BOF gas cleaning system upgrades for increased efficiency and off-gas quality

Danieli Linz Technology, specialists in BOF steelmaking and Danieli Corus, one of the market leaders in blast furnace technology, have teamed up to accelerate developments in gas cleaning for BOF plants. A design comprising an improved scrubber based on that widely applied in the blast furnace, plus an improved mist eliminator, offers significant advantages over conventional designs is described.

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D anieli entered the steel converter business in 2011 with the inception of a new, dedicated business unit, Danieli Linz. Activities ramped up rapidly in this highly demanding and conservative area of steelmaking.

Danieli Corus is already very successful in blast furnace ironmaking as well as niche markets for oxygen steelmaking. For instance, it is market leader in the supply of sublance systems, together with one of the most advanced level 2 systems. With the integration of Danieli Linz into the Danieli Corus group, a great opportunity has emerged for further developing equipment for oxygen steelmaking. Additionally, this is the first time that engineers of an equipment supplier of two disciplines (ironmaking and steelmaking) are working together in a single location. This opens up completely new opportunities for the joint development of tools and software for optimising both blast furnace and converter processes in terms of cost and resource savings.

An article on BOF design, also from this business unit, is on page 36.

In the area of converter off-gas capture, cooling and cleaning, current company activities are focused on maximising the hood design coverage at a minimum maintenance requirement. The completed redevelopment of off-gas scrubber and mist eliminator designs are discussed in this article.

WASTE GAS CLEANING – THE BACKGROUND
As BOF steelmaking is a batch process, the conditions and composition of the gas produced vary from the start to the end of a blow. When oxygen is blown, large amounts of high temperature (~1,750°C), dust-laden (70-200g/Nm³) gas are produced. This gas has to be cooled and cleaned (down to a dust level below 20mg/Nm³) before further processing. Process equipment is installed above and alongside the converter mouth to enable energy recovery as well as collection and recycling of dust.

For dust removal, either a wet or a dry type process is applied. Currently, more than 90% of the de-dusting systems deployed around the world are of the wet type. Dry systems employ electrostatic precipitators that can achieve a dust content below 10mg/Nm³. In wet systems, the gas is cleaned in venturi scrubbers followed by a mist eliminator, resulting in dust content below 20mg/Nm³. However, ESPs have a large footprint and operational disadvantages connected to preventing explosions.

The pressure drop required for gas cleaning is generated by an induced draft fan (IDF), which transports the gas through the cooling and cleaning processes. Typically, the cleaned gas with high calorific value (CO >30vol%) is stored in a gasholder before further processing, while the cleaned gas with low calorific value is flared.

In this article, the focus is on the wet-type cleaning systems. The first process step is quenching the mixture of gas and dust with water, primarily to reduce the temperature, although it also removes the coarser dust particles from the gas and entrains these in the water system. Finer dust particles remain in the gas stream. In the second stage, the gas stream is forced through a ‘narrow gap’ scrubber where the fine dust particles become entrained in the scrubbing water stream. The collected waste water streams from both stages are sent to thickener/flocculation tanks for settling and solids removal [1-3].

SCRUBBER DESIGN – VENTURI-BASED SCRUBBERS
Currently the venturi-based scrubber most commonly used in BOF gas cleaning is the ‘flap venturi’ scrubber, commonly known as the Baumco™ type. A typical example is shown in Figure 1 showing the key stages. The flaps are positioned in the adjustable throats.
TYPICAL ISSUES WITH FLAP VENTURI SCRUBBERS
Although flap venturi scrubbers are widely used, some disadvantages can be identified, including:
- Less efficient mixing of the gas and water flows in certain areas in the system, resulting in less efficient scrubbing
- Internal blockages can occur because dust deposits in internal channels and the resulting increase in pressure drop is detrimental to system performance
- The venturi throat is of a rather complicated design, with a substantial number of moveable parts
- Blockages of the nozzles used for water injection in the venturi throat occur, which results in a loss of scrubber efficiency; consequently, nozzles require regular maintenance (see Figure 2a)
- Cleaning rakes are used to address the blockages, but these are damaged frequently and need to be replaced/repaiired (see Figure 2b)
- Clogging of the scrubber outlet has a detrimental effect on the efficiency of the quencher pumps and accelerates pump wear
- Several internal 180° turns of the gas cause friction losses that do not contribute to the cleaning efficiency.

IMPROVED SCRUBBER DESIGN
Danieli Corus has identified and implemented an improved design, called an RS Element scrubber, to address stricter dust removal requirements and improve operational efficiency and costs.

Scrubber structure
An RS Element scrubber is a two-stage single tower construction as illustrated in Figure 3. Stage 1 is the pre-scrubbing/cooling section located in the upper half of the scrubber vessel. It is an open design furnished with centrally arranged non-clogging type spray nozzles. Stage 2, containing the RS Elements and RS Element sprays, is located in the lower part of the scrubber vessel downstream of the pre-scrubbing/cooling section. Water consumption can be minimised by incorporating a water recycling system which recirculates stage 2 water to the top spray nozzles in stage 1. A hydraulic control system, which is used to position the RS Cone Elements and (sometimes) the water control valves, is also part of stage 2.

RS Element scrubbers
A recent development enabling greater dust removal, is the Annular Gap or RS Element scrubber (RS = Ring Slit = Annular Gap). Figure 4 (a and b) shows the basic differences between the two types.

RS Element scrubbers offer advantages that address many of the identified issues with Flap Venturi scrubbers:
- Optimised water and gas flow patterns resulting in a more efficient design
- A longer operating life since the design is more wear resistant
- Virtually maintenance-free, as proven in many blast furnace applications
- Lower operational costs when compared to a Flap Venturi Scrubber system with the same capital expenditure costs
- Straight flow pattern with minimal gas turns
The RS Element scrubber contains an RS Element that...
is axially adjustable and forms an annular gap towards the conical outer shell. The water that is sprayed into the collar zone at low gas velocity flows through the guide pipe into the annular gap, maintaining a uniform water distribution over the annular gap cross-section. Gas and water are forced through the annular gap creating high turbulence and intensive interaction, thus, all gas streams and dust particulates are thoroughly wetted to provide maximum gas cleaning. To obtain longevity, the main parts of the RS Element, such as the conical outer shell and the male conical body, are manufactured using highly wear and corrosion resistant materials.

The pressure drop between the inlet and outlet of the RS Element predominantly determines the dust removal capacity and is shown in Figure 5. The graph shows that in order to achieve a gas dust content below 20mg/Nm³ a pressure drop above 150mbar is required.

Water injection nozzles In the scrubber, the raw gas coming from the converter is conditioned by contacting it with water sprays coming from a series of nozzles positioned in a vertical arrangement alongside the shell of the scrubber, as shown in Figure 3. Each nozzle is installed on a spray arm that goes through the scrubber shell to be connected to the water supply. By contact with water the gas is cooled and the majority of the dust is wetted, thus enabling it to mix with the water.

Although robust, one of the areas enabling improvement is in the water distribution system, i.e., the number and placement of the nozzles and spray lances. More specifically, by improving the atomisation of the water droplets, the available surface area of the water droplets for contact with gas and dust particles will increase. This can be achieved by employing a spiral type of spray head compared to an open type, shown in Figure 6 (a and b), distributed via three spray arms installed in a 2-3-2 pattern at the same height (and only spraying downward).

The benefits of placing seven spray nozzles at one level can be summarised as follows:
- The droplet size becomes much smaller, e.g., a reduction of the sauter mean droplet diameter from 2,500µm for the hollow cone spray to 1,250µm for the spiral spray type) which accelerates evaporation
- An improvement in mixing and distribution of gas and droplets
- The increased number of smaller droplets and their improved distribution greatly improves the wetting of particles
- Spiral type nozzles can withstand high dust loads and saturated water flows

As can be seen in Figure 3, spray arms are still distributed over the column but the required number of entry points is reduced significantly. In the first layer, the aim is to pre-cool and saturate the gas with water. The aim of the following two layers is wetting of the dust (to capture coarser particles) and further cooling of the gas to approximately 55-65°C.

Apart from the advantages mentioned above, the use of spiral type spray nozzles offers some additional benefits:
- These nozzles are less susceptible to clogging than the open type: spiral spray nozzles were originally designed for use in flue gas desulphurisation units for the injection of saturated slurries in a gas stream

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**Fig 3** Schematic of RS Element scrubber

**Fig 4** (a) Annular gap scrubber (b) flap venturi scrubber
The spray patterns will overlap, so improving overall scrubber performance since the presence of areas with less water coverage will become highly unlikely.

Application of multiple spray nozzles in the scrubbers increases reliability compared to conventional scrubber designs.

WATER REMOVAL
Before the cleaned gas and captured dust can be efficiently used, as much of the water as possible used in the scrubbing process must be removed. This is done in a variety of ways:

- Initial droplet separation inside the scrubber – typically sharp turns of gas flow/axial rotation
- External mechanical droplet separation – typically a vertical axial mist eliminator
- Wet electrostatic precipitators – dropout and removal on plates.

Most BOF shops use a mist eliminator, the most popular of which is an axial cyclone type where the gas and droplets are brought into a spinning motion with a number of guide vanes, resulting in separation of the droplets from the BOF gas. The axial cyclone type mist eliminator is suitable for the removal of larger droplets but is less efficient in the removal of the finer droplets.

Unfortunately, due to the pressure drop over the annular gap element in this design, a large amount of fine droplets is produced and it is estimated that the free moisture content after the annular gap elements could be as high as 250g/Nm³. In that respect, the axial mist eliminator is doing quite well taking into account that the outlet free moisture content is in the range of 4-5g/Nm³ – an efficiency of 99.6%.

Despite all of these techniques, large amounts of liquid water are found at the ID fans, gas holder and the flare stack. Some of this water originates from sprays used at the ID fans and condensed water in the duct work but, given the pollution found in the water drains, it is also clear that the current mist eliminators do not work as efficiently as they should, resulting in dust emissions at the flare stack and the collection of dust laden water from condensate traps.

The intense contact of dust and water in the Annular Gap scrubber creates droplets that also contain dust. In current designs, the remaining 5g/Nm³ of water droplets after the mist eliminator will be carried towards the flare, the gas holder and eventually the burners of the BOF gas fired boilers. When BOF gas is burned this will create a dust emission.

The BAT BREF report [4] shows that limits of 5-10mg/Nm³ can be achieved with a venturi type scrubber, but it should be noted that these low values can only be
obtained if the dust containing droplets can be removed efficiently.

Due to the intermittent operation of converters, a gas holder is a necessity to allow constant BOF gas flow to the end consumers. However, due to the holdup time in the gas holders, the dust-containing droplets will settle inside the gas holder, creating deposits that need to be cleaned regularly. The same applies for the water collected in siphons from the gas supply lines to the gas holder. The water and sludge removed need to be collected and treated due to their chemical composition.

**IMPROVED MIST ELIMINATOR DESIGN**

In power generation and the oil and gas industries, a droplet content of 5g/Nm³ is considered too high and so a more efficient type of mist eliminator was developed. This is capable of achieving a droplet content below 0.1g/Nm³. An example is shown in Figure 7.

Danieli Corus has teamed up with Sulzer, a leading OEM for separation systems in the oil and gas industry, to develop a mist eliminator based on this design which is suitable for the removal of droplets from converter gas downstream of the annular gap scrubber.

**NEW MIST ELIMINATOR DESIGN**

The newly developed mist eliminator [5] is based on a three-step approach for droplet removal:

1. Shell Schoepentoeter™ at the inlet
2. Sulzer Mellachevron™ mist eliminator
3. Sulzer Knitmesh™ & Mellachevron™

The first step of the design is the diverter inlet, the Shell Schoepentoeter™, that feeds and distributes the BOF gas into the column while removing a large portion of the coarse droplets. The second step consists of a vane type Chevron Mist Eliminator, the Sulzer Mellachevron™, which consists of vertically positioned vanes that separate droplets using their inertia. The finest droplets, which pass the Chevron Mist Eliminator, need to be coagulated before they can be separated; the third step of the removal process. This coagulation is achieved by the Sulzer Knitmesh™ that is operated in a flooded mode, creating a horizontal droplet flow. The larger droplets that are created are collected in another Mellachevron™ positioned after the Knitmesh™. The droplets from all steps are collected at the bottom of the vessel and returned to the wet scrubber. The design is shown in Figure 8. The working principles of Knitmesh are shown in Figure 9.

**Mist eliminator cleaning** A number of spray nozzles will clean the surface of the Mellachevron™ and Knitmesh™ parts of the mist eliminator to prevent clogging. This washing can be set on a regular interval or can be set on a differential pressure measurement. The wash water will be drained together with the collected droplets.

**BENEFITS**

As a result of the cooperation with Sulzer, there is now a patented mist eliminator design capable of achieving a droplet content below 0.1g/Nm³ in clean BOF gas, which equates to a removal efficiency of 99.96%. It also has a smaller footprint and similar CAPEX to conventional designs. This will lead to cleaner ducting, low dust emissions at the flare stack and BOF gas-fired boilers, trouble free ID fan operation and less maintenance and sludge arising at BOF gas holders.

**ALTERNATIVE MIST ELIMINATOR CONFIGURATION**

Where there a considerable distance between the scrubber and the ID fan an alternative design is available whereby droplet removal can be split into two separate units. These comprise a carryover mist eliminator near the scrubber...
A new mist eliminator design with a higher efficiency than the traditional axial type. Also, the application of an advanced, multi-stage mist eliminator design with proven track record in other industries is presented. The effective droplet separation further reduces particulate emissions and helps with operational problems and damages of Induced Draft fans. The elaborated design offers great advantages over conventional axial droplet-separators. The application of the improved mist eliminator that can lower the droplet content in the BOF gas to below 0.1g/Nm³ will lead to cleaner ducting, low dust emissions at the flare stack and BOF gas fired boilers, trouble free ID fan operation and less maintenance and sludge arising at BOF gas holders.

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REFERENCES

and a condensate mist eliminator near to the ID fan. This alternative line-up is summarised in Table 1.

The condensate mist eliminator consists of a Mellachevron™ and a Knitmesh™ and lowers the droplet concentration to below 0.1g/Nm³. At these low droplet concentrations, the ID fan will operate more stably and should experience less vibration. It is expected that no water wash will be required for the ID fan.

DESIGN SUMMARY
A schematic of a typical gas cleaning plant of the new design is shown in Figure 10. Design improvements are as follows:

- Application of an RS Element scrubber design based on wet scrubbing technology widely applied and proven in blast furnace ironmaking. The straight gas flow through wide passages avoids redirection and unwanted pressure drop. Water injection through quick exchangeable spiral type nozzles allows for less stringent water quality requirements at improved scrubbing performance including changes to the water dispersion patterns and their distribution throughout the scrubber tower. Application of special internal coatings reduces clogging and abrasion.

- A new mist eliminator design with a higher efficiency than the traditional axial type. Also, the application of an advanced, multi-stage mist eliminator design with proven track record in other industries is presented. The effective droplet separation further reduces particulate emissions and helps with operational problems and damages of Induced Draft fans. The elaborated design offers great advantages over conventional axial droplet-separators. The application of the improved mist eliminator that can lower the droplet content in the BOF gas to below 0.1g/Nm³ will lead to cleaner ducting, low dust emissions at the flare stack and BOF gas fired boilers, trouble free ID fan operation and less maintenance and sludge arising at BOF gas holders.

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