

# The Impact of Low-Load Operation on Power Plant Chemistry

Frank Udo Leidich

## ABSTRACT

Nowadays conventional power plants are more challenged in regard to load flexibility and especially frequent (very) low-load operation. While the so-called "dark doldrums" must be managed without de-stabilizing the grid, a bright sunny and windy day requires almost no conventional power generation. This kind of operation not only stresses the plant components mechanically and thermally, leading to accelerated aging of the plant, but the physico-chemical operation also becomes more challenging. This paper highlights the most important aspects of the impact of low-load operation on the chemical operation of a power plant. It is shown that it pays to operate the unit with water and steam that is as clean as possible.

## INTRODUCTION

In many saturated energy markets like Europe the introduction of renewable power capacity is being promoted to lower the CO<sub>2</sub>-footprint of electric power generation. Consequently, the installed base of conventional power plants is forced to change from mainly base-load-like operation to operation based on grid demand, counterbalancing fluctuating consumption and load input from the non-steady renewable production sources like windmills or photovoltaic panels.

As an example, Figures 1 and 2 [1] show the load fluctuation of renewables and the changing power demand throughout the day on February 26th, 2019, and on April 22nd, 2019, in Germany.

Both figures are self-explanatory: On Feb 26th, a cold, calm and dark winter day in Germany, the grid demand was 75.3GW at 7pm; renewable power contributed only 3% to the overall demand. As a consequence, all available conventional power plants were operated at full load. Even this was not enough. Due to the gap between production and consumption, the electricity price went up to 55€ per MWh at that time.

On April 22nd at noon, the opposite was the case. It was a not too warm, sunny and windy day. Renewables fed in almost 48.8GW, the demand was at 61.2GW and conventional power production went down to only 18.5GW. There was still power overproduction and the electricity price at that time was -62€ per MWh!

This means that the utilities in Germany are currently under enormous economic pressure. Cycling operation in general increases wear and ageing of the plants and increases the likelihood for unplanned outages and the risk of component damage.

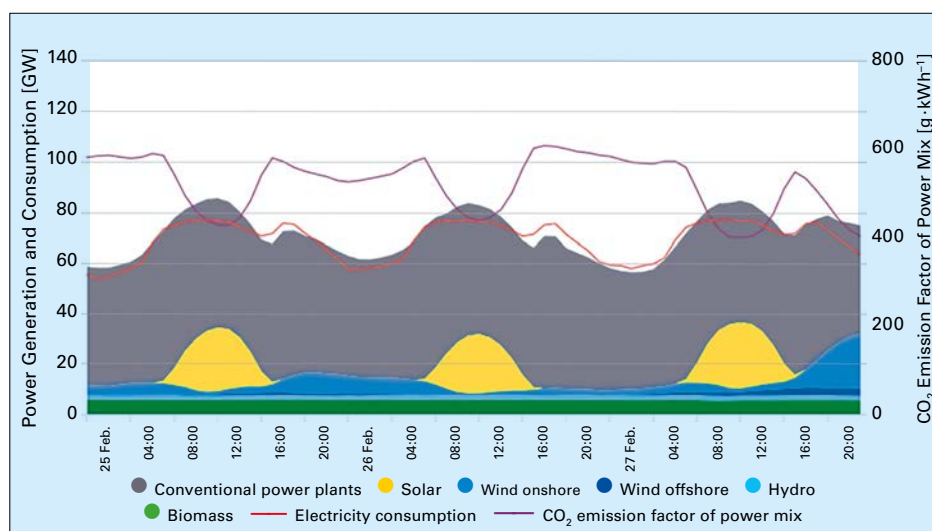


Figure 1: Calm, dark winter days in February 2019 in Germany (courtesy: Agora Energiewende).

This paper tries to describe the impact of cycling and low-load operation from a power plant chemistry perspective, aiming to give some advice on how power plant chemistry should be adapted to these challenging conditions to reduce the risk of increased operational and maintenance costs or even forced outages.

## PHYSICO-CHEMICAL PROCESSES IN THE STEAM-WATER CYCLE

During operation, the working medium, water, changes its physical and chemical properties while circulating through the steam-water cycle (see [Figure 3](#)).

Starting from the condensate pump discharge header, the condensate might pass through a condensate polishing plant, where impurities as well as the conditioning chemicals are removed from the water. Conditioning chemicals are added to the cleaned condensate to adjust pH and possibly the oxygen content (depending on the desired conditioning philosophy). The condensate is then prewarmed in the low-pressure (LP) preheater train with the help of extraction steam from the LP and intermediate-pressure (IP) turbine before it enters the deaerator and feedwater tank, where the condensate is further heated in direct contact with steam (blown into the feedwater tank) mainly from the cold reheat line, and excess oxygen is removed.

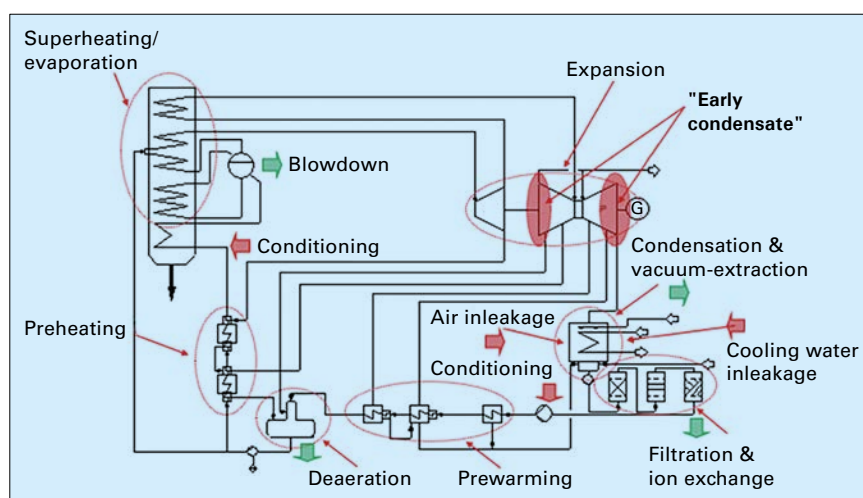


Figure 3:  
Physico-chemical processes in the steam-water cycle.

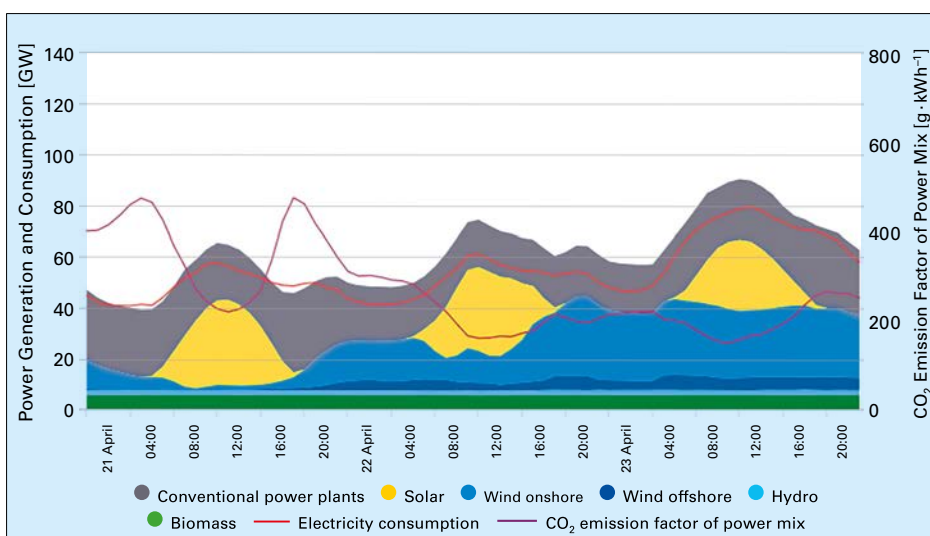


Figure 2:  
Bright, sunny and windy days in April 2019 in Germany (courtesy: Agora Energiewende).

The extraction steam used to preheat the condensate in the LP preheater train is de-superheated, condensed and eventually subcooled therein. It might be cascaded down into the condenser hotwell or, if it is thermodynamically more beneficial, pumped forward into the feedwater tank.

Downstream of the feedwater tank, the feedwater pump is used to increase the pressure of the feedwater to the operating pressure at the given load conditions. In the high-pressure (HP) preheaters, the feedwater is further heated with the help of condensing steam on the shell side of the preheaters. The steam for this purpose comes from HP turbine extraction lines. After passing through the HP preheater train, the feedwater enters the boiler, where it is prewarmed to near-

ly evaporation temperature in the economizer at the cold end of the flue gas pass through the boiler.

In drum boilers, part of the boiler water is evaporated together with (a portion of) the volatile conditioning chemicals. The steam-water mixture enters the boiler drum, where the steam-water separation takes place. Part of the boiler water leaves the cycle via the blowdown line, while the saturated steam leaves the drum on top of the drum and is routed to the super-

heater. To keep the pH of the circulating boiler water at the desired level, depending on the conditioning philosophy, additional dosing chemicals might be added. The injection point for this purpose can be the inlet or the outlet of the economizer or directly into the boiler (drum or downcomer tubes).

In once-through boilers, all the feedwater that has entered the boiler via the economizer will be transformed into steam if the load is high enough to exceed the Benson point. If the load is lower, a steam-water mixture as in the case of drum boilers leaves the evaporator section. Steam-water separation is done in this case in cyclones and/or the so-called Sulzer flask. The water is returned to the economizer in- or outlet with the help of a recirculation pump. The saturated steam is routed to the superheater, where the steam is further heated to the desired operating temperature. The superheater outlet temperature is controlled by injection of attemperator spray water. The water for this purpose is extracted from the feedwater line directly downstream of the feedwater pumps.

The superheated steam passes through the HP turbine, where it loses energy, resulting in a drop in temperature and pressure. Impurities that have been dissolved or dispersed in the steam might precipitate on the HP turbine parts if (in the case of dissolved impurities) the solubility of a particular substance is exceeded during the expansion process of the steam.

The HP turbine might have one or more steam extraction lines. The extraction steam is used to feed into the HP preheaters. After de-superheating of this extraction steam, it is condensed and eventually subcooled in the HP preheaters. This HP preheater condensate might be cascaded down, passing additional HP preheaters into the feedwater tank for recovery of the remaining enthalpy.

After passing through the HP turbine, the main steam is then returned to the boiler via the cold reheat pipelines to pick up additional heat for further enthalpy extraction in the IP and LP turbines. The outlet temperature of the reheater is controlled by attemperator spray water injection from the feedwater line as well. Part of the cold reheat steam might be used for heating purposes or driving the feedwater pump steam turbine.

After reheating, the steam is routed to the inlet of the IP turbine. Further expansion, and pressure and temperature reduction of the steam take place. The IP as well as the LP turbine might be equipped with steam extraction lines for

heating or other purposes. After expansion in the IP turbine, the main steam is routed via the crossover pipelines into the LP turbine, where further energy transformation takes place. In condensing turbines, the steam is expanded into vacuum; the absolute pressure is determined by the temperature of the cooling water in the case of a surface condenser or by the environmental air in the case of air-cooled condensers, where the steam leaving the turbine is condensed.

In large utility power plants, the make-up water is injected into the condenser on top of the condenser tube bundles. Due to the vacuum in the condenser, deaeration of the make-up water takes place there. Return process condensates (if any) usually re-enter the steam-water cycle at the condenser hotwell. The condenser and hotwell are also the places where internal drain lines from various locations in the steam-water cycle are routed to for water and energy reclaim purposes via, for example, the vacuum flash tank. Feed in and out from/to the cold condensate storage tank is usually also controlled via the condenser hotwell to manage the water hold-up in the steam-water cycle.

Looking at combined cycle power plants (CCPPs), the processes described above remain nearly the same. LP and HP preheater trains however are usually not present in modern CCPPs, as the heat contained in the flue gas is almost completely recovered in dual or triple pressure heat recovery steam generators (HRSGs) so that the flue gas leaves the stack with temperatures down to 60°C. This makes prewarming with the help of extraction steam unnecessary and uneconomical and is one of the secrets why CCPPs have such a high efficiency. All steam generated in the HRSGs can be used to produce electricity in the steam turbine directly (see Figure 4).

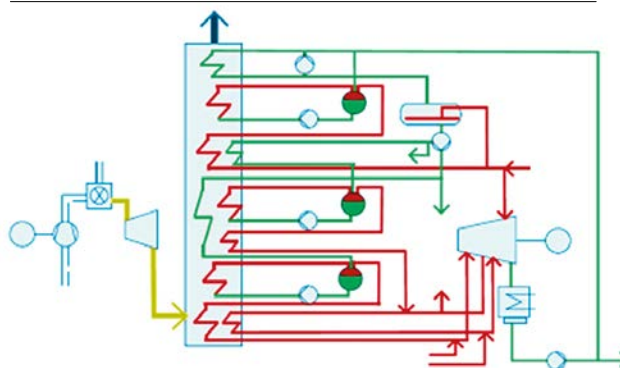


Figure 4: Sketch of a triple-pressure combined cycle power plant with an all drum-type HRSG, without a CPP, with a second unit feeding into the same steam turbine which is not shown (green and red arrows).

Quite often CCPPs are not equipped with a condensate polishing plant (CPP). Compared to power plants with direct fired boilers, many more CCPPs are equipped with an air-cooled condenser.

## PHYSICO-CHEMICAL PROCESS CHANGES IN THE STEAM-WATER CYCLE DURING CYCLING AND LOW-LOAD OPERATION – IMPACT OF IONIC IMPURITIES

Starting again at the discharge header of the condensate extraction pumps, during low-load operation the condensate flow is reduced correspondingly. Depending on the design of the CPP, low-load operation might have a beneficial or adverse effect on the quality of the clean condensate leaving the CPP.

If the plant is equipped with a bypass CPP, which allows only cleaning of a certain part of the full-load condensate flow, the bypass valve is closed more and more, so that with reduced load a larger portion of the raw condensate leaving the condenser is polished. As a result, the clean condensate quality increases with low-load operation and during start-up and shutdown.

If the power plant is equipped with a full flow CPP, usually two or more vessels are installed and operated in parallel. Low-load operation results in lower throughput through the CPP. As mentioned above, CPPs need a minimum throughput to work properly. If the minimum flow rate through the polisher vessels is not achievable due to low flow, it might happen that the ion exchange resin starts to bleed, and salts captured in the CPP system redissolve in the condensate. Stratification might be another reason for insufficient condensate quality leaving the CPP vessels caused by a too low flow rate. Depending on the CPP design, with two or more ion exchange vessels in parallel, one or more of the vessels needs to be put out of operation to avoid the abovementioned phenomena. If this is not enough to achieve minimum flow rates in the operating CPP vessels, a recirculation system needs to be installed to assure good condensate quality even at very low load. Otherwise, the clean condensate quality deteriorates with low-load operation.

Chemical conditioning should also be continued during low-load operation as at higher loads. Target values for pH and oxygen might be adapted if a plant shutdown is planned to establish better conditions in terms of corrosion protection for the lay-up time period (higher pH, lower oxygen content). Not all dosing skids are able to continuously feed in the small quantity of chemicals necessary at very low-load due to the limited span of pump capacity. Interval dosing in such cases is only the second-best choice. Retrofitting of the dosing pump drives with frequency converters might be the better solution.

On the shell side of the LP preheaters, deposits are formed following the same mechanism as on turbine blades. During low-load operation, zones in the preheaters become wet where during normal high-load conditions, de-superheating and deposition of impurities take place. The condensing steam washes off the impurities. These are mobilized and transported with the condensate to the condenser or the feedwater tank (see Figure 5).

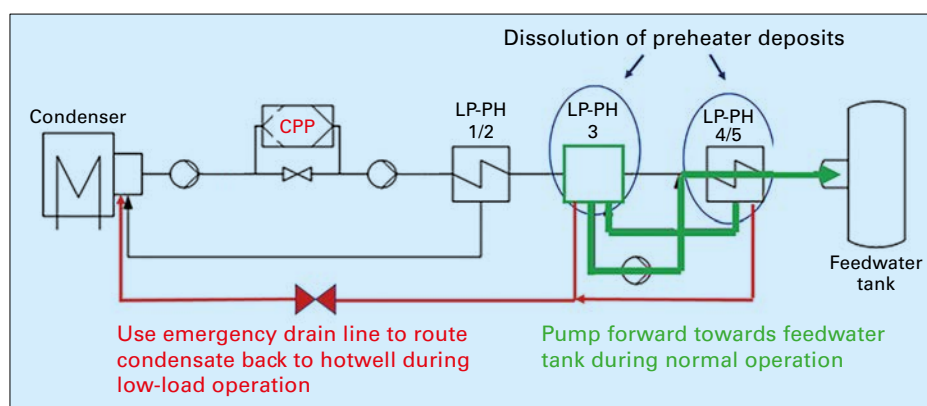


Figure 5:  
LP preheater (PH) train with forward pumping of the LP 3/4/5 preheater condensate into the feedwater tank.

It is recommended that forward pumped preheater condensates should be routed back into the condenser via the emergency drain system during low-load operation. In the case shown with a bypass CPP, all LP preheater condensates with all washed-off impurities will also pass through the CPP system, which results in a better condensate and feedwater quality.

At the HP preheater train the situation is almost the same as for the LP preheaters. During low-load operation, previously built-up deposits on the preheater tubes are (partially) mobilized during low-load operations by the condensing steam. Differently from with the LP preheaters, the shell side of the HP preheaters empty into



the feedwater tank. Emergency drain lines exist as well, routing the condensate in case of emergency into the condenser hotwell. However, without extra cooling, this way of removing dissolved solids from the HP preheaters is potentially not viable as it would result in overheating of the condensate in the hotwell. This however would damage the ion exchange resin in the CPP vessels, resulting in permanent loss of exchange capacity and release of impurities from the CPP plant.

What happens in the boiler now? The answer is simple: It depends on the boiler design and type.

Starting with a drum boiler, at low-load operation, the amount of water that is evaporated is smaller. If the design is based on natural forced circulation, the gravity difference between the water column in the downcomer tubes and the weight of the water steam mix in the evaporator/riser tubes is smaller at low-load operation. This results in a smaller driving force for the circulation. Especially in natural force drum-type boilers with horizontal tube arrangement, the flow through the parallel evaporator tubes is probably not even [2]. Some tubes might even fall dry, causing precipitation composed of the salts and conditioning chemicals dissolved in the boiler water. Consequently, the deposit might attack the boiler tubes (e.g. phosphate hide-out/hide-out return or caustic gouging by NaOH), which can ultimately lead to tube bursts (see Figure 6).

HRSGs can be built with the flue gas passing through the HRSG from bottom to top vertically. In such a boiler, the heat exchanger tubes are arranged in horizontal packages. The boiler drums



Figure 6:  
Tube wall thinning due to caustic gouging beneath insulating internal deposits during low-load operation – breakdown of natural draft circulation [3].

are located on top of the boiler structure well above the heat exchanger modules. This boiler design usually requires a circulation pump to avoid dry-out of single evaporator tubes during low-load operation. If recirculation pumps are not available, also for the fired boilers, hide-out, hide-out return and/or caustic gouging might take place.

In an alternative design, the tubes of the heat exchanger modules are vertically arranged, and the flue gas passes through the HRSG horizontally before entering the stack. Such boilers do not necessarily require pumps to assure proper circulation of the boiler water in the evaporator section at any load (see Figure 7).

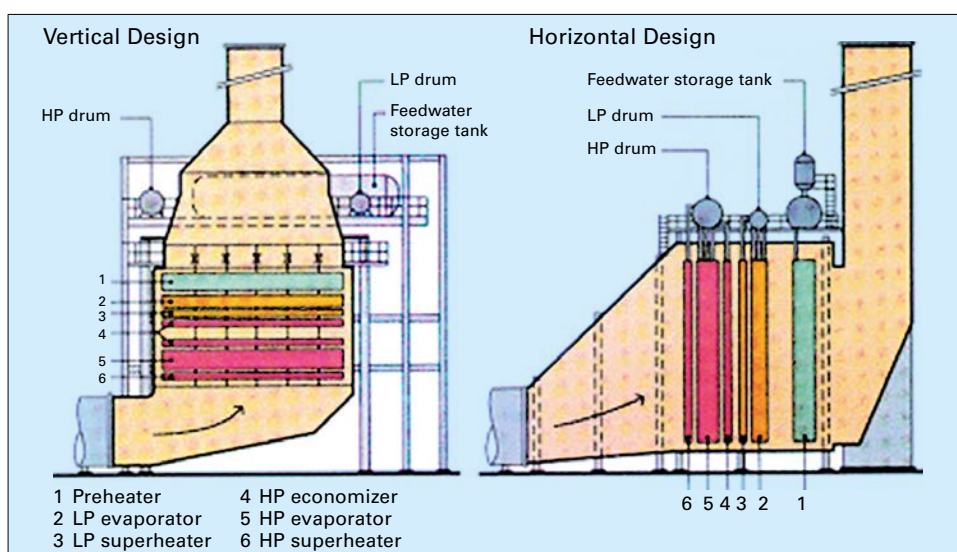


Figure 7:  
Sketch of HRSGs with vertical (left) and horizontal design (right).

If HRSGs downstream of a gas turbine are operated in idle-load conditions, the boiler pressure is reduced. The temperature of the flue gas from the gas turbine however might even be higher than at full-load conditions, but at reduced volume flow. This results in a shift of the temperature profile within the boiler sections towards higher temperatures even at the cold end (flue gas outlet of the boiler into the stack). Both can lead to first steam bubbles already being generated in the economizer.

Due to the reduced pressure, the steam expands to larger volumetric quantities, resulting in increased velocities of the water/steam mix in the economizer and evaporator. This phenomenon is more pronounced in horizontal boilers with vertical tube bundles than in boilers built in the vertical design.

A reduced pressure in the boiler evaporator has two additional effects chemistry-wise. First, the boiler water becomes depleted of ammonia, resulting in a lower pH of the water phase due to the distribution coefficient of ammonia, which is very high at lower pressure and temperature (see Figure 8) [4].

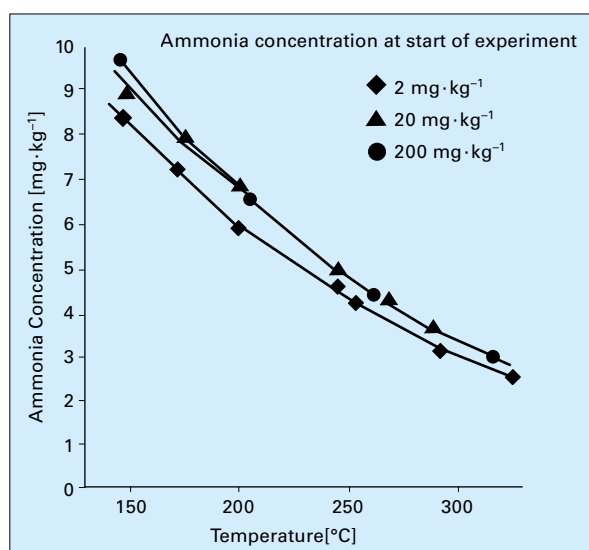


Figure 8:  
Distribution coefficient of ammonia at low temperatures.

Secondly, organics that might have come into the steam-water cycle will (partially) decompose and form organic acids. The final breakdown product is carbon dioxide, which leaves the boiler together with the steam. Of course, the higher the temperature, the higher the decomposition rate and completeness of the decomposition of such substances. However, in the evaporator section of a drum boiler, at low-load conditions not only the temperature and pressure might be lower, but the evaporation rate of the water as well, and this can lead to much longer residence times of organics and their breakdown products in the boiler water. Both in combination lead to (incomplete) decomposition of organic matter with the formation of shorter and longer C-chain carbonic acids.

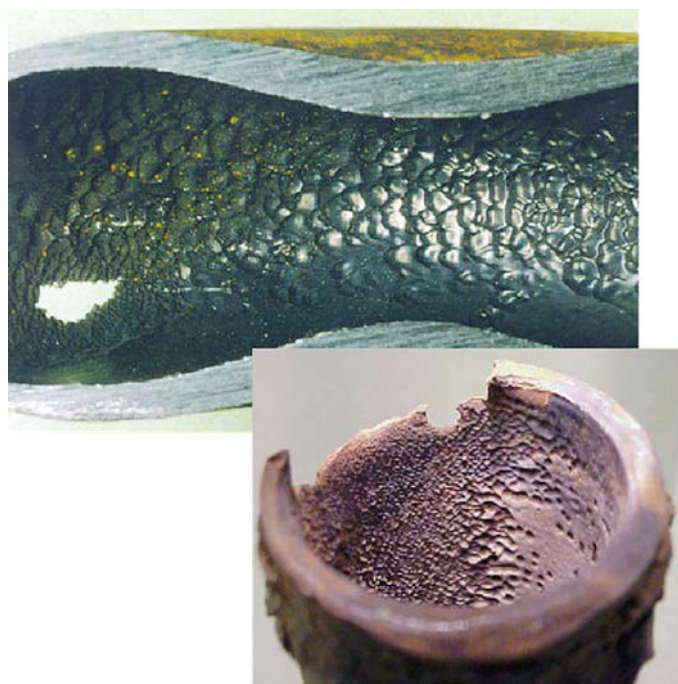


Figure 9:  
FAC in HRSG LP-boiler tubes.

The combination of both effects might cause lowering of the boiler water pH and thereby can increase the risk of FAC, especially in LP HRSG boiler parts (see Figure 9).

As already described above, HRSGs in the flue gas path of gas turbines might face a shift in the temperature profile towards higher temperatures at the hot and cold end of the HRSG. Triggered by this effect, more attemperator spray water is needed for control of the superheater and reheater steam outlet temperature. The injection of larger quantities of attemperator spray water results in mobilization of deposits from the superheater and reheater inner surfaces due to temperature shock effects and dissolution of salts in the water droplets that might hit the tube walls (see Figure 10). Consequently, the steam purity degrades and the conductivity of the steam increases.

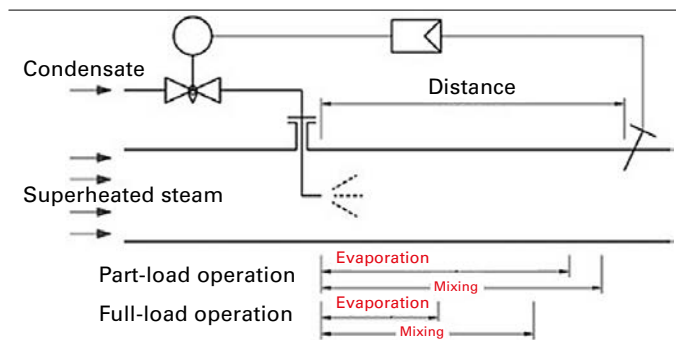


Figure 10:  
Effect of increased attemperator spray water injection at low-load conditions.

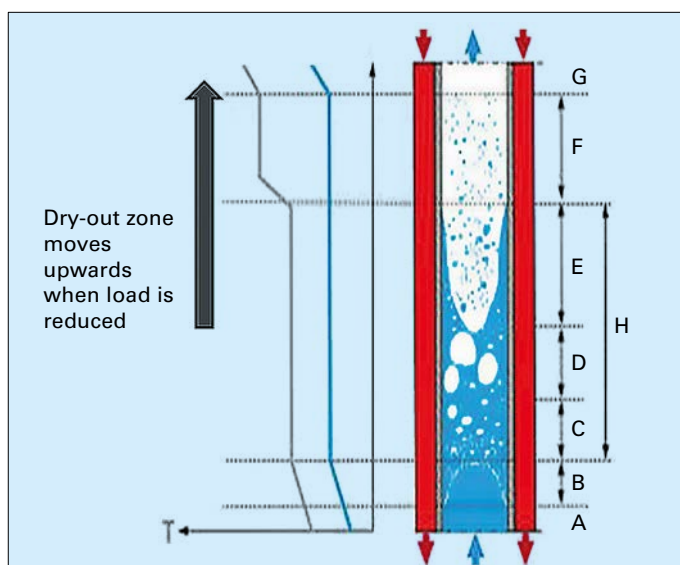


Figure 11:  
Effect of load variation on the location of the dry-out zone in the evaporator tubes of once-through boilers above the Benson point.

Looking at once-through boilers, we need to distinguish between load operation at reduced load above the Benson point and low-load operation below the Benson point.

If once-through boilers are operated at low load but above the Benson point, the dry-out zone (zones E and F in Figure 11) will move towards the outlet end of the evaporator tubes.

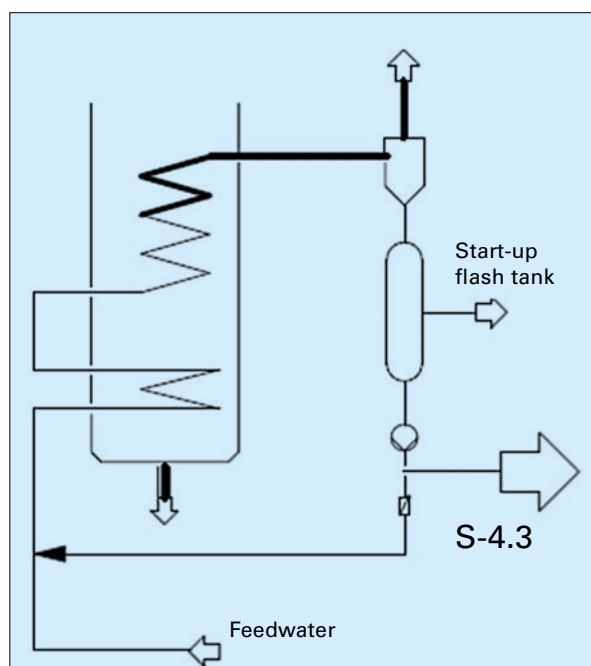


Figure 12:  
Recommended location of sampling nozzle for boiler water sampling in Benson-type boilers during low-load operation.

Deposits formed during previous operation in zone F will be redissolved in the boiling water and in part transported out of the tube into the steam. Therefore, the amount of impurities in the steam increases during load transition. This might cause deposition of such impurities on the steam turbine.

If once-through boilers are operated at low load below the Benson point, the evaporator runs in recirculation mode, like a drum boiler. Deposits formed during previous operation in zone F (see Figure 11) will be redissolved in the boiling water and in part transported out of the evaporator into the steam. Most of these redissolved impurities together with the amount of impurities entering the boiler with the feedwater (which is increased at low-load conditions) remain in the boiler water and might concentrate there. This requires control of the boiler water conductivity and eventually from time to time blowdown of the boiler water as it is needed in drum boilers at any time (see Figure 12) [5].

Such rejected water from the Benson boiler in recirculation mode is usually routed to a flash box. The condensate from the flash box might be reused after cooling and polishing. If this is not feasible, it should be dumped. The steam from the flash box is normally fed into the feedwater tank. It is doubtful that the quality of this steam meets the requirements of feedwater quality, therefore dumping the steam should be considered as well.

At low-load operation it might happen that the steam entering the steam turbine has a lower pressure than at base-load conditions. In principle, the processes in the steam turbine remain the same. However, due to the lower inlet pressure, any kind of precipitation caused by impurity oversaturation might be shifted towards the inlet of the turbine.

In the reheater the steam's enthalpy is increased that is again transformed into rotation energy in the IP and LP turbines. Due to the shift in the temperature profile of the flue gas in the boiler at low-load conditions and the reduced steam flow in the reheater tubes, it might be necessary to use more attemperator spray water for reheater outlet temperature control. As mentioned above, this spray water is contaminated with more impurities due to washing/mobilization effects in the boiler and pre-boiler system during low-load operation. This additionally amplifies the purity degradation of the steam at the reheater outlet.



In the IP turbine, the same situation exists as in the HP turbine. Precipitation of impurities occurs at places of oversaturation. Due to reduced pressure, the location where this might happen is shifted towards the inlet of the IP turbine.

Low-load operation also causes a shift of the phase transition zone (PTZ) in the LP turbine in the direction of the steam inlet. This means that the formation of the first condensate droplets occurs at an earlier stage of the turbine. Deposits on turbine blades that are dry during base-load operation become wet or are (partially) re-dissolved in the wet steam and washed off from the blades, increasing the salinity of the condensate. As a consequence, very strong electrolytes can form in the area of the white deposit line, lowering fatigue strength and/or leading to the formation of corrosion pits (Figures 13 to 15) [6].



Figure 13:  
White deposit (arrows) on L-1 turbine blades composed of common salt.

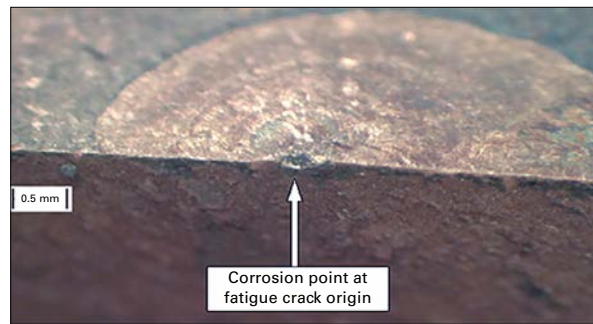


Figure 15:  
Blade rupture caused by corrosion fatigue at the PTZ on a row L-1 blade starting from a corrosion pit.

Finally, the expanded wet steam enters the condenser for condensation. Usually, the cooling water flow is not reduced at low-load conditions. Due to the lower heat load, the condensation temperature is therefore lower, resulting in a better vacuum (lower absolute pressure) on the shell side of the condenser. This again might result in potential risks for the entire power plant unit. A lower pressure at the condenser shell side causes higher velocities of the wet steam entering the condenser hitting the outer condenser tube rows. This might lead to droplet impingement causing condenser leaks. Especially at low cooling water temperatures, the water droplets can severely damage condenser tubes by droplet impingement. Titanium does not perform better than admiralty brass in this respect (see Figures 16 and 17) [7].

If for whatever reason small in-leakages of cooling water or air happen to occur, the impact of the impurity ingress is twice as pronounced due to the higher pressure gradient compared to

full-load operation, the higher amount of impurity entering into the condenser and the lower dilution due to lower condensate flow.

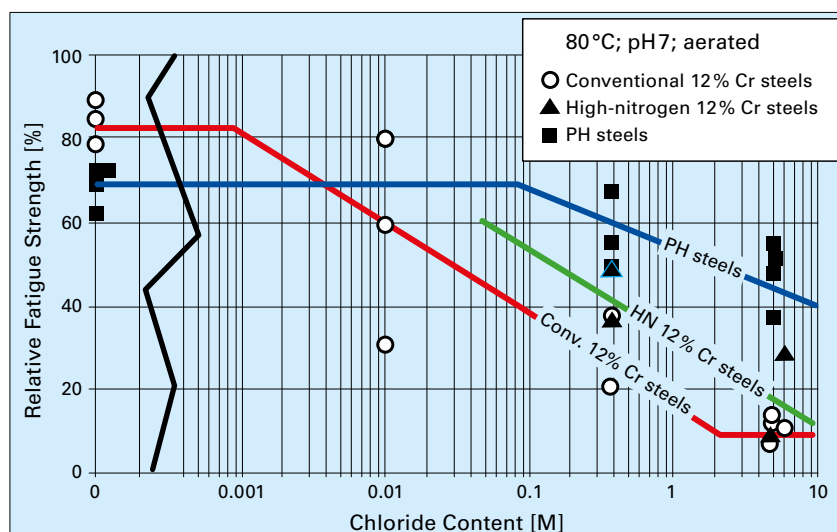


Figure 14:  
Reduction of the fatigue limit in dependence on the chloride concentration at L-1 LP blades.





Figure 16:  
Titanium condenser tube sample showing severe droplet erosion from the outside.

on the different thermal expansion coefficients of the base metal (steel alloys) compared to magnetite ( $\text{Fe}_3\text{O}_4$ ). Figure 18 shows the linear expansion coefficient of iron and magnetite over temperature in the range from 0 °C to 400 °C.

If this stress exceeds the bonding forces of the magnetite on the steel substrate, the magnetite might partially flake off (see Figure 19).

The released particles are transported with the water and steam through the entire steam-water cycle and can cause severe disturbance of operation. An example of the abrasive effect of magnetite particles circulating in the steam-water cycle is shown in Figure 20, where the insert of a control valve is displayed.

Due to the heavy abrasion shown in Figure 20, the valve has lost its control characteristics. Flow rate fluctuations and oscillations might be the result.

Blockage of valves due to the accumulation of magnetite deposits in the clearance between moving and stationary parts of a valve might be another effect of magnetite spallation. Flaked-off material builds up deposits on, for example, hot surfaces in boiler tubes. The deposit forms a thermal insulation barrier inside of the tubes. The tubes then are insufficiently cooled, causing overheating of the tube materials that results in increased creep of the tube material and finally ends in fishmouth-openings and tube bursts (see Figure 21).

As can be deduced from the diagram in Figure 22 [8], every steep temperature rise or drop leads to mechanical stress at the interface of the iron base metal and magnetite layer. As the diagram shows, the clean condensate downstream of the

boiler tubes. The deposit forms a thermal insulation barrier inside of the tubes. The tubes then are insufficiently cooled, causing overheating of the tube materials that results in increased creep of the tube material and finally ends in fishmouth-openings and tube bursts (see Figure 21).



Figure 19:  
Typical appearance of a steam tube's inner surface with partially flaked-off magnetite.

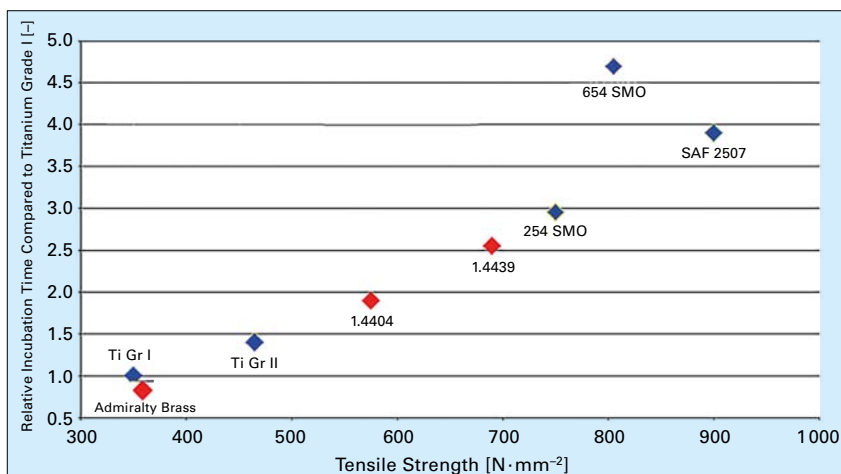


Figure 17:  
Relative incubation time to droplet impingement for various condenser tube materials.

## PHYSICO-CHEMICAL PROCESS CHANGES IN THE STEAM-WATER CYCLE DURING CYCLING AND LOW-LOAD OPERATION – IMPACT OF PARTICULATE IMPURITIES

Phenomena like increased attemperator spray water demand at low-load conditions and temperature shift in HRSGs can also mobilize particulate deposits or even cause (partial) spallation of magnetite (the so-called protection layers) in boiler tubes and elsewhere. This effect is based

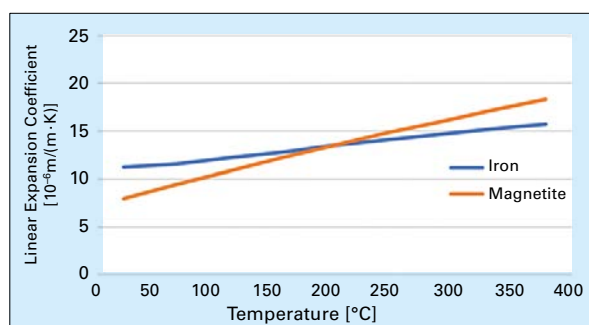


Figure 18:  
Linear expansion coefficient of iron and magnetite in the temperature range from 0 °C to 400 °C.

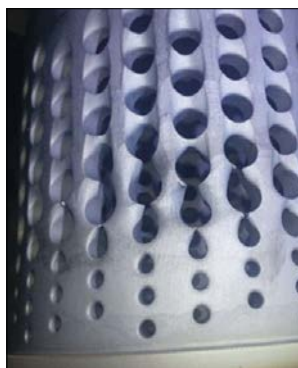


Figure 20:  
Valve insert after several thousand hours of operation affected by magnetite particle erosion.



Figure 21:  
Iron oxide deposits in boiler tubes leading to tube bursts with the typical fish-mouth-openings.

CPP is almost iron-free and meets the requirements as per standards and codes like VGB-S010 [9]. The iron concentration at the LP feedwater sampling point however is by far too high during load transients compared to the action level 1 limit given in the standard.

Iron release during load transients is a good key word for another effect that releases iron into the steam-water cycle, however mainly in dissolved form. This phenomenon is simply based on the solubility of iron(II) oxide in dependence on temperature and pH (see Figure 23).

As can be seen in Figure 23, the highest total iron concentrations in the LP feedwater can be measured when the load is increased after low-load operation. As stated above, during low-load operation, the temperature profile in the steam-water cycle is shifted towards lower temperatures in most parts of the system. At around 150°C the solubility of iron(II) oxide is at a maximum, especially at lower pH. Components operated in this temperature range during low-load conditions will release more iron(II) oxide. When the load increases again as well as while passing through the steam-water cycle, the water temperature will rise. This will result in oversaturation and the excess iron(II) oxide will precipitate (see Figure 23). Again, thermal insulation barriers will build up that might lead to tube failures due to overheating of the tube material.

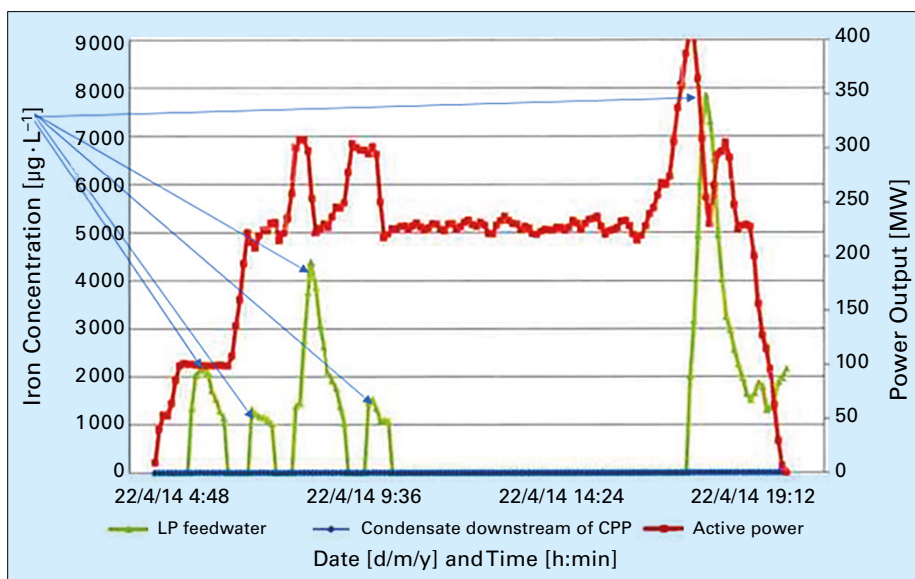


Figure 22:  
Total iron content in feedwater and condensate during load transients of a typical CCPP with an air-cooled condenser.

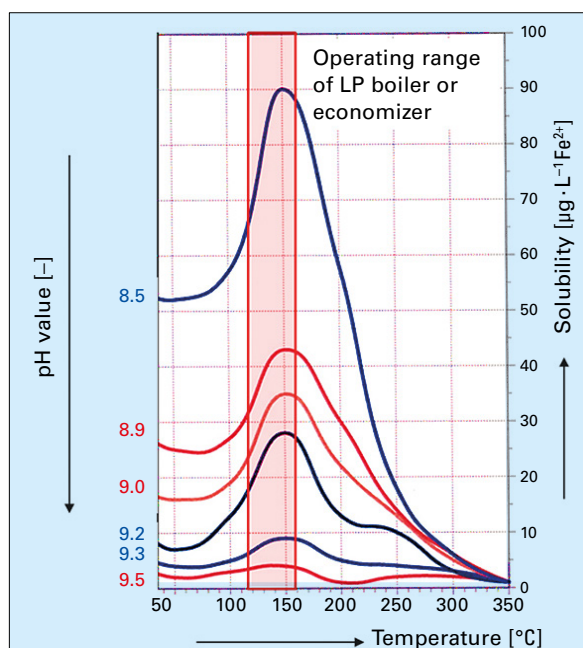


Figure 23:  
Temperature and pH dependence of iron(II) oxide solubility.

## RECOMMENDATIONS AND CONCLUSION

As discussed here, it turns out that physico-chemical operation of a power plant based on a "good enough" philosophy might be an economically viable solution for base-load operation, but it is not good enough when it comes to frequent load changes with a high portion of low-load operation. Impurities that may have come into the system in different ways and have formed deposits (and have thereby been "removed" from the circulating water and steam in the steam-water cycle) might be remobilized during low-load operation. To avoid such remobilization with all its consequences, such as an increased level of salts in the working media, build-up of deposits in the boiler tubes or on turbine blades, corrosion, etc., as good as possible water chemistry should be aimed for. This might require plant modifications and/or better monitoring and control of the physico-chemical operation of the power plant. Corrosion product sampling is not trivial, starting with the location of sampling points, sampling itself and finally the analysis in the lab with different methods and preparation steps. A good summary with advice on what and how sampling of particulate matter from the steam-water cycle should be done is given in the IAPWS technical guidance document (TGD) 6-13 [10]. Special attention should be given to the potential sources and locations of impurity ingress, like condenser leaks, make-up water quality, impurities coming into the system with dosing chemicals or being brought in with the reuse of, for example, return condensate. Good advice and guidance are given, for example, in the VGB Feed Water, Boiler Water and Steam Quality Standard S-010 [9] together with the VGB standards for sampling S-006 [11] and dosing S-042 [12] and the following IAPWS guidance documents TGD 1-08 [13] and TGD 2-09(2015) [14].

## ACKNOWLEDGEMENT

While preparing the article, the author learned of the passing of Hans-Günter Seipp, a former colleague and good friend. Hans-Günter Seipp was with Alstom Power Support GmbH, Mannheim (formerly part of Brown Boveri & Cie), from 1968 until his retirement in 2003, where he first headed the Water Chemistry and Corrosion Group. He actively contributed to several working groups under VGB and DIN, among others, for more than 38 years and published more than 100 technical papers on power plant chemistry. Since 2003, Hans-Günter Seipp had been active as a consultant in the field of power plant chemistry.

The international community has lost in Hans-Günter Seipp a bright researcher and colleague. I will always honour his memory.

## REFERENCES

- [1] *Power Generation and Consumption, 2019*. Agora Energiewende, Berlin, Germany. Available from <https://www.agora-energiewende.de/en/>.
- [2] Collier, J. G., Thome, J. R., *Convective Boiling and Condensation (Oxford Engineering Science Series)*, 1994. Clarendon Press, Oxford, UK.
- [3] Sosa, I. H., *Review/Refresher of Tappi Water Quality Guidelines and Contamination Procedures for Mill Boilers Operating on High Purity Water, 2014*. Available from <http://www.wcblrbac.org>.
- [4] Donath, G., Heitmann, H. G., Messer, J., Schott, M., *Determining the Distribution Coefficients of Volatile Alkalis Agents between Steam and Water and Their Effects on the Corrosion Behaviour of Materials in the Water-Steam Cycle of Power Plants*, 1977. Verlag Chemie, Weinheim, Germany.
- [5] *Sampling and Physico-Chemical Monitoring of Water and Steam Cycles, 2012*. VGB PowerTech Service GmbH, Essen, Germany, VGB-S-006-00-2012-09-EN.
- [6] "Power Plant Water Chemistry" presented at Alstom User Symposium, 2005 (Washington, DC, USA). ALSTOM Power Generation AG, Germany.
- [7] Schulz, W., "Neuberohrung von Turbinenkondensatoren", presented at VGB Workshop "Das kalte Ende", 2013 (Papenburg, Germany). VGB PowerTech Service GmbH, Essen, Germany [in German].



- [8] Rziha, M., "Total-Iron at Cycling CCPPs – The Underestimated Parameter with Cost Intensive Effects", *presented at the 6th European HRSG Forum EHF2019, 2019* (Athens, Greece), International Association for the Properties of Water and Steam, BHT GmbH, Germany.
- [9] *Feed Water, Boiler Water and Steam Quality for Power Plants/Industrial Plant, 2011*. VGB PowerTech Service GmbH, Essen, Germany, VGB-S-010-T-00;2011-12.EN.
- [10] *Technical Guidance Document: Corrosion Product Sampling and Analysis for Fossil and Combined Cycle Plants, 2013*. International Association for the Properties of Water and Steam, IAPWSTGD6-13(2014). Available from <http://www.iapws.org>.
- [11] *Sampling and Physico-Chemical Monitoring of Water and Steam Cycle, 2012*. VGB Power Tech Service GmbH, Essen, Germany, VGB-S-006-00-2012-09-EN.
- [12] *Chemical Feeding and Feed Systems for Water/Steam Circuits, 2018*. VGB PowerTech Service GmbH, Essen, Germany, VGB-S-042-00-2018-01-EN.
- [13] *Technical Guidance Document: Procedures for the Measurement of Carryover of Boiler Water into Steam, 2008*. International Association for the Properties of Water and Steam, IAPWSTGD1-08. Available from <http://www.iapws.org>.
- [14] *Technical Guidance Document: Instrumentation for Monitoring and Control of Cycle Chemistry for the Steam-Water Circuits of Fossil-Fired and Combined-Cycle Power Plants, 2015*. International Association for the Properties of Water and Steam, IAPWS TGD2-09(2015). Available from <http://www.iapws.org>.

## THE AUTHOR

**Frank Udo Leidich** (M.S., Chemical Engineering, University of Dortmund, Ph.D., Technical University Darmstadt, both in Germany) studied chemical engineering at the Technical University Dortmund and wrote his Ph.D. at TU Darmstadt on molten carbonate fuel cells. From 1992 to 2019 he worked with ABB, now GE Power AG, in the Power Plant Chemistry Department in Mannheim (Germany). Frank Udo spent the first twelve years of his professional career commissioning all kinds of power plants and performing trouble shooting/forensic analyses for power plant equipment. He then managed the power plant chemistry and materials departments at the Mannheim site for many years. In his role as technology board committee leader, he was responsible for organizing and promoting knowledge capturing and sharing among GE's chemists across all sectors and businesses. Since 2012 he has been lecturing at the RWTH Aachen University on power plant chemistry. In August 2019 he joined the International Advisory Board of the PPCHEM® Journal.

## CONTACT

Frank Udo Leidich  
Germany

E-mail: [fuleidich@online.de](mailto:fuleidich@online.de)

## PPCHEM® Journal

appreciates any information on planned conferences, workshops, and meetings in the field of power plant chemistry.

Visit us at [journal.ppchem.com](http://journal.ppchem.com)