INBA® slag granulation system with environmental control of water and emissions

As the demand for granulated BF slag continues to grow and environmental constraints become more severe, improvements to slag granulation technology are required. New designs involving the combination of a granulation basin, counter-current condensation tower and use of very fine water sprays result in improvements in granulation, sand product and emissions.

AUTHORS: Patrick Leyser and Christian Cortina
Paul WURTH S.A.

Wet granulation of blast furnace slag has been practised for many years. Various systems are in use and all are based on the quenching of molten slag with water. The original process was the OCP granulation system (gravel layer filtering plant) – the starting point for further development of the granulation process and plant design. Improvements have become a must since the environmental demands imposed by local authorities in various countries become ever more stringent.

INBA GRANULATION PLANT – INITIAL PLANT DESIGN
At the beginning of the 1980s, SIDMAR and Paul WURTH (PW) developed the INBA granulation system. The initial plant layout was designed with a blowing box in combination with a cold runner (see Figure 1). In the original system the water-slag mixture flowed to the receiving hopper and was then fed to the de-watering unit via an internal feeding arrangement.

The de-watering unit (see Figure 2) consists of a de-watering drum (1) which has vanes (2) on its inner circumference to remove the sand out of the drum and on its outer circumference there are screens for de-watering (3). The slurry is fed by means of a feeding arrangement comprising a distributor (4) and slow-down boxes. The aim of the distributor is to distribute the water-sand slurry evenly over the whole drum length while the slow-down boxes reduce the impact of the slurry flowing from the receiving hopper via the distributor into the drum, and thus protect the screens.

GRANULATION PROCESS
The aim of wet granulation is the fast quenching of molten slag. During the quenching process the molten slag converts into glassy sand with 97% of the particles less than 3mm, and an average slag sand particle size of less than 1mm. The impact point of the slag stream and...
the granulation water depends on the slag flow, its temperature and the slope and shape of the hot runner (see Figure 3). The heat exchange between molten slag and granulation water has to take place very quickly. The granulation water jets break up the slag stream into molten slag lamellae which decompose initially into filaments and then into droplets. The best heat transfer occurs when the contact surface between the molten slag and the water is at maximum, i.e., when slag has been converted into droplets and fully enclosed with water. The solidification time depends on the size of the slag droplets, the temperature difference between the molten slag and the granulation water, and the contact environment between the slag and the water. Depending on the granulation water temperature around the slag droplet, different heat transfer mechanisms take place:

- **Heat removal only through steam release** – applicable if the granulation water temperature is equal to water boiling temperature
- **Heat removal through steam release and heat transfer into granulation water** – applicable to most cases
- **Heat removal without steam release but only through heat transfer into granulation water** – applicable if the granulation water is cold and allows an immediate condensation of the generated steam

In general, boiling temperature will not be reached when granulating with cold water, except for local spots due to transient high slag flows. Heat removal without steam release can take place if granulating with cold water and where good turbulence between the slag and the water allows optimum removal of heat. However, the most common situation is heat removal through steam release and heat transfer into granulation water (see Figure 4).

The granulation process can be performed with hot or cold granulation water, allowing for two different water circuit layouts:

**Hot water circuit (see Figure 5)** An installation designed as a hot water granulation circuit does not have a cooling tower. The granulation water, circulated in a closed loop, heats up close to boiling temperature and heat removal from the molten slag during hot water granulation is mainly via steam release. Cold make-up water is added to the system only to compensate for steam and moisture losses. The average water temperature in the circuit is approximately 90–95°C. At the impact point, where the granulation water comes in contact with the molten slag, water temperatures of ~95°C and even higher are to be expected.
Cold water circuit (see Figure 6) The closed cold water circuit is equipped with a cooling tower whose purpose is to keep the process (granulation) water at a constant cold temperature. Heat removal from the molten slag in contact with cold granulation water takes place via heat transfer into the water and partly through steam release. Heat transfer through steam release varies depending on the granulation water temperature and the instantaneous slag flow. At low slag flows the heat transfer of the molten slag will be mainly through transfer into the cold water, whereas at high slag flows steam release takes place. An installation with a cold water circuit has a higher potential for a fast heat removal compared to a hot water circuit.

PLANT LAYOUTS
Cold runner design The cold runner is installed as a continuation of the hot runner, with a built-in blowing box at the front end. The blowing box is fully embedded in the cold runner which is installed below the hot runner end spout. The cold runner serves the purpose of guiding the water-slag/sand mixture to the receiving hopper and is equipped with a wear-resistant lining as the granulated slag sand is very abrasive. The heat flux of the molten slag requires some water spraying alongside of the cold runner at the front end.

Granulation with cold runner layout The granulation process starts when the granulation water comes into contact with the molten slag (see Figure 7). The slag flow breaks up into lamellas and filaments, then into droplets. Only part of the slag is granulated on the way through the cold runner to the receiving hopper, but is likely to be completed after hitting the impact plate inside the receiving hopper and falling into the receiving hopper. With this design, only part of the water flow is directly used for the granulation process as part is used to cool the wear protection plates alongside of the cold runner front end.

Granulation basin design The granulation basin located below the hot runner spout end consists of a water basin which can vary in size depending on the plant layout (see Figure 8). The basin, filled with water to a defined level, permits water additional to the circuit water to be available for granulation. Thus granulation, being sustained by the turbulent water bath, takes place much faster when compared to the cold runner layout. The layout allows the design of water circuits with less water flow, but nevertheless having more water available for granulation, without compromising on safety. The basin can easily be protected against wear, which in the case of the cold runner, needs high maintenance. The basin layout has the potential to reduce the amount of...
total installation below ground level. The molten slag falls from the hot runner and hits the granulation water jets of the blowing box. The impact point of the slag stream and the granulation water jets is located just above the water level in the granulation basin. The granulation water breaks up the slag stream and helps to push the slag into the granulation basin below the water level. The heat exchange between the slag droplets and the water is now not only given by the water jets from the blowing box, but also from the water surrounding and enclosing each droplet in the water basin. The water jets hitting the water surface inside the granulation basin contribute to creating turbulent conditions in the basin and help to promote a faster cooling effect of the slag droplets into sand particles. Although this design has a reduced water to slag ratio, more water volume is available for granulation, i.e., water volume in the basin and the water flow at the blowing box. The granulation process takes place faster and thus the solidification time is reduced.

An overview of the particle size distribution of the sand quality generated via the different installation layouts is shown in Figure 9.

EMISSION OF SULPHUR COMPOUNDS
Blast furnace slag has a sulphur content of around 1–2 wt.%. The major sulphur compound is calcium sulphide (CaS) and during granulation gaseous sulphur compounds are generated and emitted. These consist mainly of hydrogen sulphide (H₂S) and sulphur dioxide (SO₂) according to the following simplified reaction equations:

\[ \text{CaS} + \text{H}_2\text{O} \rightarrow \text{H}_2\text{S} + \text{CaO} \]  
\[ \text{CaS} + \frac{3}{2} \text{O}_2 \rightarrow \text{SO}_2 + \text{CaO} \]

These reactions occur mainly at temperatures above 1,100°C and are illustrated in Figure 10. As long as the slag droplet is liquid, CaS is sufficiently available to feed the slag/steam surface. The supply of sulphur to the contact surface takes place through flow and diffusion, however, once the surface of the droplet hardens (skin), the transfer of sulphur takes place only through diffusion. Since the coefficient for solid diffusion is much less than for liquids (10⁻⁴ versus 10⁻⁸), further supply of sulphur from the liquid to the surface is stopped. Once a hard skin has been formed, only sulphur contained in the skin reacts with the steam. As the steam is the product of H₂O vapour and gaseous

The following table shows the emissions comparison:

<table>
<thead>
<tr>
<th></th>
<th>Hot water system</th>
<th>Cold water system</th>
<th>Cold water system with steam condensation (new design*)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stack</td>
<td>Stack</td>
<td>Conditioning tower</td>
</tr>
<tr>
<td>H₂S mg/Nm³</td>
<td>100–800</td>
<td>30–300</td>
<td>–</td>
</tr>
<tr>
<td>SO₂ mg/Nm³</td>
<td>50–200</td>
<td>50–500</td>
<td>–</td>
</tr>
</tbody>
</table>

(*) Within limits as defined by TA LUFT
(H₂S concentration <= 3 mg/m³, SO₂ concentration <= 350 mg/m³)

Data are average figures.
sulphur compounds (H₂S, SO₂) in contact with the surrounding granulation water the sulphur compounds will go into solution according to the relevant partial pressures. The prevailing conditions like water temperature, pH value of water and solubility of H₂S and SO₂ define the amount of sulphur compounds released via the steam and emitted to the atmosphere or bound with CaO contained in the water.

A comparative table of emissions between hot water granulation, cold water granulation with cold runner design and cold granulation with granulation basin including steam condensation is shown in Table 1. The data are average figures from various installations.

STEAM CONDENSATION SYSTEM
(see Figure 11)
Emissions cause potential odour and corrosion problems. The gaseous sulphur compounds emitted depend strongly on the type of granulation system, slag flow rate, slag/water ratio and on the granulation water temperature. Since the solubilities of H₂S and SO₂ decrease with rising water temperature, lower gaseous sulphur compound emissions are observed in cold than hot water systems. As a result of the environmental requirement specified for different countries, the plant layout for a cold water granulation system with steam condensation has become the preferred solution for integrated steel plants situated in urban areas. In order to further reduce the gaseous sulphur compound emissions, the generated steam released inside of the granulation basin is routed into a condensation tower.

CONDENSATION TOWER DESIGN –
CO-CURRENT FLOW/ COUNTER CURRENT FLOW
The initial design of the condensation tower is co-current flow. The tower consists of an outer shell and an inner condensation chamber with by-pass openings (see Figure 12). The steam flows up the annular opening between the outer shell and the inner condensation chamber. At the top the steam is introduced into the condensation chamber by means of the draft generated by the spray nozzles injecting the condensation water.

The water jets from the blowing box, also acting as injectors, introduce air into the condensation system and the two phase condensation system (steam/water) converts into a three-phase system, having air as a third medium. Since air cannot be condensed, the condensation system gets disturbed if excess air enters the system (herein after called ‘false air’).

In the case of the co-current flow design, false air is sucked into the annular opening, the velocity inside the annular opening increases, reaching figures of
The counter-current flow condensation design consists of a condensation chamber (tower) of larger diameter than for the co-current design (see Figure 13). The water is sprayed on the up-coming steam counter-current to the steam flow direction. Due to the lower steam ascending velocity and virtually no false air in the system (design with granulation basin), the performance of the condensation tower has been improved.

Spray nozzles The thermal exchange of steam condensation has been further improved by the generation of very fine condensation water droplets thus increasing the water reaction surface for the thermal exchange while condensing. This was achieved through introduction of spray nozzles which generate very fine droplets ($d_\text{w} \sim 660\ \mu\text{m}$).

CONCLUSIONS

The first step to reduce emissions is associated with the implementation of a cold-water circuit granulation system. The introduction of the granulation basin along with the counter-current flow condensation system has become a must if severe environmental constraints are imposed by the local authorities. The granulation basin allows the introduction of a sealing hood as a barrier to false air, besides generating additional benefits such as higher resistance to wear, reduced height design and reduced pipe investment due to less water flow in the circuits. The implementation of counter-current flow condensation permits better thermal exchange between the water sprays and the ascending steam. The introduction of the spray nozzles generating very fine sprays contribute to further improve the thermal heat transfer, and therefore the condensation tower height can be reduced. The introduction of both granulation basin and counter-current flow condensation has brought customer and their environmental authorities to no longer consider the condensation tower as an emission source.