate ore treatment.

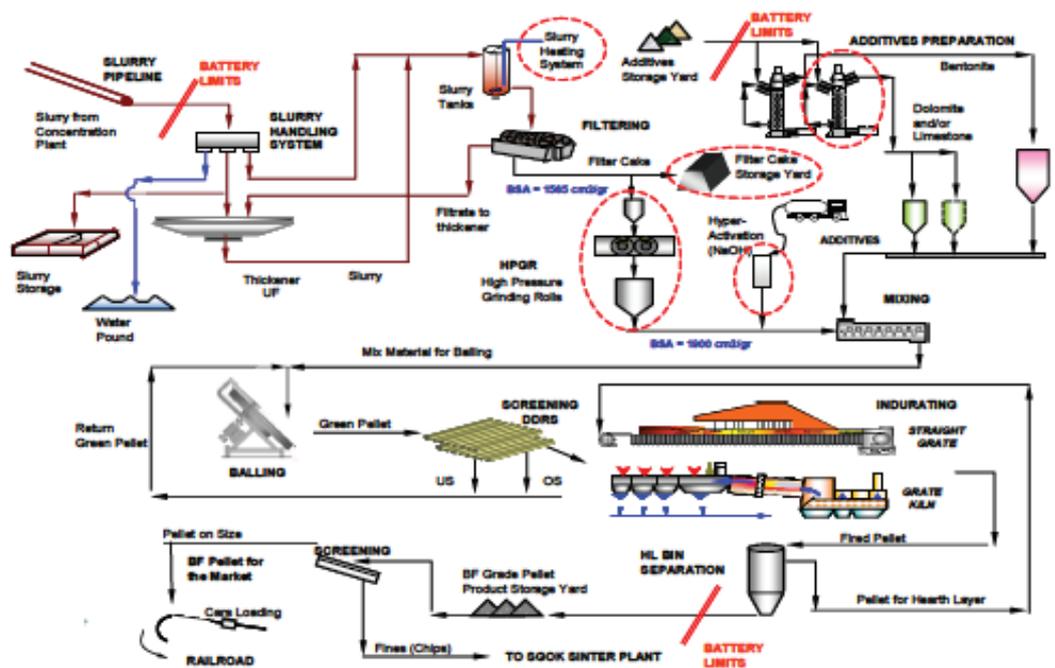


Figure 2: Pelletizing plant—travelling grate induration machine.

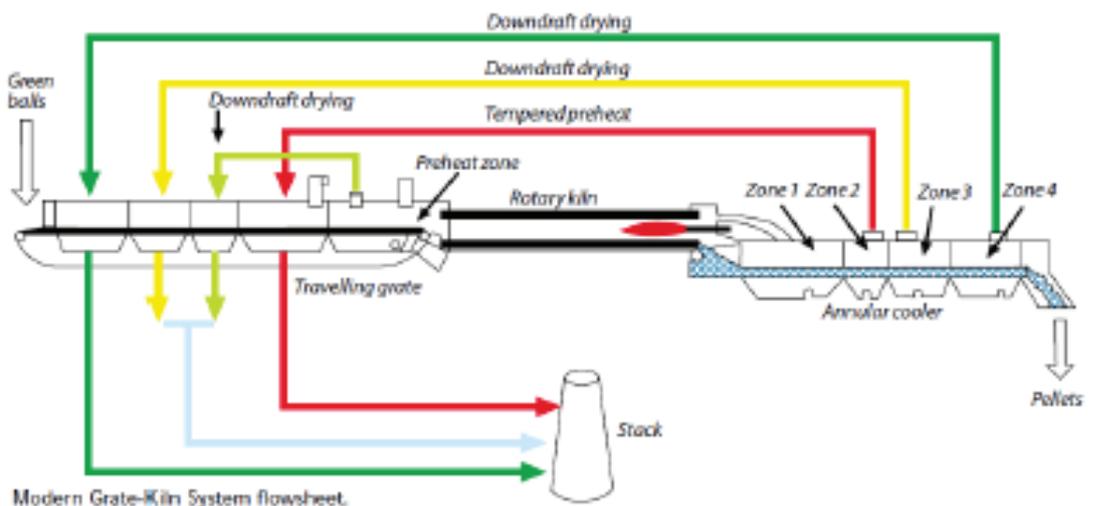


Figure 3: Schematic diagram of grate-kiln system.

The pelletizing furnace consists of multiple compartments, each designed to optimize output. Hot gas from the cooling sections is used to heat the cold pellets entering the furnace. The temperature in the furnace is in the range of 1250 to 1500°C. Waste gas generation is comparatively small and the temperature of the exhaust gas can be as low as 50°C. Dust is recycled to the pelletizing plant. The belt temperature is maintained below 300°C to avoid thermal degradation and mechanical deformation. A hearth layer with a thickness of approximately 200 mm is used to protect the belt from over-heating. The thickness of the hearth layer is increased to about 400 mm during start up and curing of the refractory lining in the sintering furnace. For chromate, the typical plant capacity would be in the range of 100,000 to 700,000 tons per annum. Steel belt sintering is very energy-efficient but carries higher technical risk.

Advantages of pelletizing are as follows: excellent product quality in terms of shelf life and furnace feed characteristics; complete utilization of mined ore (this advantage is shared with nodulizing and the sintering options); negligible generation of undersize; negligible dust carryover into the off-gas.

Disadvantages of pelletizing relative to other treatment options are the follows: pelletizing is not established technology for processing manganese ore; research and development work needed to develop optimal pelletizing conditions; lower manganese grade in the pellets because of the use of binder; need to mill all the ore to -75 µm; higher capex and opex; higher expected repair and maintenance cost; operating factor lower than other options with fewer unit operations.

### 3.3. Manganese ore sintering

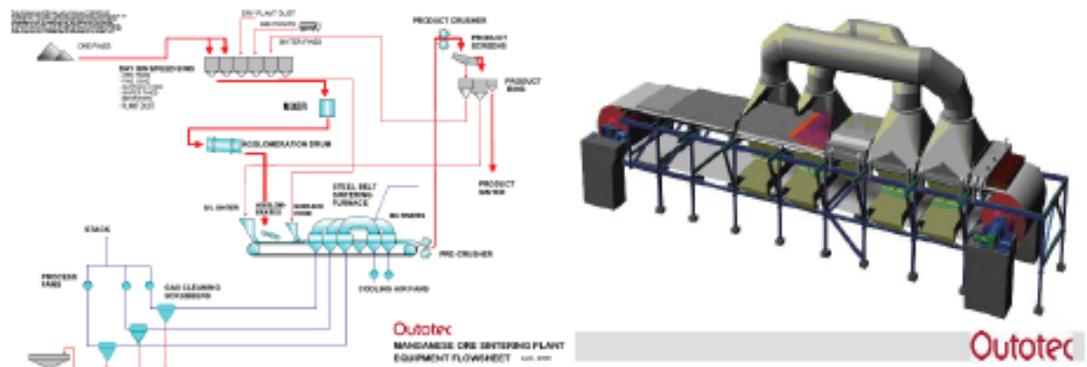
#### 3.3.1. Steel belt sintering of manganese ores

Steel belt sintering is analogous to travelling grate sintering with some important differences:

the grate has been replaced by a steel belt; the ignition hood has been eliminated; energy recovery from hot waste gases has been optimised.

Steel belt sintering is successfully applied for production of chromate ore. Outotec [1] have done test work on steel belt sintering of manganese ores and have developed a conceptual flow diagram for this process (Figure 4).

Suitably sized ore is mixed with low volatile reductant (about 3–7% on the charge mix), undersize sinter, other recycle materials, and bentonite binder (about 1%). The mix is agglomerated in a drum with some water and charged on to the steel belt. The



**Figure 4:** Schematic process flow diagram for steel belt sintering of manganese ore.

moisture content of the 'green' agglomerated material is relatively high (4.5–20%) to minimize dust formation in the drying zone of the sinter plant.

The sinter bed comprises a protective hearth layer of about 200 mm thick made of sized sinter product (the 6 – 15mm) to ensure a controlled pressure drop across the layer) on which the agglomerated mix is spread out. The bed of green sinter is between 250 and 350mm thick. A thin layer of coarser solid fuel (2 – 5mm size fraction) is loaded on the top of the bed to serve as fuel in the reaction zone.

The steel belt sintering furnace is divided into four zones. The preheated cooling gases from the two cooling zones are used as a secondary energy source in the two heating/sintering zones. The counter-current gas flow between the zones is readily visible in the three-dimensional perspective of a conceptual manganese steel belt sintering plant (Figure 4).

Drying takes place in the first zone using secondary cooling gases at a temperature of 200 to 400°C from the final cooling (fourth) zone.

Decarburation and sintering reactions take place in the second, reaction zone where the carbon layer on top of the bed is ignited at 550 – 600°C by oxygen in the hot gas from the primary cooling zone (at a temperature of between 800 and 900°C). A melt zone is established that moves down the bed as the belt proceeds through the reaction zone. Hot process gases escaping through the melt layer results in the formation of a porous sinter product and dries the feed.  $MnO_2$  and carbonate minerals are decomposed in the reaction zone. Bentonite lowers the solidus temperature of the mix and minimizes the risk of free lime being present in the sinter product.

When the reaction front reaches the top of the hearth layer the primary sintering reactions are terminated and cooling of sinter starts (this is third zone of machine or first cooling zone). The hot process gas is conveyed to the second reaction zone.

Some re-oxidation of iron and manganese in the cooling zone causes an increase in the temperature of the process gas to between 800 and 900<sup>0</sup>C.

Secondary cooling takes place in the fourth zone. Air from the fourth zone at a temperature of 200 to 400<sup>0</sup>C is sent to drying zone for initial drying of the green sinter. It is claimed that about 70% of the heat is recovered through the counter current gas flow arrangement.

Under optimal conditions the sinter is expected to be in the 6 to 63 mm size range.

The throughput of a 6 m x 50 m steel belt sintering machine is claimed to be up to 1900 tonnes per day of ore feed. The sinter production capacity of such a machine will be about 1500 tonnes per day or ~0.5 million tonnes per year at a 90% operating factor.

The grate factor (productivity per day per square meters of the sintering zone) is the primary design parameter of any sinter machine. For the state-of-the-art iron ore sintering machine the grate factor can be as high as 48–52 t/m<sup>2</sup>/day [2]. The sintering area of a Steel Belt sintering plant for a manganese or chromite application is unknown. Based on Outotec testwork on manganese ore it is deduced that the sintering area of a Steel Belt plant will be about 0.2 times of the total belt area. Based on an annual production of 500,000 tonnes sinter and an availability of 90% the grate factor for the sintering zone is estimated to be 27 t/m<sup>2</sup>/day (Grate Factor =  $500,000 / (365 \text{ days} * 0.9) / (6 \text{ m} * 50 \text{ m} * 0.1875) = 27 \text{ t/m}^2/\text{day}$ ). Coke fines, anthracite or coke breeze with less than 2% volatiles are used as a fuel.

Advantages of Steel Belt sintering: high thermal efficiency; lower (up to 40%) fuel consumption; improved control of sintering process compared with travelling grate; lower particulate emissions compared with travelling grate process; better sinter shelf life compared with travelling grate process.

Disadvantages of Steel Belt sintering: not proven for manganese ore; lower manganese grade in the sinter because of the use of binder; less flexible turn-down ability because of reduced enthalpy of the off-gas from the cooling zone at lower productivity; turn-down conditions may require additional fuel and potentially the use of an ignition hood; performance and sinter quality is heavily dependent on sizing and preparation of feed mix; compared with travelling grate, additional crushing and milling of Mn ore may be required; the need for a significant amount of reductant in the –1 mm size range may require a facility to crush reductant; lower grate factor compared with travelling grate sintering process; complex process control and a need for higher skill levels to operate the plant.

### 3.3.2. Linear travelling grate sintering

The linear, down-draught, continuous travelling grate sintering process was broadly implemented about 60 years ago for the iron making industry (Figure 5). The process is characterized by its simplicity, robustness and productivity.

Modern iron ore sinter plants have a sintering area of up to 600 m<sup>2</sup> and an annual capacity about 6.5 million tonnes of sinter/year. The grate factor is in the range of 45–52 t sinter/m<sup>2</sup>/day [2]. The availability of the sintering machine is 90% or higher.

Manganese sinter plants are much smaller. Capacity does not exceed 1 million ton/year and grate factor is about 35 t/m<sup>2</sup>/day. Sinter plant uses undersize ore in the 1–9 mm size range and capable to process any type of manganese ore: oxide; mixed oxide and carbonate and pure carbonate.

Undersize manganese ore and solid fuel in the form of coke breeze or anthracite fines with a low volatile content below 2% are mixed with undersize sinter and other recycle materials in a mixing drum to form the raw material mix for the sintering process. Fuel comprises about 6% of the mix. Water is added in the mixing drum to obtain a consistent mix. The desired moisture of the raw mix is 5%.

For more efficient combustion the burner air can be pre-heated or a carbon layer can be applied on top of the bed. The firing rate in the ignition hood is around 100–125 MJ/tonne of sinter. The exposure time of the raw mix under the ignition hood is about 2 minutes at a temperature of 1200°C. This translates to a total heat exposure of 65 MJ/m<sup>2</sup>. For normal operation the thickness of hearth layer is set to approximately 30 mm.

Advantages of the down-draught travelling grate sinter technology: robust technology, well proven for manganese ore sintering; no capacity constraints and extended turn-down range; possibility to reduce throughput by decreasing the strand speed or changing the bed depth; higher than Steel Belt grade of sinter since binder is not required; simpler ore preparation.

Disadvantages of the down-draught travelling grate sinter technology: lower energy efficiency than Steel Belt technology and, consequently, higher operating cost; somewhat shorter sinter shelf life because of higher sinter basicity (no binder addition); performance is somewhat dependent on feed quality; higher dust loading in the off-gas.

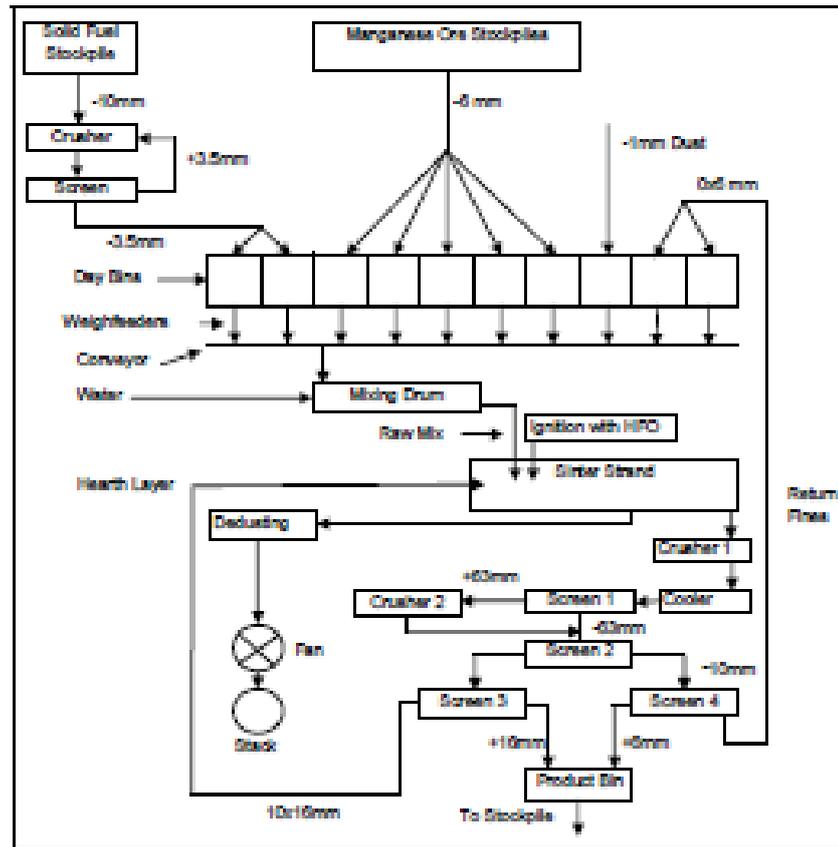


Figure 5: Flow diagram of travelling grate sintering.

### 3.3.3. Circular down-draught travelling grate sintering machine

The circular travelling grate machine has two concentric annular walls designed to move on a circular track-way, which rests on a conventional superstructure. A number of pallets are placed between the two walls. The pallets are hinged to the outer wall and are held in horizontal position by individual locking mechanisms. Water cooling is used to control differential expansion of the moving parts. The circular travelling grate machine has a heating zone, cooling zone and discharge or dumping station. The feed is introduced through a feed chute onto the pallets in the heating zone.

Circular sinter machines are currently being built and used in China for sintering iron ore for small iron making blast furnaces. These machines produce approximately 1500 t of sinter per day.

It is claimed that the Capex of circular machines is 30% lower than that of linear sinter machines. Other benefits are a smaller footprint, shorter construction time and lower opex. Air ingress is said to be minimized by simultaneous movement of the pallets, wind boxes and the use of a water seal providing higher thermal efficiency

(compare to a linear travelling grate without recycling hot cooling gases to the ignition hood). Fuel specifications are similar to the linear travelling grate machine

Disadvantages of the circular travelling grate process over the linear travelling grate process: capacity constraints; higher maintenance cost; more restricted turn-down flexibility; technology is not widely established for manganese ore sintering.

### 4. Technology Comparison and Conclusions

Comparison and ranking of Mn ore pre-treatment technologies are presented in Table 1.

TABLE 1: Comparison of pre-treatment options for Mn ore.

Parameter /Ranking (Ranking: Rank 1 is better and Rank 3 is worth than Rank 2)	Calcination	Nodulizing	Pelletizing	Steel belt sintering	Travelling grate sinter
Technical risk	Not proven in industrial scale for Mn ore: Tests required	Proven on Mn ore. Need to be optimised	Not proven for Mn ore at industrial scale	Not proven for Mn ore at industrial scale	Proven for Mn ore
Product quality Rank 2 - Shelf life of travelling grate sinter	3 No sintering takes place; Formation of Fines during processing; free CaO increases hydration risk	1 Formation of liquid phase provides strong bond between particles	1 Less fines; binder helps to stabilise free lime from decomposition of calcite. Good for transport.	2 Similar reactions and conditions as travelling grate	2 Good porous structure; high strength and reducibility. Long distance transportation not possible.
Ore sizing	Lumpy ore (>10 mm). Horizontal kiln tolerates course fines	< 12 mm. Some lumpy ore can be tolerated	< 75 µm ultra-fines only	-6 mm fines only (30% -1 mm may be desirable)	-6 mm fines only
Need for ore pre-treatment	No crushing; screening to remove fines	Crushing to a top size of 12 mm	Crushing and grinding to a top size 75 µm	Crush to -6mm	Crush to -6mm
Typical plant capacity (Calcination data - for limestone)	Vertical kiln: < 500000 t/y (800t/d). Horiz. kiln: > 500000t/y (1400 t/d)	< 500000 t/y (600-800 t/day)	> 500000 t/y (for iron ore up to 22500t/day)	~500000 t/y (proposed 1500 t/day for Mn ore)	≥500000 t/y for a linear strand. Smaller capacity for carousel plant
Consumptions Fuel Electrical power	For lime: 3.7 GJ/t -vertical kiln; 4.2 - 4.6 GJ/t -horizontal kiln 20-40 KWh/t	4.6-5GJ/t nodule 25-40 KWh/t	1.1 GJ/t iron ore 30 KWh/t for induration	1.8 GJ/t (estimated) 45-80 KWh/t (strand)	3 GJ/t Mn ore 3 30-40 KWh/t (strand)
Capex. Rank 2 - Capex of travel. grate sinter plant (500000 t/a).	1	3	3	1	2

Parameter /Ranking (Ranking: Rank 1 is better and Rank 3 is worth than Rank 2)	Calcination	Nodulizing	Pelletizing	Steel belt sintering	Travelling grate sinter
Turn-down ability	Max. 30% to maintain product quality	Max. 30% to maintain prod. quality	Easy to adjust, stop/start operation	Required process adjustment	Easy to adjust, stop/start operation
Maintenance Rank 2- Sinter travelling grate maintenance.	1	2-3 Risk of ring formation.	2	3 Risk of belt deformation	2
Fugitive emissions. Rank 2 - from travelling grate sintering.	Vertical kiln: 1-2 Horizontal kiln: 2-3	2-3	1-2	2	2
Product Yield. Rank 2- product quality of r travelling grate sinter.	Vertical kiln: 1-2 (Less fines formation in the vertical kiln). Horizontal kiln: 2-3.	1 More glassy phase binder	1	2	2

1. For pre-treatment of manganese ore, the only proven technologies are nodulizing and travelling grate sintering (linear grate and carousel grate).
2. Calcination is a low capex and opex process for the treatment of lump ore with a narrow size range. There are capacity constraints per production unit if a vertical shaft furnace is selected for calcination. The shelf life of calcined ore is expected to be in the region of 24 to 48 hours and calcining has to be done at the smelting site. It is not commercially proven yet for Mn ores.
3. Nodulizing requires crushing and further size reduction of lump ore. The process has relatively high specific thermal energy consumption and there are capacity constraints per production unit. Kiln maintenance requirements are relatively high. The Mn nodules have a good shelf life and require a less carbon for smelting than ROM oxide ore. Nodules should be viewed as a niche product with an export potential.
4. Pelletizing is best suited for friable, rather than highly competent ore such as Mn. Pelletizing and induration involve several processing steps and both capex and opex are high. The process carries significant technical risk when applied to Mn-type ore.
5. Sintering is well proven for the simultaneous calcination and agglomeration of undersize, manganese ores. Sintering can be conducted in a down-draught linear

travelling grate sintering machine, a steel belt sintering machine and a down-draught circular travelling grate machine. Steel belt technology is unproven for manganese ore and while it is more energy efficient, does not have the turn down flexibility afforded by travelling grate technology. Circular travelling grate machines have capacity constraints and are likely to be more maintenance intensive than the linear machines.

6. The down-draught linear travelling grate sintering technology is proven for manganese ore, robust and offers significant turn-down flexibility.

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