INNOVATIVE ENVIRONMENTAL SOLUTIONS FOR STEELMAKING[1]

Karl Jamek [2]
Peter Puschitz[2]

Abstract
Siemens VAI (SVAI) offers a wide range of Primary and Secondary waste gas cleaning solutions for the steelmaking industry. The main purpose of this article is to present the latest developments of it. Comparison between tradition solutions and our solutions will be done and main advantages pointed out as well. In the field of Dry-type Primary Waste Gas Treatment, an Electrostatic Precipitator technology is the most advanced environmental solution available. In the field of Wet-type Primary Waste Gas Treatment, SVAI successfully developed and implemented the innovative annular gap technology. Additionally, the high-temperature converter off-gas is used for generating steam in boiler-type cooling stack. In the field of Secondary Dedusting Systems, SVAI has made a cost-saving innovation with the development of static coolers. Finally, latest developments in electric arc furnace (EAF) dedusting are presented.
Key words: Electrostatic precipitator; Annular gap; Cooling stack; Static cooler; Forced draught cooler.

SOLUÇÕES INOVADORAS PARA TRATAMENTO DE GÁS PARA ACIARIAS Á OXIGÊNIO

Resumo
Siemens VAI (SVAI) oferece um vasto range de soluções de limpeza de gás para as plantas de aciaria. O propósito principal deste artigo é apresentar os últimos desenvolvimentos desta tecnologia. Comparações entre as soluções tradicionais serão feitas e as principais vantagens ressaltadas. No campo da solução de despoeiramento primário via seca, o precipitador eletrostático é a mais avançada solução. No campo da solução de despoeiramento primário via úmida, SVAI desenvolveu e implementou com sucesso a inovadora solução do tipo cone anular. Adicionalmente, as altas temperaturas do gás primário permitem a geração de vapor na chaminé refrigerada. No campo do despoeiramento secundário, SVAI têm feito uma solução inovadora e de custo reduzido, a partir do desenvolvimento de trocadores de calor estáticos. Finalmente os últimos desenvolvimentos em despoeiramento para fornos elétricos são apresentados.
Palavras-chave: Precipitador eletrostático; Lavador tipo cone; Chaminé refrigerada; Trocador de calor estático; Trocador de calor forçado.

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2 *Sales Head Engineer, Siemens VAI, Linz, Austria*

1 INTRODUCTION

The distinctive red dust cloud swirling into the atmosphere above an industrial site was the characteristic trademark of steelmaking plants in the past. For every ton of liquid steel tapped, between 15 and 20 kilograms of dust are generated. Thanks to major advances in offgas treatment and dedusting processes, environmental emissions from steelworks can be reduced today to levels previously thought to be unattainable and previously still visible stack plumes have been conducted to non visibility.
This article describes the scope and benefits of advanced offgas cooling and cleaning systems, including CO gas recovery. Siemens VAI provides integrated environmental solutions for oxygen and electric steelmaking. With these solutions, steel producers can fully meet all legal requirements in a cost- and energy-efficient manner. These solutions are available both for new dedusting systems as well as for the upgrading and modernization of existing steelmaking facilities.
The dry-type primary offgas treatment system based on electrostatic precipitator technology is the most advanced environmental solution available. In the field of wet-type primary offgas treatment, annular gap technology is considered to be the best technology available today. Special attention is placed on energy- and gas-recovery solutions. This allows the consumption of fossil fuels to be reduced, significantly reducing the energy costs in steelmaking and with a simultaneous reduction of air and water emissions.
In the field of secondary dedusting systems, advanced pulse-jet-filter technology is applied. This article also presents a cost-saving innovation, the application of absorption coolers, which significantly increase the efficiency and safety of secondary dedusting systems.
Finally, latest developments in electric arc furnace (EAF) dedusting are presented.

2 MATERIALS AND METHODS

2.1 Primary Offgas Cleaning and Recovery Systems for LD (BOF) Converters

In the oxygen-steelmaking process, large quantities of gas at temperatures up to 1,700 ℃ are emitted from the LD (BOF) converter s. These contain high concentrations of dust and carbon monoxide. Ambient air which is sucked into the converter gas stream through the converter mouth and the lowest part of the cooling stack (so-called skirt) contains oxygen for the combustion of the converter gas. Depending on the amount of ambient air, the combustion of the converter gas takes place under: Over stoichiometric conditions($n>1$);full combustion Stoichiometric conditions ($n = 1$) or Under-stoichiometric conditions ($n < 1$); suppressed combustion.
The combustible gases coming out of the converter are CO and H2. The blown oxygen reacts with the carbon of the hot metal, thereby forming CO gas. Low concentrations of H2 are formed from the pyrolysis of water, which is brought into the converter mainly with the added alloys, lime or scrap (humidity). The thermal energy of the hot converter gas can be largely recovered in a boiler-type cooling stack where steam is generated (approximately 70 kg/t of steel) for use in other applications. The converter offgas is cooled in this step to approximately 800–1,000 ℃.

2.1.1 Dry-type primary dedusting system (DDS)

Downstream of the cooling stack, the gas is cooled down further to around 200 ℃ in an evaporation cooler where water and steam are sprayed into the gas stream using special dual-flow nozzles. The coarse-dust fraction is removed from the offgas at this stage. The evaporation cooler is designed in such a way that the route and the retention time of the offgas will result in a completely dry dust discharge. The gas then passes through a round-type electrostatic precipitator (ESP) where the fine dust is electrically charged by means of discharge electrodes. It then migrates to oppositely charged collecting electrodes where it accumulates. At certain intervals, the dust is mechanically rapped from the collecting and discharge electrodes by a series of hammers. The fine dust accumulates at the bottom of the ESP from where it is removed by an extraction system. The figure 1 shows a plant configuration of this system.

Both the coarse dust from the evaporation cooler and fine dust from the ESP can then be briquetted at the briquetting plant followed by recycling to the steelmaking converters. This substitutes iron ore and scrap. As an option, the quantity of zinc in the fine dust can be determined with the use of a special laser device and, when the concentration is above a certain threshold, the zinc-rich dust portion can be extracted for subsequent use by external customers.

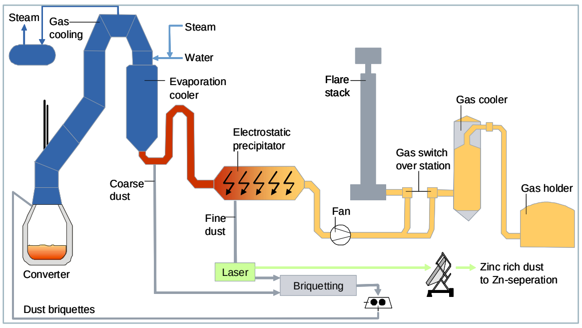

Figure 1. Typical plant configuration of a dry-type primary offgas treatment system for LD (BOF) converters.

The converter offgas is exhausted through the dedusting system with an axial induced-draft (ID) fan. Depending on the calorific value of the converter gas, the gas is either exhausted via a flare stack or guided to a gasholder for further use in the steel plant. DDS are distinguished by their high dedusting efficiency with a clean gas dust content down to 10 mg/Nm3.

2.1.2 Gas recovery system for DDS

At the start of blowing, the oxygen content in the offgas will decrease steadily until zero, whereas the CO and CO2 concentration will increase. In the first minutes of blowing, the plant is operated with a high post-combustion rate which is achieved with an opened skirt and high ID fan speed. This is important for producing a high concentration of inert CO2 gas to purge the offgas ducts and thus increase process safety. In the main decarburization phase, the plant is operated with suppressed combustion for maximizing the production of high-calorific CO gas. On the one hand, this is achieved by closing the skirt and thus reducing the ingress of air in the gap between converter mouth and cooling stack. On the other hand, the ID fan speed is continuously adjusted in such a way to keep the gas pressure in the converter hood slightly below zero. As shown in figure2, in this blowing phase, the CO content will rise up to about 70% and the CO2 content will go down to around 15%.

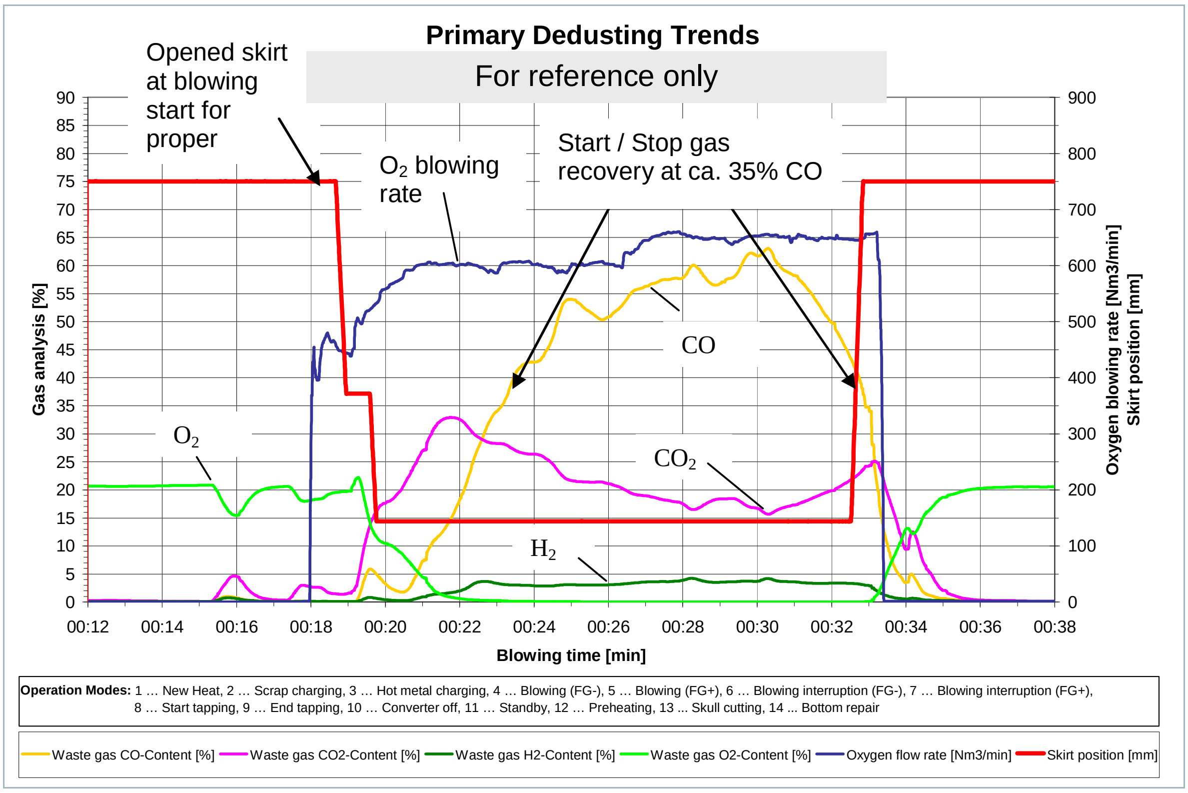

Figure 2. Typical converter gas trend for suppressed combustion.

If the CO content of the cleaned converter gas is above a certain concentration, as measured by the gas analysis unit, it can be recovered. In the gas switchover station, the CO-rich gas is routed to a multi-nozzle gas cooler where it is cooled down to below 70 ℃ by means of water injected in the count er-flow direction. The gas is then stored in a gasholder for subsequent use within a steel plant, such as for heating applications or for the generation of electricity. CO gas recovery is typically in the range of 70–100 Nm3 converter gas per ton of produced steel. This, of course, substitutes fossil fuels and significantly reduces energy costs and overall CO2 emissions. For the gas recovery system, strict requirements are defined for ensuring high safety standards and a high degree of reliability. This is reflected by the use of a special hydraulic unit in combination with advanced automation solutions.

2.1.3 Wet-type primary dedusting system (WDS)

Offgas cleaning in oxygen steelmaking plants was performed for the first time applying wet-type dedusting systems. Many steel plants today still operate with wet-type systems. Coarse dust in the offgas stream is first precipitated in the quencher by water injections. In a second step, fine dust is removed in a specially designed scrubbing unit where a highly turbulent mixing of gas and scrubbing water takes place.

Cone-type scrubbers with annular gap technology (shown in figure 3) are the best available technology in the field of wet-type dedusting. These are characterized by their simple design, high dedusting efficiency (down to 30 mg dust/Nm3), low energy requirements and low investments costs. If requested, rectangular venturi-scrubbers are also available. Otherwise, gas exhaustion through the system with a radial ID fan and CO gas recovery is performed similar as in DDS plants.

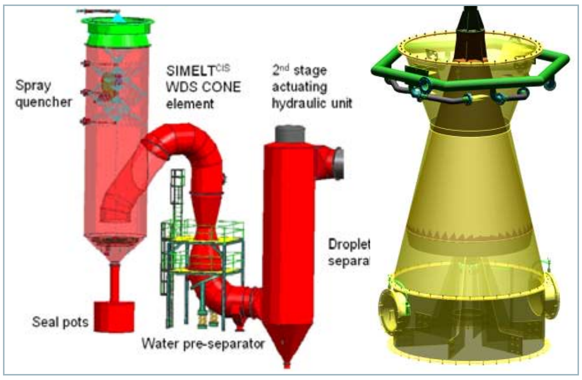

Figure 3. Typical plant configuration of a wet-type dedusting system.

2.2 Secondary Waste-gas Treatment Systems

In the steel production process, during the charging of hot metal and scrap into the converter, and during the tapping of liquid steel the major fume emissions are occurring. Considerable quantities of dust and fumes are released to the surroundings primarily from hot-metal reladling stations, hot-metal desulfurization and deslagging stations, Other sources of internal plant emissions include the secondary metallurgical facilities, such as ladle furnace or ladle-refining stations, as well as the material-handling systems for alloys, additives and fluxes. To combat this problem and to provide more acceptable working conditions for operating personnel, advanced solutions and systems are available that efficiently capture and clean secondary emissions arising within a steelmaking plant.
Dust-laden fumes are collected directly at their emission source and are evacuated by powerful fans. From the various emission points, suction ducts are guiding the fumes to a central bag filter station where the dust is filtered and precipitated before the cleaned gas with a dust content less than ten milligrams per standard cubic meter is released to the atmosphere. With pulse-jet cleaning, the filter cake accumulated on the surface of the bag filter is periodically dislodged by a reverse jet of air. The dust is removed from the system and conveyed to intermediate storage silos for subsequent recycling or disposal.
Radial ID fans located downstream of the bag filter provide the required draft to efficiently evacuate the fumes. The entire secondary dedusting system functions completely automatically and is coordinated with the converter charging and tapping cycles. The volume of the offgas emitted from the stack as well as the dust content is measured at the stack exit to assure that the bag filter system is working properly and that the prescribed dust emission levels are met. [1]

2.2.1 Installation of absorption coolers for increasing the performance

Siemens VAI has recently introduced an innovative absorption cooler system installed in the converter-charging suction ducts. Up until previously, the design rule for the evacuation performance of secondary dedusting systems was orientated to the converter tapping size only. Considering the limitations with respect to the filter inlet temperature, the hot charging gases have to be cooled down to a level so that the filter bags are not damaged by overheating.
Typically, the gas entering the pulse-jet filter may not exceed a temperature of 130 ℃. This is achieved by mixing the hot charging gases with fumes coming from “cold” evacuation sources, and also by activating the so-called “emergency cooling

air flaps" located at the pulse jet filter inlet as a source for cold ambient air for mixing. This led to a design evacuation flow for the secondary offgas which is – within in a certain range – proportional to the converter tapping size. Secondary dedusting systems following this simple approach based on the converter tapping size only (applying the method of "cooling by mixing") are classified as "conventional design."
Experience shows that for the thermal design and flow balancing of secondary dedusting systems the term "thermal power Pth" is the suitable physical magnitude for balancing,[2] which is defined as follows:

- The air and fumes have a certain specific heat: cp [kJ/Nm³, ℃] or cp [BTU/cf (s.c.), ℉].
- The temperature increase ΔT [℃], [℉] of the sucked offgas with an ambient temperature to the maximum filter inlet temperature multiplied with the specific heat "cp" results in the specific thermal energy content "Espec" of the gas i.e., Espec = ΔT x cp.
- The actual volumetric secondary offgas flow VA [m³/h] is converted by means of the fume temperature (and pressure) to a certain offgas mass flow VM [Nm³/h] or VM [cfm (s.c.)].
- The specific thermal energy content "Espec" of the gas multiplied with the mass flow results in the total energy flow, equivalent to thermal power "Pth" expressed in kilowatt [kW]or megawatt [MW], or [BTU/h] respectively, i.e., Espec x VM = Pth.
  It has to be noted that the converter emits thermal power. The scrap usually contains combustibles, mostly in the form of hydrocarbons such as paint, plastics, grease and oil, etc. as well as galvanized metals. During the charging of hot metal into the converter onto the scrap, energy is brought into the system.

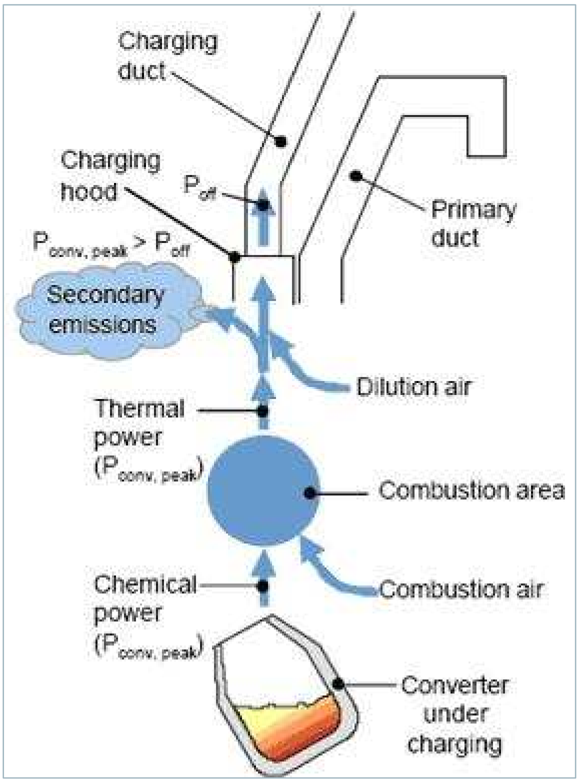

Figure 4. Thermal power emission of converter during hot metal charging.

As illustrated in figure 4 Zinc or tin is vaporized, the hydrocarbons are heated up, but they cannot combust due to the lack of combustion air inside the converter. Therefore, they form pyrolysis gases (such as CO, H2 and CH4 compounds) which, together with the vapors of Zn or Sn ("combustible gases"),[3] exit the converter carrying the energy in a chemical phase.

The converter emits a continuous flow of combustible gases; depending on its composition, the gas has a certain specific heating value. Gas flow and heating value are forming a magnitude equivalent to chemical power Pth. These gases come into contact with the oxygen-bearing ambient air and combust. The chemical energy converts to thermal energy and the permanent gas flow creates the thermal power emission of the converter (Pconv).

For the design of the secondary offgas system with respect to the cooling capacity (Poff), the maximum thermal power emission of the converter (Pconv,peak) is the key design factor. Only in the case when the value for Poff is higher than the value for Pconv,peak is the dedusting system able to absorb and remove the thermal power emission of the converter. In cases not fulfilling this criterion, the charging hood cannot remove all the fumes and secondary emissions accumulate in the charging hood, leading to fugitive secondary emissions. The buoyancy of the hot combustion area also sucks dilution air into the combustion zone, increasing the total gas volume. In any case, excess combustion air is required for avoiding incomplete combustion which could lead to dangerous explosive gas mixtures[4].

During the past 10–15 years, the energy content in the scrap has increased steadily and rapidly. On the one hand, clean return scrap continually decreased inside the steel production. On the other hand, outside scrap in the form of metal cuttings, domestic scrap and also an increased number of scrapped car bodies accounted for an increased energy input into the charge. This type of scrap contains 2 to 4 kg (4 to 8 lb) of combustibles per ton scrap.

An example highlights the situation in steel mills, which are increasingly encountering problems in connection with thermally overloaded offgas systems:

- Scrap weight of 50 tons (55 sh tons) for charging and a content of combustibles of 3.0 kg/t (7 lb/sh ton); the total weight of combustibles in the scrap chute amounts to 150 kg (330 lb)[5].
- The energy content of this quantity of combustibles compared to oil shows an energy equivalent of 120 kg (264 lb) oil or 150 liters (40 gal) oil – nearly one barrel of oil.
- The burning of this energy in less than one minute results in the release of 4,800 MJ (4.5 x 106 BTU), leading to an average thermal power emission of 4,800/60 = 80 MW (270 x 106 BTU/h)

Under these circumstances, conventional secondary offgas systems are normally overloaded. Starting in 2003, Siemens VAI improved the design of secondary dedusting systems:

- By quantifying and qualifying thermal power emissions (use of power flow diagrams)
- By applying high-performance cooling capabilities to cover the difference between the converter power emission and the cooling capability of the dedusting plants under conventional condition.
- By integrating thermal power emission-control systems to protect the plant against thermal overload (safety issue)
- By reducing the flow resistance in the duct systems to optimize the gas flow using CFD-calculation tools.

Figure 5 shows a typical diagram with absorption coolers.

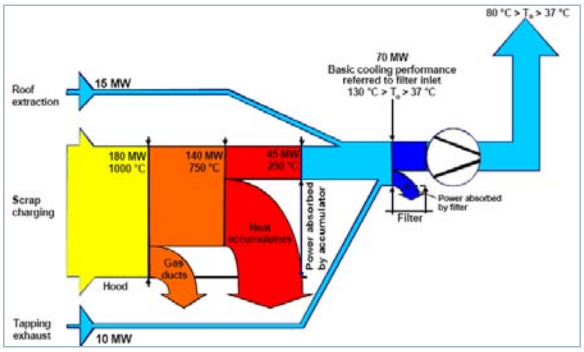

Figure 5. Power flow diagram for absorption coolers.

As can be seen in Figure 6, the absorption coolers absorb the heat released during hot metal charging and thereby reduce the gas temperature significantly. In the charging hood, temperature peaks of 600 -1000 C are measured during hot metal charging. However, after passing through the coolers, the gas temperature is reduced down to approximately 100 C.

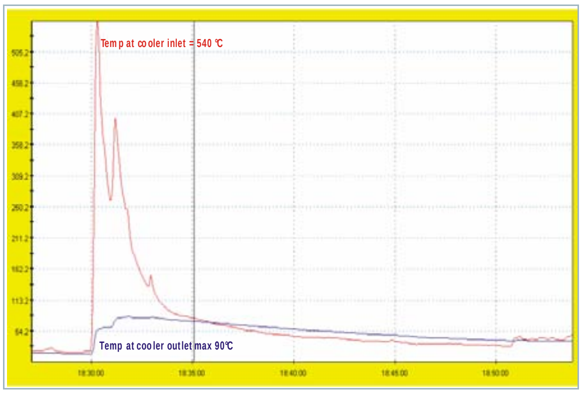

Figure 6. Typical temperature profile of absorption coolers.

2.3 Advanced Offgas Treatment Solutions for Electric Arc Furnaces

While EAF emission limits have never been so strict, the portion of metallic- and plastic-contaminated steels in the furnace charge continues to increase. This, compounded by the urgency to slash costs, does not make life easy for electric steelmakers. Environmental regulations governing EAF emissions of dust, volatile organic compounds (e.g., dioxins and furans), heavy metals and other hazardous materials are becoming progressively stricter. For example, at many production sites, legislation is already demanding that the dust content of the cleaned offgas be less than five mg/Nm3, and that dioxin be reduced to 0.1 nanograms (i.e., one ten-billionth or 1/10,000,000,000 of a gram) per Nm3. Furthermore, dust-disposal and -dumping costs are becoming prohibitive, calling for an improved optimization of the EAF process in addition to effective recycling solutions to minimize the generation and emission of dust.

The evacuated primary offgas from EAF melting operations first passes through a drop-out box where the coarse dust is removed. If required, the offgas can be post-combusted in a refractory-lined chamber to neutralize volatile gases. Cooling of the offgas down to less than 600°C then takes place in a water-cooled hot-gas line, which significantly reduces the volume of the offgas. As an option, the waste heat can be utilized to produce hot water and also saturated steam for various applications within the steel mill (e.g., for heating purposes or vacuum-degassing operations).

In a second cooling step, the primary offgas temperature is then rapidly lowered to between 200 and 250 C in a plate-type forced-draught cooler(figure 7) to minimize the reformation of harmful dioxins or furans (de novo synthesis). The type of forced draught cooler has been changed from pipe type to plate type. The pipe-type cooler has a high risk of getting plugged with dust in major pipe sections. Dust passing inside the pipes adheres to the inner wall and the dust settlements cannot fall down due to the arch effect. As a consequence, the roughness and the pressure drop of singular pipes is increasing leading to lower flow velocities and even increased dust settlements inside the pipes, which can lead to a total plugging and loss in heat transfer area. Cleaning is very difficult. Therefore Siemens VAI supplies only coolers of plate type since these coolers require low maintenance only:

No cleaning required (the flat cooling surfaces are allowing settlements braking off due to thermal expansion movements of the cooling plates and to fall down to the hopper)

No stuffing boxes which have to be maintained by retightening

Secondary offgas and dust emissions from the EAF area itself, from the hot-metal reladling station, canopy hood, slag-skimming station, secondary- metallurgical facilities as well as from material handling are then mixed with the primary offgas stream for common dedusting in pulse-jet-type bag filters. The offgas from the primary and secondary emission sources are exhausted through the entire system by means of powerful radial ID fans.

The dust that is removed from the offgas stream is transported to storage silos by a conveying system. After pelletizing or briquetting, it can be recycled to the steelmaking process. With repeated recycling sequences, especially when zinc-bearing scrap from cars and other coated steel products are charged to the furnace, the zinc content of the dust gradually increases, which may lead to possible metallurgical and system problems. When the zinc content of the dust exceeds a certain threshold level, as determined by an on-line, laser-based zinc-measuring system, this dust can be removed from the system and sold to the zinc industry. The dust content of the clean gas exiting the stack is typically below ten mg/Nm3, if required, less than five mg/Nm3. EAF offgas treatment and dedusting systems are available for all EAF sizes. Fume-suction capacities typically vary between one and three million actual m3/h.

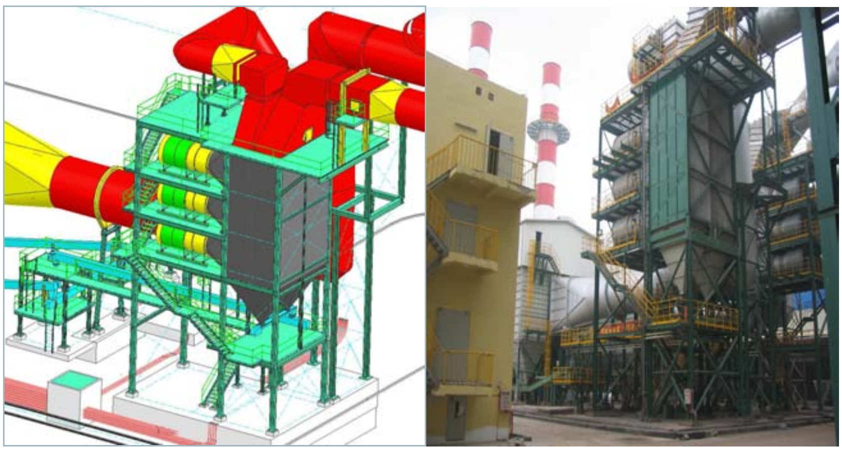

Figure 7. A 19-MW forced draught cooler in 3-D design and after installation.

3 RESULTS AND DISCUSSION

3.1 Comparison of Dry- and Wet-type Primary Offgas Ceaning and Recovery Systems

Investment costs for wet-type dedusting systems are only about 70 percent of those of DDS plants. However, because a high differential gas pressure must be maintained in wet-type systems to ensure efficient gas cleaning, this results in a higher electrical energy consumption of the ID fan. In comparison with WDS plants, dry-type systems do not generate sludge which must be treated, dried or otherwise disposed of. This dispenses with the need for a slurry-water-treatment plant. The dust from DDS plants can be briquetted and recycled to the steelmaking process. These process-inherent features of DDS installations significantly reduce operational costs. Furthermore, the higher dedusting efficiency fully meets international legislation with respect to converter emissions, including the stricter values anticipated for the future. For these and other reasons, dry-type systems with recycling solutions generally become more economical than wet-type systems within a period of about three years following plant start-up (European basis).

Table 1. Main features and achievable results of primary offgas treatment systems at a glance

General	Dry type	Wet type
Converter size	70–350 t	
Primary gas volume flow	Typically about 70,000 Nm^3/h dry (for 120-t converters) to about 200,000 Nm^3/h dry (for 350-t converters)	
Mode of operation	Suppressed combustion post-combustion rate of about 10%	
Type of cooling stack	boiler-type cooling stack with steam generation	
Coarse-dust cleaning	Evaporation cooler	Quencher
Fine-dust cleaning	Electrostatic precipitator	Scrubber (annular gap or venturi)
Dust recycling	Possible	Possible after sludge separation and drying
Type of ID fans	Low-pressure axial ID fan (about 6–8 kPa total pressure increase)	High-pressure radial ID fan (about 20–25 kPa total pressure increase)
Energy requirements	about 3 kWh/t steel	about 6 kWh/t steel
Results	Dry type	Wet type
Steam generation	About 70 kg/t steel	
Steam condition	Saturated (typically 12–15 bar g after pressure-reducing station)	
Gas recovery	Typically 70–100 Nm^3 converter gas/t steel	
Temperature of recovered gas	Typically 55–70℃ depending on gas-cooler design	Typically 70℃
Clean-gas dust content	Down to 10 mg/Nm^3	Down to 30 mg/Nm^3

3.2 Results – Impact of Absorption Coolers for Secondary Dedusting Systems on Plant Performance

With the application of absorption coolers the following advantages can be achieved:
Operational and safety benefits:

- Emergency cooling air is not required, therefore a high gas throughput remains
- Reduced fume emissions at the charging hood
- No spark arrestors are required to protect the filter bags from sparks and smoldering dust (temperature of hot particles is already reduced to a safe level)
- In combination with the charging power-control system there is no explosion risk in the secondary dedusting system since under-stoichiometric combustion conditions are avoided.

Commercial benefits:

- Shorter hot metal pouring times
- With less contaminated scrap the fastest pouring speed can be applied (pouring times less than 40 seconds).
- This allows more heats to be produced on a daily basis.
- Cheaper scrap usually with a higher content of impurities can be charged to the converter without the risk of thermal overloading of the system.
- The evacuation capacity and cooling performance of new and existing plants can be increased at relatively low investment costs.
- 1 MW (or 1x106 BTU/h) cooling capability of absorption coolers substitutes approx. 20,000 m3/h (3,500 cfm (a.c.)) of cooling air for “cooling by mixing” purposes.

Figure 8 shows the power removal capacity of secondary offgas systems with a conventional design and with the installation of absorption coolers. The respective arrows show the increased cooling capacity thanks to the application of absorption coolers.

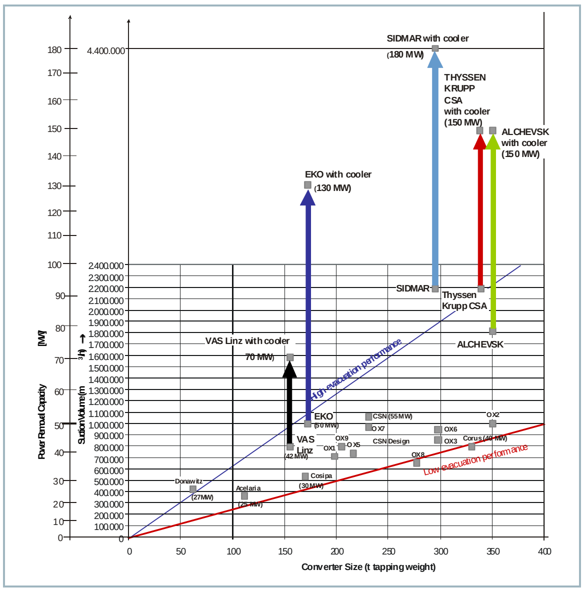

Figure 8. Effect of absorption coolers and power removal capacities.

4 CONCLUSIONS

This paper provides an overview of future-oriented technologies from Siemens VAI for the efficient extraction and cleaning of converter offgas and secondary fume emissions from steelmaking plants. Furthermore, optimized systems for maximum utilization of the inherent heat of the offgas to generate steam, for cost-saving CO gas recovery as well as for profitable ferrous and zinc-dust recycling are presented.

The dry-type dedusting system with electrostatic precipitator features the highest gas cleaning and energy efficiency in the field of primary offgas treatment. Wet-type

dedusting systems with annular gap or venturi scrubber technology provide an interesting alternative, particularly for revamping projects in existing steel plants where older wet-type gas cleaning system are already installed. Advanced pulse-jet filters are used both for secondary dedusting systems and for EAF steelmaking operations.
The installation of absorption coolers in the charging ducts – a major innovation for secondary dedusting facilities –is described in this paper. By absorbing the excess heat during hot metal charging, less cooling air is required, the suction efficiency increased and process safety improved. Furthermore, the hot metal pouring time is reduced considerably since overheating of the pulse-jet filter is avoided.
The environmental technologies presented in this paper can be applied both in new installations as well as for the upgrading and modernization of existing steelmaking facilities. These environmental solutions assure full environmental compliance of a BOF and EAF steel plant and are key factors for environmentally compatible and sustainable steelmaking operations.

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