INTENSIVE MIXING AND GRANULATION SYSTEM: SOLUTIONS FOR ULTRA-FINES IN SINTERING[1]

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Abstract

One of the global trends that are constantly challenging the iron and steel producers is related to worsening of the iron ore grades. The run of mine is not producing ores with the same purity of the past and materials like silica need to be removed before further processing. Therefore, a larger amount of iron ore has to be further beneficiated and concentrated and the result is a significant amount of pellet feed available to the market. However, most of the integrated steel plants have sintering plants at their sites in order to agglomerate the fines and prepare a good blast furnace burden. But the fines are now finer than before and operators are uncertain about the impact of these ultra-fines in their sinter raw mix. After years of development and now with several industrial references operating, Siemens VAI brought to the market the Intensive Mixing and Granulation System (IMGS) which processes efficiently pellet feed in sinter plants. The objective of this paper is to demonstrate what the latest developments are in this system and what Siemens VAI is doing to overcome the remaining challenges in this field.

Key words: Mixing; Iron ore; Ultra-fines; Sinter plant.

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1 INTRODUCTION

The Intensive Mixing and Granulation System comprises of a proportioning bins system, an intensive mixing unit and a granulator or a standard granulation drum. One out of different possible flow sheet variants is shown in Figure 1. Different raw materials stored in separate bins are precisely dosed onto a conveyor belt in sandwiched layers. Modifications to the chemical composition of the sinter product are easily carried out by automatic adjustments of the raw material dosing rates according to the sinter recipe. This is remotely performed in the control room applying a sophisticated Level 2 process-optimization (Expert-)system. The raw materials extracted from the dosing bins are transferred to the intensive mixer where they are thoroughly homogenized. After the material exits the intensive mixer, it is transported to the granulator where it is granulated with the required permeability prior to charging onto the sinter strand.

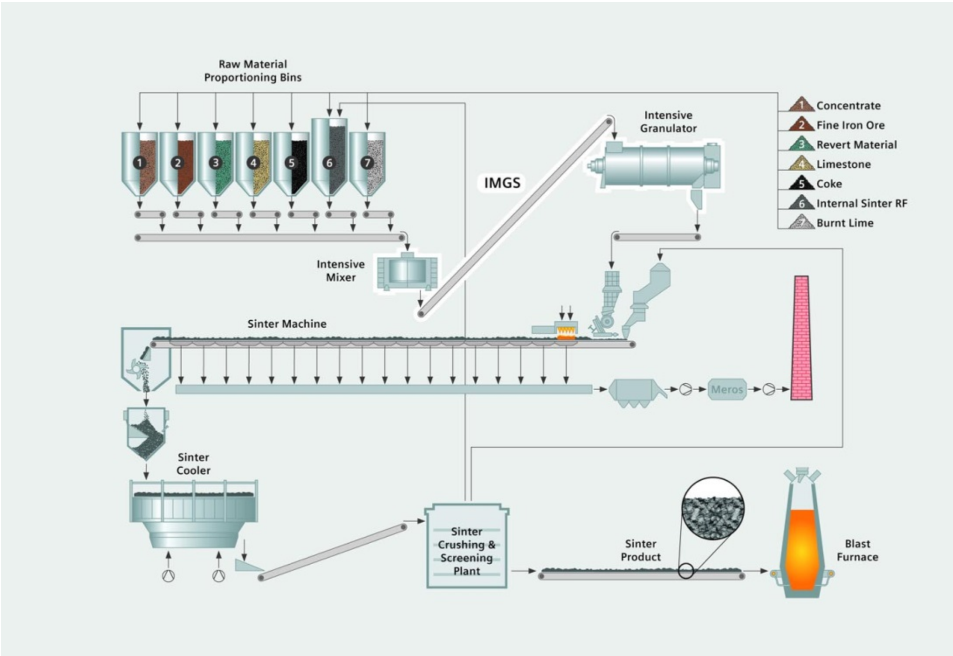

Figure 1. Flow sheet of the Intensive Mixing and Granulation System with intensive mixer and horizontal granulator.

2 PROCESS INVESTIGATIONS AND DEVELOPMENT

Exhaustive investigations were carried out using different mixing and granulation machine types and designs. A wide range of iron ores with varying grain-size distributions, even up to 100% pellet feed, were also systematically tested. After the mixing and granulation steps, the material was sintered in sinter pot test equipment to evaluate its performance in the sintering process. The focus of investigations in the mixing step was to obtain a high homogeneity of the sinter raw mix, while the main issue in the granulation step was to maximize the permeability of the material mix. Coarse and very fine sinter raw mixes were compared.
It was shown that a higher homogeneity of the material mix could be achieved in an intensive mixer compared with a conventional mixing drum. Furthermore, superior homogeneity results were reached in shorter residence time using the intensive mixer.

Different material mixes were then investigated in the granulation step. It was determined that carefully controlled water additions to the material mix and, in particular, the ratio of water injected into the mixer and granulator units are decisive for proper granulation and for ensuring a high degree of permeability. A key target in the granulation tests was to attain good permeability with the lowest possible amount of water. When high portions of fine ore were used in the sinter mix, the quantity of burnt lime added to the mix was increased accordingly.

When comparing the agitating-type intensive mixer with the conventional mixing drum, the following can be stated:

- the agitating-type intensive mixer introduces high energy with its mixing tools directly to the raw materials to be mixed, achieving an even distribution of all raw materials within the sinter raw mix and bringing iron ores and fluxes in tight contact;
- the conventional mixing drum can only use gravity forces for distribution and mixing of the raw materials, which very much limits the mixing efficiency;
- the homogeneity of the produced mixture is therefore substantially higher using the intensive mixer.

The granulation in a granulator unit offers a number of advantages compared with conventional granulation in a drum. For example, high amounts of ultra-fine materials can be processed without adverse effects on the granulation process. Self-cleaning of the inside walls of the intensive granulator is conveniently performed by rotating arms. (Very fine material often sticks to the inside wall of the granulation equipment.) Furthermore, the rotation speed of the granulation tools can be adjusted in the intensive granulator, whereas a conventional granulation drum has only one rotational speed. Residence time and granulation behavior is adjustable via changing the filling degree.

Cold permeability tests were carried out using a special apparatus in which defined quantities of sinter raw-mix granules were subjected to differential pressure for a certain material height. The results were measured, compared and analyzed using an on-line computer system. A direct relationship could be observed between granulation behavior, permeability and the productivity of the sinter strand. It was shown that excellent permeability is achieved for both coarse and very fine material using the granulator unit.

Sinter pot tests were then performed to produce sinter using different mixtures of sinter raw mix. Coarse and very fine materials were used. The sinter product and the respective productivity rates were compared. It was even possible to produce a good-quality sinter using 100% pellet feed, but at decreasing productivity rate. The results depend to a major extent on the raw materials used and the selection and combination of equipment to produce the sinter raw mix. To make precise statements, each raw material combination has to be carefully investigated applying mixing, granulation permeability and sinter-pot tests.

3 RESEARCH AND TEST CAMPAIGN

As a leading and innovative company in the field of iron ore agglomeration, Siemens VAI has executed thoroughly a series of research programs and research campaigns to establish the optimum relation between the mixing and granulation steps and the sinter quality and productivity. Some explanations and results are shown below.

3.1 Raw Materials

Different raw material mixes have been used for the comparison. One sinter raw mix with rather coarse material and secondly a sinter raw mix with 70 -100 percent (basis iron ore) of pellet feed was used.

3.2 Apparatus

Following mixing and granulation apparatus have been used during these tests.
Mixing apparatus:

- conventional horizontal mixing drum;
- vertical-type intensive mixer;
- horizontal-type intensive mixer.

Granulation apparatus:

- conventional horizontal granulation drum;
- vertical-type granulator;
- horizontal-type granulator.

As there are countless numbers of different raw materials not only one solution is to be provided but the optimum solution has to be established. Therefore different combinations of mixing and granulation units have to be used to reach the optimum mixing and granulation. The two steps of mixing and granulation have to be investigated and treated separately. For the mixing step the investigations focuses on high homogeneity wherein the granulation step the permeability of the material mix is the main issue. Coarse and very fine sinter raw mixes have been compared in the investigation studies.

3.3 Homogeneity of the Raw Mix

3.3.1 Theory

In order to compare the homogeneity of different aggregates a standard procedure has to be established. To measure the homogeneity a tracer (either additional or in situ component) will be used. A certain amount of tracer is added, samples are taken and the tracer or specific chemical elements are analyzed.
Most important is:

- the kind of tracer to be used;
- number of samples to be taken;
- amount of sample to be taken;
- investigation of the variance;
- detection of the accuracy of the measurement.

The variation coefficient is a good indication for comparing homogeneity.
The variation coefficient is:

$$V = \frac{s}{M} 100 (\%)$$

And comprises out of the standard deviation “s”:

$$s_x = \sqrt{s_x^2} = \sqrt{\frac{1}{k-1} \sum_{i=1}^{k} (c_{M,i} - \overline{c_M})^2}$$

And the mean value “M”.

The coefficient of variation is therefore defined as:

$$s_x^2 = \frac{1}{k-1}\sum_{i=1}^{k}(c_{M,i} - \overline{c_M})^2$$

- $c_{M,I}$ is the concentration of the individual tracer element
- c_M is the average concentration

The ideal, real mixing curves regarding homogeneity are shown in Figure 2. Also a de-mixing is possible in different equipment after a certain time.

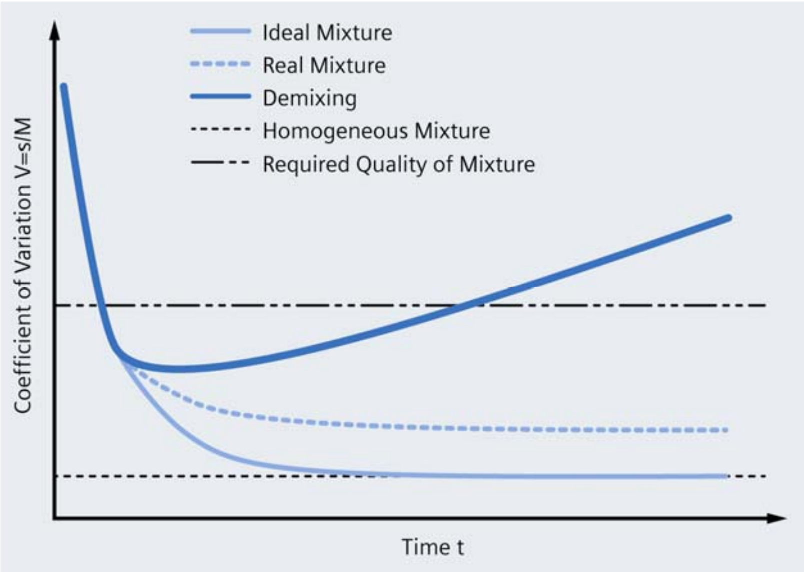

Figure 2. Typical mixing development regarding homogeneity during mixing.

Figure 3 shows that a higher homogeneity (means lower variation coefficient) can be reached in the intensive mixers than in a conventional horizontal mixing drum. Furthermore, the high homogeneity in the intensive mixer was reached by far earlier than in a conventional drum.
In regard to homogeneity only it can be stated that both kinds of intensive mixers tested (vertical and horizontal-type) show the similar homogeneity levels.

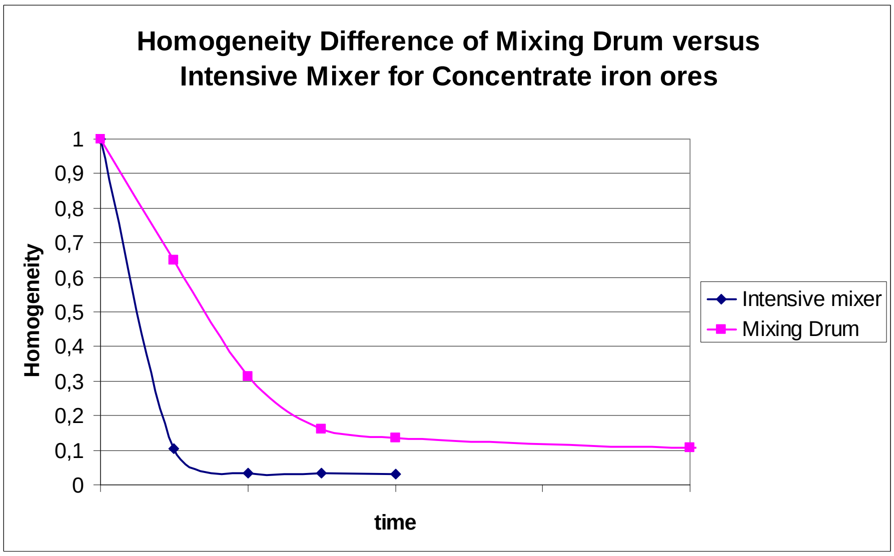

Figure 3. Homogeneity reached with different mixing units over time.

3.4 Granulation

After mixing the second step is the granulation. The sinter raw mix will be fed to the granulation unit. Water addition (besides burnt lime addition) is more or less the decisive factor for granulation behaviors of the sinter raw mix. Therefore, water control of the sinter raw mix is essential for reaching high permeability, which has a directly correlation to the productivity of the sinter strand.

4 MEASUREMENT OF COLD PERMEABILITY

Cold Permeability is measured with specially developed permeability apparatus. Figure 4 shows a simple sketch of this kind of measurement device. The differential pressure across a certain amount of sinter raw material granules is measured and computerized.

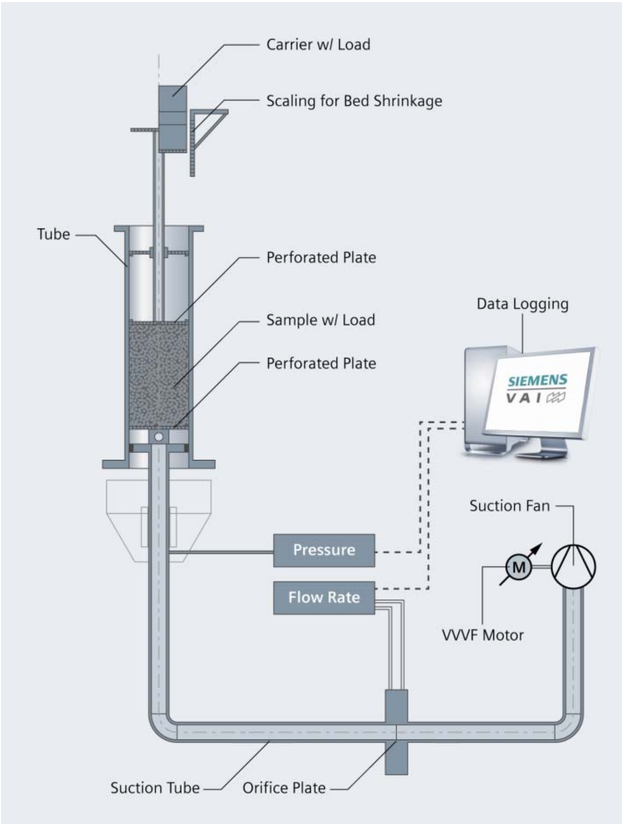

Figure 4. Specially developed permeability apparatus.

Looking at the sinter process water addition cannot be extended to very high levels otherwise slumping of sinter bed on sinter machine in cold or in hot conditions might occur. Therefore one of the targets is always to reach a good permeability with the lowest possible amount of water.
The conventional granulation drum is basically a very good granulation equipment with excellent granulation results. Nevertheless sometimes the sizes of the different granules is often taken as an indication of permeability. This is not always accurate because the permeability depends not only on the grain size distribution.
The permeability of a raw material mixture increases with mean particle size “dp” and voidage “eps” (assuming the particle shape stays the same). In the turbulent regime, permeability can be evaluated by eps3/(1-eps)*dp. Grain size distribution with higher

mean particle size do not necessarily have a higher permeability, since the voidage can decrease. Especially particle size distributions with wide size range show low voidage.
Different granulated sinter raw mixes are shown in the figure (5). It shows that the grain size distribution of the tested material, using different equipment is not the same. The conventional horizontal granulation drum generates a higher amount of bigger granules. Nevertheless the permeability of the different granulated mixtures remains the same.

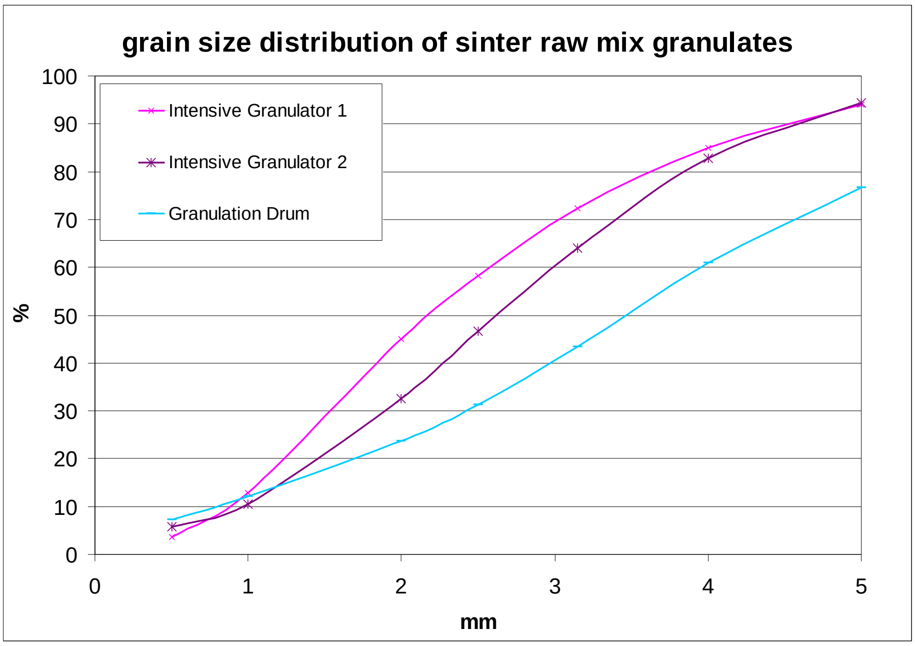

Figure 5. Grain size distribution of sinter mix utilizing different granulation equipment.

Advantages of using an granulator unit versus a conventional horizontal granulation drum:

- lower equipment weight for installation;
- high amount of ultra-fine materials can be processed without deteriorating the mixing and granulation process;
- self-cleaning of the granulator (very fine material often sticks to the wall of the granulation equipment);
- at a horizontal granulation drum a de-mixing effect may also occur due to segregation;
- possibility of speed adjustment of the granulation tools (conventional granulation drum has only one rotational speed) and filling degree (residence time).

The test results demonstrate that, with coarser or with very fine material, a high permeability can be reached also with an granulator unit, horizontal or vertical-type.

5 SINTER POT TESTS

Sinter pot tests have been performed with different sinter raw mix materials. Coarse material and very fine material (up to 100% of pellet feed (100%<100my) was used. Also different equipment combinations have been used for the mixing and granulation steps.

It has been shown that with the various combinations of intensive mixing and granulation, high quality sinter and high productivity can be reached using up to 80% of pellet feed. It was also possible to sinter 100% of pellet feed but with lower productivity levels. All these results depend very much on the raw materials itself. To make precise statements every different raw materials combination have to be investigated and have to undergo mixing, granulation, permeability and sinter pot tests.

The ultimate goal of all scientific understanding is the preservation of the largest possible factual report in the smallest possible number of axioms and hypotheses. Albert Einstein

6 INDUSTRIAL APPLICATION

The first Intensive Mixing and Granulation System was first put into operation at the sinter plant of voestalpine Stahl Donawitz, Austria, in the late 1990s. Installation of the system at the sinter plant no.1 of Dragon Steel Corporation, Taiwan in 2009 meant that blending yards could be dispensed with altogether. The latest plant start-ups of the Intensive Mixing and Granulation System were at the Ipatinga and Cubatao steelworks of the Brazilian steel producer Usiminas S.A. in late 2011 and early 2012, respectively. Intensive mixing and granulation system has been installed and commissioned in Taiwan. Next start-ups and commissioning will take place in India as shown at the Table 1.

The Intensive Mixing and Granulation System can be installed within new sinter plant projects and as well as a 100% add-on package within existing sinter plants of various sizes.

Table 1. Siemens VAI installations of Intensive Mixing and Granulation System for sinter plants

Reference Installation	Sinter Plant area	IMGS Configuration	Use of some Ultra-fines
voestalpine Stahl Donawitz GmbH, Austria: 1998	120sqm	Single mixing and granulation unit	no
Dragon Steel Corporation, Sinter Plant No. 1, Taiwan: December 2009	248sqm	Intensive mixer and granulation drum	yes
Usiminas S.A., Ipatinga steelworks, Sinter Plants Nos. 1 and 2, Brazil: 2011	90/180 sqm	Intensive mixer and granulation drum	yes
Usiminas S.A., Cubatao steelworks, Sinter Plant No. 3, Brazil: 2012	268sqm	Intensive mixer and granulation drum	yes
Dragon Steel Corporation, Sinter Plant No. 2, Taiwan; start-up: October 2012	387sqm	Intensive mixer and granulation drum	yes
National Mineral Development Corporation (NMDC) Ltd., India; planned start-up: 2014	460sqm	Intensive mixer and intensive granulation	no
Jindal Steel & Power Limited (JSPL), India; planned start-up: 2014	490sqm	Intensive mixer and intensive granulation	yes

7 INTENSIVE MIXING AND GRANULATION SYSTEM AT VOESTALPINE STAHL DONAWITZ, AUSTRIA

The system was first tried and put into operation at the sinter plant of voestalpine Stahl Donawitz, Austria, in 1998.

Due to space constrains in the steel works (the plant is situated in a valley of the Austrian Alps) installation of blending yards have not been possible. An old combined mixing and rolling drum was replaced by a single intensive mixer unit used for mixing and granulating. Additionally, own special sinter feed of sideritic iron ore from close iron ore mine was utilized. All these fields of applications led to several improvements of mixer tools, speed adjustment, moisture content and water addition, etc. All these factors led to higher homogeneity, higher life time of the tools, better sinter bed permeability, higher productivity and even reduction of solid fuel consumption, as shown at Table 2.

Table 2. Results achieved in voestalpine Stahl Donawitz, Austria after replacement of the existing combined mixing and rerolling drum by a single Horizontal Intensive Mixer

Plant Operational Data:	Before IMGS	After IMGS
Suction Area	120 sqm	120 sqm
Bed Height	600 mm	600 mm
Suction Pressure	140 mbar	140 mbar
Productivity	33 t/m2/24h (approx. 4.000 t sinter/day)	35 t/m2/24h (approx. 4.200 t sinter/day)

The author wishes to express his gratitude to voestalpine Stahl GmbH for their support in the development of the Intensive Mixing and Granulation System.

8 INTENSIVE MIXING AND GRANULATION SYSTEM AT DRAGON STEEL CORPORATION SP1 AND SP2, TAIWAN

At Dragon Steel Corporation, located in the Taiwanese province of Taichung, two sinter plants were awarded to Siemens VAI: the sinter plant no. 1 has 248sqm of suction area and is in operation since December 2009, and the sinter plant no.2 with a sintering area of 387sqm successfully performed beginning of October 2012 see Table 3. Both sinter plants at Dragon steel are equipped with the Siemens VAI Intensive Mixing and Granulation System, and fully operate without blending yards.
For the proportioning of the raw mix, 22 sets of raw materials bins were installed and no blending yards are necessary to achieve the desired mixture and homogeneity for sintering. With the smooth, even and automated-precise discharge from the proportioning bins and a respective number of bins in combination with the Intensive Mixing and Granulation System no blending yards are needed any more. In the vertical intensive mixer, the materials are mixed and homogenized. In order to adjust the optimum moisture content of the sinter raw mix, water is also added in the intensive mixer to meet the requirements for achieving high permeability on the sinter strand. For optimization of the sintering process, an even distribution of the ores, additives and fuels within the sinter raw mix is of ultimate importance.

8.1 Mixing and In-Plant Return Fines Addition

For the primary mixing, a vertical-type intensive mixer is applied, as shown at Figure 6. The sinter raw mix generated in the intensive mixer is transported via a belt conveyor to the horizontal granulation drum, as per Figure 7. The in-plant return fines are charged to the sinter raw mix before the granulation drum, evenly distributed on the belt conveyor by dosing weigh feeders.

Figure 6. vertical-type intensive mixer at the sinter plant no.1, Dragon Steel Corporation.

Figura 7. Horizontal granulation drum at the sinter plant no.1, Dragon Steel Corporation

8.2 Granulation Step

For the granulation step a horizontal granulation drum. This so-called late return fines addition functions as additional nuclei for the formation of granules in the granulation drum. There the final moisture is also adjusted to improve the granulation effect, thus optimizing the permeability on the sinter strand. The granulated sinter raw mix is charged via an oscillating belt conveyor to the sinter machine feeding hopper.

Table 3. Intensive Mixing and Granulation System installations at Dragon Steel Corporation, Taiwan

	Sinter Plant no.1	**Sinter plant no.2**
Sintering area	248sqm	387sqm
Intensive mixer throughput	414 tons per hour	605 tons per hour
Granulation drum length	12 meter	18 eter

9 INTENSIVE MIXING AND GRANULATION SYSTEM AT USIMINAS IPATINGA AND CUBATAO WORKS, BRAZIL

The latest Siemens VAI installations of the Intensive Mixing and Granulation System were retrofitted at the existing sinter plants located at the Ipatinga and Cubatao steelworks of the Brazilian steel producer Usiminas S.A. with respective start-ups in late 2011 and early 2012.
At both of these sites a vertical-type intensive mixer has been installed upstream of the existing combined mixing and granulation unit (18.5 and 21m in length). This combined unit has been modified to a granulation unit only. Additionally, by-pass sets

for the intensive mixer, a dedusting unit and pneumatic conveying system for dust have been implemented. The intensive mixer was installed to significantly increase the portion of iron ore fines that can be added to the sinter raw mix and to be processed in the sinter plants. The target of 25% of concentrate iron ore (basis of iron ore) has been processed successfully.

10 INTENSIVE MIXING AND GRANULATION SYSTEM UNDER INSTALLATION IN INDIA

At two Indian sinter plant projects the Intensive Mixing and Granulation System consists of a vertical-type intensive mixer and a horizontal-type granulator, similar to the demonstrated at Figure 8. At NMDC sinter plant in Nagarnar normal sinter feed shall be used, however at the JSPL sinter plant in Angul up to 60% of pellet feed shall be added to the sinter raw mix, as shown in Table 4.

Table 4. Intensive Mixing and Granulation System under installation in India

	Jindal Steel & Power Limited (JSPL), India	**National Mineral Development Corporation (NMDC) Ltd., India**
Sinter Plant location	Angul, India	Nagarnar, Chhattisgarh, India
Sintering area	490sqm	460sqm
Intensive mixer Unit	vertical-agitating-type	vertical-agitating-type
Intensive granulator Unit	Horizontal-agitating-type	Horizontal-agitating-type
Iron ore input (foreseen)	Up to 60% pellet feed	Mainly sinter feed

Figure 8. Horizontal-type granulator.

11 MAIN BENEFITS OF SIEMENS VAI INTENSIVE MIXING AND GRANULATION SYSTEM*

- Lower investment costs;
- no pre-blending (blending yards) required (only bunker blending system);
- increased flexibility in the selection of raw materials;
- improved sinter raw mix homogeneity, including recyclable in-plant reverts;
- reduced solid fuel consumption, because of best possible fuel distribution;
- excellent sintering results even using high portions of ultra-fine iron ores;
- reduced space requirement for sinter mix preparation;
- completely homogeneous sinter raw mix with high and even permeability;
- economically reuse of revert materials, i.e. dusts, sludge, scales, and others;

- high and stable sinter quality, resulting in high performance of the blast furnaces;
- lower electric energy consumption even when the sinter machine is operated with high bed height.

* Compared with conventional sinter raw mix preparation systems.

12 CONCLUSION

The ideal combination of mixing and granulation machine types and dimensions is made on the basis of the available raw materials. The industrially proven Intensive Mixing and Granulation System from Siemens VAI therefore offers producers customized and cost-optimized solutions for achieving maximum sinter plant performance and achieving highest product quality. However, as all raw material mixes behave in different manners throughout the sinter process, a closer investigation is required to evaluate the optimum configuration of the system.

Furthermore, the Siemens VAI Intensive Mixing and Granulation System can be installed in existing or in Greenfield plants, as 100% add-on or fully integrated.