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SPECIAL PRINT

Tray installation – increasing performance of a wet FGD without additional pressure loss and with simultaneous reduction of operational costs

by Sven Kaiser, Stefan Binkowski,
Uwe Schadow and Axel Thielmann

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Kurzfassung

Installation neuer Trays zur Erhöhung der Leistung einer nassen Rauchgaswäsche ohne Druckverluste bei gleichzeitig niedrigeren Betriebskosten

Am Braunkohlekraftwerk Novaky wurde der SO_2-Abscheidegrad von ca. 96 % auf >99 % gesteigert, um den von der Industrieemissionsrichtlinie 2010/75/EU vorgeschriebenen Emissionsgrenzwert von 200 mg/Nm^3 einzuhalten. Gleichzeitig wurde der Druckverlust über die gesamte REA leicht reduziert und eine komplette Sprühebene demontiert. Hierdurch reduzierte sich die Pumpenleistung um ca. 700 kW.

Zwei unterschiedliche Effekte werden durch die Installation des neuen Trays erreicht. Zum einen wird die Phasengrenzfläche zwischen dem Gas und der Suspension vergrößert, sodass sich die Absorptionsrate von SO_2 und SO_3 erhöht. Zum anderen wird durch den lokal aufgeprägten Druckverlust eine Vergleichmäßigung der Rauchgasströmung im Absorber erreicht. Die Effektivität der übrigen Sprühebenen wird hierdurch ebenfalls erhöht.

Mit der Nachrüstung der REA auf die erprobte Tray-Technologie von Steinmüller Engineering wurden die Betriebskosten minimiert, der Abscheidegrad und die Flexibilität hinsichtlich des Kohlebandes erhöht bei gleichzeitiger Einhaltung der geforderten Emissionsgrenzwerte. Durch die maßgeschneiderte Kombination weiterer Maßnahmen, wie dem neuen Sprühebenen-Konzept und neuen Sprühdüsen, konnte darüber hinaus garantiert werden, dass sich der Druckverlust durch die Maßnahme nicht erhöht.

Authors

Dr. Sven Kaiser
Process Engineer Flue Gas Cleaning

Dr. Stefan Binkowski
Department Manager
Flue Gas Cleaning Process

Uwe Schadow
Department Manager
Flue Gas Cleaning Design

Dr. Axel Thielmann
Department Manager
Proposals Flue Gas Cleaning

Steinmüller Engineering GmbH
IHI Group Company
Gummersbach, Germany

Background

The flue gas from coal fired power stations contains sulphur oxides resulting from the sulphur content of the burned coal. Modern coal fired power stations are therefore equipped with flue gas cleaning equipment to remove the hazardous sulphur oxides. The most commonly used process in power stations is wet flue gas desulphurisation (FGD) with limestone or lime as sorbent and gypsum as by-product.

The changing structure of electrical power generation is driving demand for more flexible operation of coal fired power stations. To enable economic operation, it may be necessary to look at a broader range of coal qualities. This also includes the use of world-market coal with a higher sulphur content.

Another motivation for improving FGD efficiencies is the progressive reduction of emission limits in the European and national legislative regulations. As of 01.01.2016 the limit value for SO_2 for large fossil power plants in the EU was lowered from 400 mg/m³ down to 200 mg/m^3 (at STP). Further reduction is expected with the revision of the BREF (Reference documents on Best Available Techniques according to IED2010/75/EU) in early 2017.

Especially in Europe, many power stations were designed in the 1970s and 1980s for a specific quality of coal from a nearby mine. This also applies to the flue gas cleaning equipment.

Therefore, the removal efficiency of the installed flue gas equipment is in most cases not adequate to handle a higher sulphur dioxide concentration. Among the various upgrade options, a tray retrofit is often the most economical solution. Nevertheless a holistic approach is required to avoid any drawbacks such as increased power consumption.

With the customised combination of a new spray level design, the use of new spray nozzles, optimised mist eliminators and the tailored tray design it was possible to guarantee no additional pressure loss and achieve the new SO_2 emission limits of 200 mg/Nm^3 even for extremely high inlet SO_2 concentrations and increased flue gas volume flow at the lignite fired power station in Novaky.

Principle of wet flue gas desulphurisation absorbers

The most commonly used desulphurisation process in power stations is wet flue gas desulphurisation, the absorption of sulphur oxides into a lime or limestone slurry with integrated forced oxidation to form gypsum as an end product. For this purpose, the flue gases are intensively mixed with the scrubbing suspension in an absorber or scrubber.

The limestone slurry is pumped from the lower section of the absorber to spray levels where nozzles create small droplets of suspension which fall back into the lower part of the absorber. On the way down SO_2 (and SO_3) is absorbed from the flue gas.

The different dissociation reactions to sulphur acid and sulphuric acid are shown below.

$$SO_2 + H_2O \leftrightarrow HSO_3^- + H^+ \leftrightarrow SO_3^{2-} + 2H^+ \quad \text{(Eq. 1)}$$

$$SO_3 + H_2O \leftrightarrow HSO_4^- + H^+ \leftrightarrow SO_4^{2-} + 2H^+ \quad \text{(Eq. 2)}$$

The physical absorption of the SO_2 is the first reaction step.

The rate of absorption is determined by the driving force (partial pressures), the mass transfer coefficient and the available mass transfer surface. The larger the transfer surface the more and the faster the sulphur dioxide can be absorbed. To achieve a high surface for mass transfer, spray absorbers are used in the majority of the FGD plants installed in coal fired power stations.

The absorbed species are subsequently oxidised inside of the absorber sump or reaction tank. Hence most of the sulphur will be present in the sixth oxidation state. Based on the different solubility products of the dissolved salts, mainly $CaSO_4 \cdot 2H_2O$ (gypsum) will precipitate.

The overall chemical reaction can be written as:

$$SO_2 + CaCO_3 + 2H_2O + \frac{1}{2}O_2 \leftrightarrow CaSO_4 \cdot 2H_2O + CO_2 \quad \text{(Eq. 3)}$$

Principle of tray elements

The removal efficiency of flue gas desulphurisation plants can be enhanced by enlarging the contact surface between flue gas and the absorption liquid (limestone suspension). This is achieved with a tray. The tray creates a bubble layer and in this layer the absorption of sulphur dioxide, sulphur trioxide and dust is increased. Below the lowest spray bank of the absorber additional residence time is created for the droplets. The remaining solid limestone particles will dissolve and the droplets can further absorb SO_2 from the flue gas.

In addition to the increased mass transfer area also the precipitation mechanism is changed. The inertial separator effect of the droplets might not efficiently remove smallest dust particles and aerosols. These are caught in the bubble layer of the tray elements. Hence SO_3 absorption and fine dust removal is also increased in the absorber.

The installation of a tray level will create a small, wanted additional pressure loss to force the flue gas flow to evenly distribute over the entire cross section of the absorber (see Figure 1). Sneakage and untreated gas lanes are efficiently avoided throughout the absorption zone. The effect is especially strong if very high SO_2 inlet concentrations are present. Untreated lanes of flue gas could – with insufficient contact time and mixing with the absorption slurry – then result in a drop of overall removal efficiency.

As a rule of thumb the contribution of a tray level to the overall removal efficiency of an absorber is comparable to that of one conventional spray level. Of course this effect could be even higher since the removal characteristic of an absorber with tray level is different from the characteristic of an open spray tower (see Figure 2).

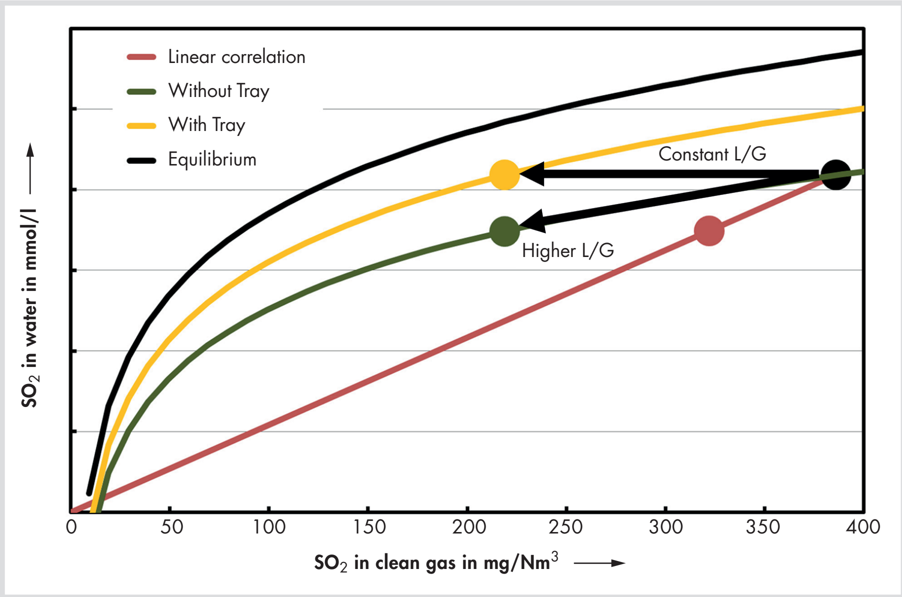

Fig. 2. Possible clean gas values (example) as function of L/G.

In principle the removal efficiency of any absorber can be increased if the amount of recirculated scrubbing liquid, the so called liquid to gas ratio L/G, is increased. If the gas flow rate remains constant, an increased L/G means that each droplet only needs to absorb a smaller amount of SO_2 to achieve the same overall removal efficiency. The increase in efficiency that can theoretically be achieved is shown schematically in Figure 2. The black dot represents the original operation case of the absorber. Assuming pure physical absorption of SO_2, the increase in efficiency respectively the achievable clean gas value would be represented by the red line (according Henry's law).

Since the absorption of a FGD is chemically enhanced the achievable clean gas values could be represented by the green line, if the L/G is increased. In the shown example the recirculated amount of liquid would have to be increased by approx. 20 % to achieve the desired clean gas value (green dot).

By installing a tray basket level the removal characteristic of the absorber is changed (represented by the yellow curve). This curve is much closer to the theoretical maximum of the chemical equilibrium, represented by the black curve. One can see that the desired removal efficiency could be reached without increasing the L/G.

In contrast, if it is not necessary to increase the removal efficiency, it is possible to reduce the amount of recycled slurry. In this example, the pumping capacity could be reduced by approx. 15 % and therefore the operational costs would be reduced.

In general the removal efficiency of a FGD absorber will benefit from the installation of a tray. The extent of this benefit of course depends on the specific plant. In general the effect on gas flow maldistribution and the residence time of the slurry droplets will always be positive. The design of the tray, e.g. the free cross section, has to be adopted according to the defined boundary conditions and desired achievements.

Construction principles of tray elements

Tray technology was introduced in the US in the early 80s to comply with legislative mandates (e.g. at IPL Petersburg an upgrade from 80 % to 93 % removal efficiency was achieved [1]). Good experience has been gained since then.

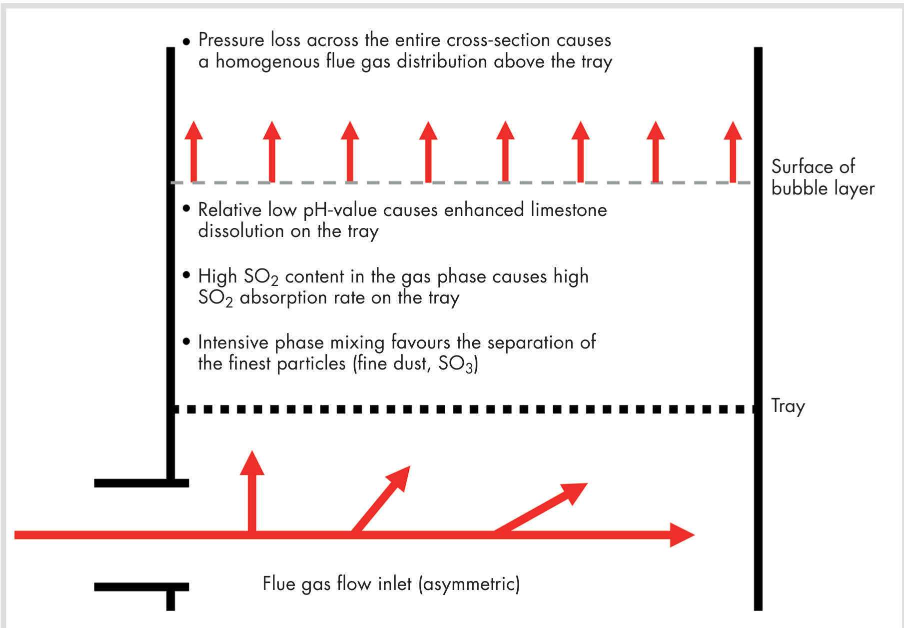

Fig. 1. General function principle of the tray level.

Most tray installations in the US aim to achieve very high removal efficiencies (see also [1]), since the regulations are based on a credit system. This has not been necessary in Europe up to now.

Therefore it was possible to tailor the design of the tray to the available pressure loss (e.g. 3 to 4 mbar compared to 5 to 6 mbar in some US installations).

The structural materials used in the US are alloy materials of different grades. In European installations, PP (polypropylene) is more commonly used for spray banks and other internals. Accordingly, Steinmüller Engineering uses PP for the tray basket design as an economical construction material.

The nozzles used in the spray banks inside a flue gas desulphurisation absorber are also different in Europe. Modern installations (and upgrades) use double hollow cone nozzles with wide spray angles. These nozzles provide good coverage of the cross section as well as a positive effect on the absorber gas-side pressure loss due to the water jet effect of the co-current spray cone. In the US single cone nozzles are more often used.

The first tray designs used flat perforated steel plates. These plates formed only a single flat area. The scrubbing suspension was not guided and could be easily pushed away by the gas flow. The uniforming effect of today's design was therefore not achievable.

Steinmüller Engineering has developed "tray basket elements" (see Figure 3) manufactured from reinforced poly propylene. These elements come in standard sizes and can easily be joined together to cover the entire cross section of an absorber. Installation requires only a very short outage of the plant.

The basket design encloses a defined amount of the scrubbing liquid and prevents it from being forced aside by the gas flow. Therefore the basket design is an integral part of the self-regulating effect of the gas flow stratification. At sections with higher local velocity a higher local pressure loss is created and hence the local gas flow is slowed down. The uniforming effect is optimised and maldistribution is reliably reduced.

When covered with planking, the tray basket level also offers a convenient working platform for accessing the recycle spray headers to clean or replace spray nozzles if required.

Holistic optimisation approach

The presented project was realised in an FGD absorber that had originally been built in the early 1990s. The absorber treats the flue gas from two lignite fired units, each rated at about 110 MWel. The reaction tank of the absorber is cylindrical whereas the counter-current absorption zone above the flue gas inlet is rectangular. This rectangular section was originally equipped with 7 spray levels, each supplied by a dedicated recycle pump. The clean flue gas exits the absorber after passing through a droplet separator and is reheated in a gas to gas heat exchanger with heat from the raw gas before it is emitted via the dry stack. The wet ID fan is located between the absorber and the gas to gas heater.

Due to the new SO_x emission limit of 200 mg/Nm^3 from 2016 on, it was required to upgrade the existing absorber. Also the coal quality is gradually degrading over time. During the last years the used coal mix resulted in raw gas SO_2 concentrations of up to 10,000 mg/Nm^3. Average operation values have been measured in the range of 6,000 to 8,500 mg/Nm^3. Today the inlet concentrations are often in a range of about 12,500 mg/Nm^3 with maximum values of even 14,500 mg/Nm^3. (All concentrations refer to 6 % oxygen and dry flue gas.) The operated volume flow could reach values of more than 1.4 million Nm^3/h (wet).

A very special and challenging requirement for the upgrade was the fact that the total pressure loss of the system was not to be increased. To achieve a significant increase of the removal efficiency while keeping the pressure loss at the same level (or lower) a holistic optimisation approach was applied.

As primary measure a tray basket level was installed to meet the requested removal efficiency. The required space inside the absorption zone was gained by removing(!) one of the lower spray banks. The remaining support structure was modified. On the outside of the absorber additional stiffeners and reinforcements were installed. A new inspection and maintenance opening was created to allow easy mounting of the new equipment. The opening can now be used for easy access to the tray level and the levels above.

To overcompensate the removal efficiency of the demolished spray level, the tray was designed with a rather high local pressure loss of about 5 to 6 mbar at full load. (Normal installations would only use 3 to 4 mbar.) Consequently this new local pressure loss had to be recovered in other sections within the absorber to maintain the guaranteed "no-increase" limit. A first step was already achieved by removing one of the existing spray levels. The gain of pressure loss amounts to approx. 2 mbar. Further savings were reached by modifying the existing droplet eliminator. The replacement of the original 2 layer flat type mist eliminator with a tailored double roof mist eliminator reduced the pressure by a further approx. 2 mbar.

The remaining 2 mbar were compensated for by using new spray nozzles. The original helical nozzles were replaced with different types of tangential twin absorb nozzles (see Figure 4, right).

The tangential feed of the new nozzles required horizontal connections. Therefore the existing spray lances had to be turned thru 90°, since the original helical nozzles had been connected vertically (see Figure 4, left). Only minor modifications to the existing support structure were required. Close to the walls some transition pieces were installed. These modifications were optimised using modern in-house CFD simulations to analyze the original status of the absorber and to stepwise identify the optimal solution (see Figure 5).

With this holistic approach, it was possible to significantly increase the removal efficiency of the absorber and also meet the requirement to not increase the total pressure loss of the system. The following chapter will show some results from the operation before and after the successful upgrade.

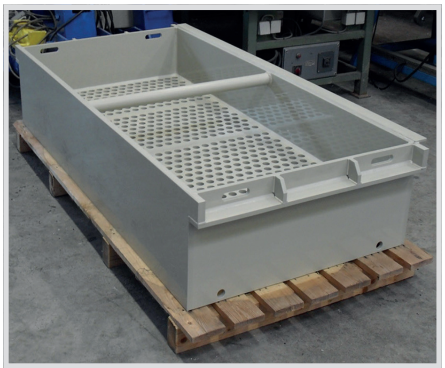

Fig. 3. Tray basket element.

Fig. 4. Replacement of old helical nozzles with tangential bi-directional nozzles (reusing the existing spray lances, turned thru 90°).

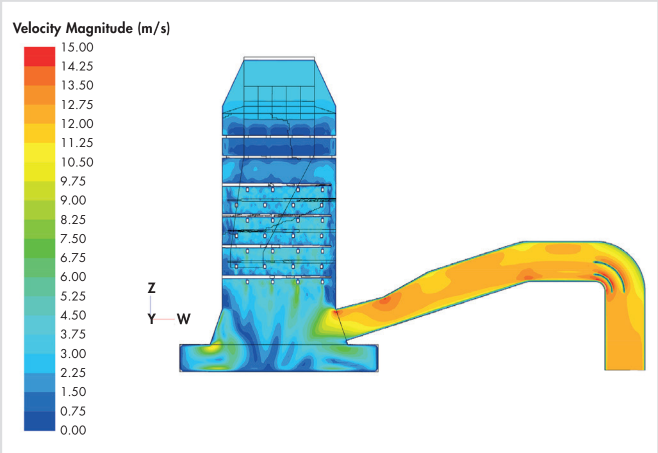

Fig. 5. CFD Analysis of the original flow situation as basis for the optimised tray and spray bank and nozzle design.

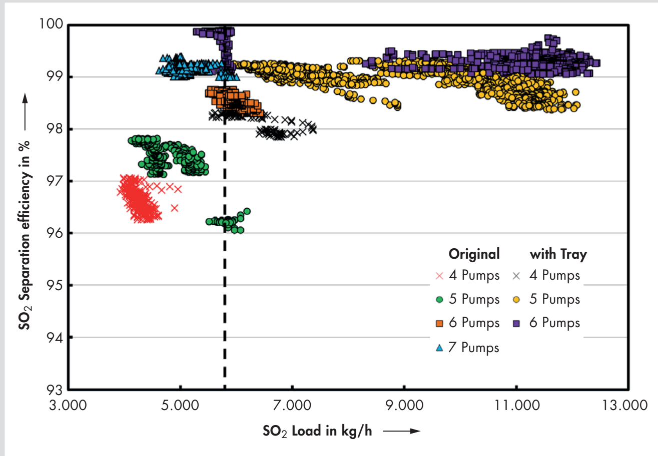

Fig. 6. SO_2 Removal efficiency as function of the separated SO_2 load for different numbers of operated spray levels before and after FGD upgrade.

Operational experience

Pressure loss

At the beginning of this upgrade project measurements were conducted to determine the gas side pressure loss of the absorber system. The number of spray banks in operation was varied and the influence on the total pressure loss for different gas flow rates was measured. These measurements formed the basis for later verifications, that the guaranteed aim to not increase the pressure loss was achieved. It has to be noted that before the upgrade one spray bank more had to operate continuously for comparable removal efficiencies. At the end of the upgrade project the pressure loss was measured again by an independent body. It was recorded that the gas volume flow was much higher after the upgrade due to other modifications at the boilers (see below). Nevertheless the guaranteed non-increase of the pressure loss was achieved. Even for the now increased SO_2 removal efficiency it is slightly lower.

SO_2 removal efficiency

The existing ID fan was limiting the maximum possible load case for the power station before the upgrade: In addition to the absorber upgrade other modifications at the boiler were implemented (e.g. flue gas recirculation with a new fan). These modifications have now reduced the load towards the ID fan. It is no longer the limiting bottle neck and the absorber can be operated with much higher flue gas flows. As leakage has been reduced in the boiler flue gas path the oxygen content of the flue gas has also been reduced. Since the mentioned SO_2 concentrations all refer to the reference concentration of 6 % oxygen, the total SO_2 load to be treated within the absorber system was further increased. The upgraded FGD is capable of this separation task as shown in Figure 6. The diagram summarises the removal efficiency of the absorber system and compares operation cases before and after the upgrade. The number of operated spray levels is indicated for the different load cases. On the x-axis the SO_2 load in kg/h is given. It is calculated by a multiplication of the SO_2 concentration with the flue gas volume (both corrected to the same oxygen content and moisture).

The diagram clearly shows the significant increase of the removal efficiency achieved with the tray installation. Before the upgrade a relatively low SO_2 load of about 6,000 kg/h (reflecting a SO_2 inlet concentration of about 8,000 mg/Nm^3) required the operation of 5 spray banks to achieve a SO_2 removal efficiency of 96.2 % (green circles) whereas after the upgrade only 4 spray levels have to be operated to achieve a removal efficiency of 98.3 % for the same SO_2 load (black crosses). Furthermore it can be seen that for comparable removal efficiencies now 2 spray banks less need to be operated (e.g. compare orange squares with black crosses) to achieve the same results. In general it has to be noted that after the upgrade with the tray basket elements, now extremely high SO_2 loads of more than 12,000 kg/h (reflecting SO_2 inlet concentrations of up to 14,500 mg/Nm^3) can be treated with achievable removal efficiencies clearly above 99 % (purple squares). The vertical dotted line in the diagram shows the average operation condition before the upgrade. For comparison of the achieved removal efficiencies before and after the upgrade the efficiencies for different numbers of spray banks in operation are summarised in Table 1.

The FGD operation is stable and reliable since the upgrade. Only if the coal quality decreases further the capacity of the fresh limestone slurry supply line will have to be increased. The stable operation is also documented in Figure 7. The photos show the tray level after 8 months of continuous operation. No deposits or blockages can be seen. (The gray layer on the elements is merely remaining solids from the suspension after shut down. It can easily be wiped off by hand and will be dispersed again after startup.)

Operational costs

Besides the increased removal efficiency of the FGD absorber the tray retrofit also reduces the operational costs of the plant. The pressure loss was a crucial boundary condition. It had to be guaranteed that the overall pressure loss would not be increased. Due to the above described measures, it was even possible to lower it slightly and therefore no additional operational costs are caused by the ID fan. As shown in figure 1, the locally lower pH on the tray yields better limestone utilisation and therefore decreases the costs for limestone usage. The biggest contribution to the savings of overall operational costs is the reduced number of operated spray pumps. To achieve the same removal efficiency as before the upgrade, one or even two pumps less need to be operated. Another factor, possibly not recognisable immediately is that the maintenance costs during outages will also be reduced. For example it is no longer required to empty and clean the absorber reaction tank for the erection of scaffolding, since this can be supported directly on top of the tray level. This will not only save the costs for the scaffolding but also reduces the down time by one or

Tab. 1. Removal efficiencies depending on number of operated spray levels before and after tray installation.

Number of operated spray levels	4	5	6	7
Before tray installation	–	96.20 %	98.60 %	99.14 %
After tray installation	98.30 %	99.14 %	> 99.5 %	–

Fig. 7. Tray level after about 8 months of continuous operation.

two days. Visual in-between inspections are also easier and more areas can be inspected prior to planned outages and thus supports the planning of required activities during the outage. Table 2 summarises the above described effects. Depending on the operation scheme of the Novaky power station operational cost savings of up to 500,000 EUR/year can be achieved.

Conclusion

Installing a tray basket level is an expedient way of increasing the overall removal efficiency of a flue gas desulphurisation absorber. The Steinmüller Engineering tray basket design allows for customised coverage and is tailored for effective use of available pressure loss reserve. Furthermore, tray basket levels could be installed in absorbers with limited space between or below existing spray levels, where new spray levels are not an option or difficult to install.

The basket design is very efficient to unstratify the flue gas flow and remove flue gas lanes or dead zones. At the same time the scrubbing suspension is prevented to be pushed aside and limestone utilisation is increased.

The upgrade project at the Novaky power station exemplifies how the two contradicting aims of increased SO_2 removal efficiency and non-increased pressure loss can be achieved successfully. The new SO_2 emission limit of 200 mg/Nm^3 is met even with extremely high inlet concentrations of over 14,500 mg/Nm^3. The pressure loss of the system was slightly decreased. Several measures have been combined to support this task. The core modification was the installation of the tray level. It was combined with the redesign of the spray banks and the use of new bidirectional spray nozzles. The droplet separator was redesigned as well.

The FGD can now be operated with less spray banks and achieves much higher removal efficiencies. Since the pressure loss was not increased, the operational costs of the plant have been reduced considerably.

Tab. 2. Impact of tray on operational cost.

Electrical consumption of recycle pumps	↓
Electrical consumption of ID-fan	→ (↘)
Limestone consumption	↘
Maintenance costs (scaffolding)	↘
Downtime	↓

Literature

[1] James L. Murphy, Michael A. Sandell, Stefan Binkowski (2010): *Demonstrated Experience in Upgrading WFGD Installations to Achieve SO_2 Removal Requirements Anticipated for Future CCS*, PowerGen Europe 2010.