Advanced and state-of-the-art preservation of combined cycle power plants

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Kurzfassung

Fortschrittliche und „state-of-the-art" Konservierung von GuD-Kraftwerken

Durch die Deregulierung des Energiemarktes und den Anstieg des Gaspreises können Gas-Kombikraftwerke in Europa nicht wirtschaftlich in Grundlast betrieben werden. Heutzutage werden diese Kraftwerke in der Regel zur Deckung der Spitzenlast eingesetzt. Dementsprechend befinden sich Gas-Kombiblöcke sehr häufig im Stillstand von unterschiedlicher und meist nicht vorhersehbarer Dauer. In der Sommerperiode werden viele dieser Kraftwerke stillgelegt.

Um dennoch sicherzustellen, dass die geplante Lebensdauer des Kraftwerks während der Stillstandsphasen nicht negativ beeinflußt wird, zur Verhinderung von Korrosion an den Kraftwerkskomponenten, Vermeidung von Wirkungsgradminderungen durch Folgen der häufigen Stillstände, bei minimalem Investitionskostenaufwand und geringsten Wartungs- und Instandhaltungskosten, muss ein kraftwerksspezifisches, angepasstes Konservierungskonzept ausgearbeitet werden.

Dabei ergeben sich die folgenden Zielkonflikte:

- *Schnelles Wiederanfahren/hohe Verfügbarkeit ⇔ Optimaler Korrosionsschutz/beste Konservierung*
- *Häufige Stillstände ⇔ Standardanlagenkonzept mit Grundlastbetrieb*
- *Minimale Kosten (Investitionen, Personal) ⇔ Anlagenauslegung und Materialkonzept*
- *Allgemeine Konservierungsempfehlungen ⇔ Anlagenbesonderheiten/lokale Anforderungen*

Im vorliegenden Beitrag werden die prinzipiell möglichen Konservierungsmethoden erläutert und Anwendungsbeispiele für verschiedene Kraftwerkssysteme und -komponenten diskutiert. Dabei wird insbesondere auf eine systemintegrative Konservierung Wert gelegt.

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Introduction

Many combined cycle power plants (CCPP) in Europe cannot be operated economically due to market conditions. Therefore they only run in peaking operation with frequent standstills of variable lay-up time or even are taken off the grid for longer time like summer periods. Cycling and peaking operation as well as frequent starts however consume lifetime in terms of equivalent operation hours. If preservation is not applied during lay-up times, corrosion processes at all components of the power plant are likely to occur in addition to the above and lead to additional lifetime consumption and performance degradation.

To assure that the intended lifetime of CCPPs and their components can be achieved, a suitable tailor-made preservation concept needs to be elaborated, applied and monitored.

The plant is not to be preserved component-wise, but all interfaces between the various sub- and auxiliary systems of a power plant are to be covered. In Figure 1 the main sub-systems of a CCPP are highlighted in different colours.

Each of these sub-systems comprises of various components, pipelines, valves etc. and might be connected to a number of other sub-systems. For example the boiler is connected upstream to the feedwater system of the water steam cycle (WSC). Downstream it is linked to the HP, IP and LP steam systems. In parallel to the boiler, the once-through cooler (OTC) is feeding steam into the steam system and is fed itself by feedwater or LP boiler water.

On the flue gas side of the boiler there are interfaces to the flue gas outlet of the gas turbine and the exhaust from the boiler goes into a flue gas duct or stack directly.

Another example for a component with various and complex interfaces to other sub-systems and components is the steam turbine:

It is not only an integral part of the water steam cycle with interfaces to the steam systems and the condenser but might also have a number of steam extractions that connect the turbine to the feedwater tank, preheaters and/or district heaters. In addition the turbine is equipped with a lube oil system that needs to be considered as well in terms of preservation at least during longer outages. The lube oil system itself again might be more complicated than expected with filters, heat exchangers, pumps valves, actuators, etc.

Of course all suppliers deliver a manual that contains preservation recommendations for the very components. However, these recommendations by nature cannot consider the requirements at system interfaces and beyond limits of supply. Therefore, it is always necessary to adapt the procedures given in the component documentation to the site specifics, ideally without conflicting with warranty issues.

Usual preservation methods recommended by suppliers comprise:

- dry preservation,
- wet preservation,
- preservation with inert gas (nitrogen capping) and
- oil preservation and preservation with organic agents

Dry preservation keeps the electrolyte that is necessary for any corrosion process away from the component´s surfaces by keeping the relative humidity (rH) of the air surrounding the component to be preserved below 40 % rH. In an industrial environment or close to the shore line, where salt mist or corrosive gases, for example SO_2, are likely to be present in the air, it is recommended to keep the humidity below 30 % rH.

Dry preservation is commonly recommended for steam turbines and gas turbines [1, 2]. Here it is the only viable way to prevent corrosion during standstill periods without dismantling of the turbine or other complicated or costly preparation. It can be used for short intermediate and long lay-up periods. For very long outage times, however, the energy consumption of the adsorption drier for regeneration of the de-humidifier might become an issue and it should be considered to adapt oil preservation or preservation with organic agents like volatile corrosion inhibitors (VCI) combined with an air-tight enclosure (wrapping-in) for the rotor. This method is very well established for long storage periods and it is (almost) maintenance free. Especially when it can be combined with a necessary overhaul that anyway requires opening of the turbine casing, this method should be taken into consideration.

Dry preservation can also be applied to the waste heat steam generator (HRSG), the OTC and the water steam cycle. Longer outage periods usually starting from a few weeks onwards is the method of choice for these components.

Wet preservation keeps the oxygen away from the component surfaces that is needed for corrosion. Most times, this method is combined with the elevation of the pH of the water (condensate, feedwater, boiler water) used for preservation to minimise the solubility of the protective iron oxide layers in the water. For all ferrous metallurgy systems, a pH increase to pH >9.5 is recommended, for CCPPs equipped with an air-cooled condenser this should be not less than even pH 9.8. The oxygen concentration in the water shall not exceed 5 ppb during lay-up time. Therefore, it is good advice to already lower the oxygen content in the WSC during load reduction and shutdown by opening the feedwater deaeration vent completely and stop oxygen dosing beforehand. Of course water losses and leaks should be minimised during the outage period. A good number for the allowed water loss is <1 % per week of the filling volume. In case the system needs to be refilled anyway due to water losses, it is good advice to use de-aerated water for refill. Such water can be taken from a sister unit or by membrane de-aeration of demineralised water. After de-aeration the pH of the refill water shall be adjusted to the desired target value.

The components, for which wet-preservation usually is the method of choice, are the OTC, the HRSG and the water steam cycle.

Nitrogen capping is based on the same principle as wet preservation: It keeps the oxygen away from the components' surfaces that is needed for corrosion. Therefore, it can easily be combined with wet preservation, what designates this method for boiler preservation. The economiser and evaporator sections of the boiler are wet preserved whereas the steam containing parts like drum and superheaters are filled with nitrogen for preservation. A good preserving nitrogen atmosphere does not contain more than 0.5 % of oxygen. To avoid air ingress into the system or component to be protected, a slight overpressure should be established. Of course nitrogen capping suffers even from small leakages as due to the overpressure this results in gas losses, which if too high, might make this method in-economic. On the other hand the overpressure should not be chosen too small compared to the ambient air pressure as temperature fluctuations (even caused by night and day temperature cycling) might already result in 20 mbar pressure differences.

Besides the boiler, the OTC, the generator and the fuel gas system can be protected against corrosion by nitrogen filling. Nitrogen filling is also used for long-term storage and transportation of components that can be fully isolated (encapsulated) from the environment.

Oil preservation and organic preservation agents are used especially for transportation and long-term storage of components and of course for lube and sealing oil systems. The basic principle behind is that the oil or organic preservation agent forms a layer on the component that prevents the direct contact between the electrolyte and the surfaces.

Oil preservation as well as preservation with organic agents is easy to apply and suitable for long-term corrosion protection.

What needs to be considered when choosing this method of corrosion protection is the ease of removal before re-commissioning or the potential interaction of the preservation chemical with the operation medium (water, steam or oil). A second hurdle is that these preservation methods cannot be checked with objective evidence, e.g. by measurement of the humidity or oxygen content as an early warning before corrosion arises. Functioning of this kind of preservation methods is usually checked visually, i.e. corrosion signs are looked for. Finding signs of corrosion, however, means that it is too late and the corrosion process has already started.

Volatile corrosion inhibitors (VCI) are mainly used for the same purpose as oil preservation and preservation with organic preservation agents. As such, they have the same advantages and disadvantages as oil preservation.

VCI products are available in many different forms: powders, fluids, pellets, impregnated foils and papers, etc. All these different forms have in common that the preservation agent itself is released from the substrate in gaseous form and forms a layer on the material's surface to be protected. This intrinsically requires an enclosure (gas tight wrapping or closed container/box) around the part to be protected. If only the inner surface of a vessel or tube shall be protected against corrosion by application of VCI, it is sufficient to close all openings of the vessel or tube ends to avoid loss of VCI vapour.

The reason to apply preservation on components and systems is to assure that the intended lifetime of the power plant is not negatively impacted during lay-up time by corrosion reactions or any other kind of degradation of plant components. Looking into the manuals of the component suppliers might help to find a suitable preservation method for the particular component. However, quite likely, different requirements or methods are recommended for components connected to each other without the possibility to isolate one from the other, e.g. by closing of a valve. In such a case, a compromise needs to be found or a method chosen that works for both components. In addition to this complication compared to single component preservation other conflicts of goals also arise.

Very often, the time when the unit is to be restarted is fairly not known when the unit is shut down, i.e. that the duration of standstill is not known. The standstill time is one of the important parameters to decide for the one or other preservation method. In many cases there is a strong economic need for fast re-start ability of the power plants. This, however, restricts in principle the applicable preservation methods to those that do not require long and extensive preparation work for lay-up and re-start. It might as well conflict with the aim to assure perfect corrosion protection/preservation to avoid any performance or lifetime degradation.

Frequent layup times might clash with the original plant concept and design that very often assumes base load operation. A common requirement from owner's side is the realisation of preservation concepts with minimum efforts in manpower and investments. This very often does not fit together with the original plant design and materials concept that are mainly focusing on least investment costs.

In can be summarised that a general preservation guideline cannot take into account all these controversial requirements

Tab. 1. Recommended preservation methods for a steam turbine including condenser dependent on the lay-up period.

Type of preservation	Hot standby preservation	Short-term preservation	Medium-term preservation	Long-term preservation
Typical period	< 2 days	2 to 10 days	10 days to 10 weeks	More than 10 weeks
Measures steam turbine	Hot standby and CECD	Washing and CECD or dry air preservation	Dry air preservation	Dry air preservation
Measures steam side condenser	Hot standby and CECD	CECD or dry air preservation	Dry air preservation	Dry air preservation
Measures water side condenser	Keep filled	Periodic flushing with fresh water	Periodic flushing with fresh water or drain and dry air preservation	Drain and dry air preservation
Measures hotwell	Keep filled	Drain	Drain and dry air preservation	Drain and dry air preservation

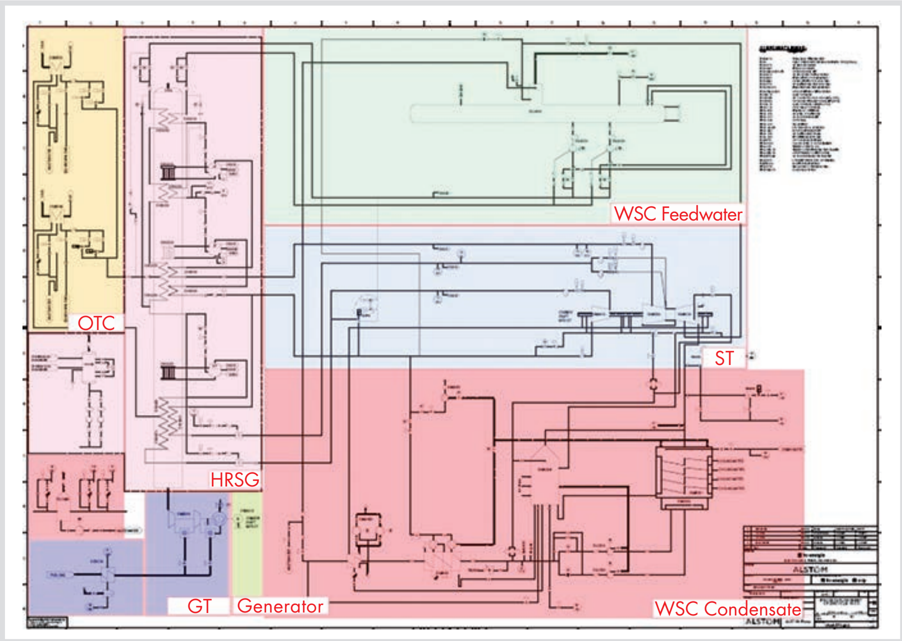

Fig. 1. The main (sub-)systems of a combined cycle power plant.

and requests. This can only be covered by a tailor-made plant specific preservation concept. In the following, a few examples are given.

Table 1 lists the recommended preservation methods for a steam turbine combined with the preservation recommendations for the condenser. Wet preservation is not possible for a steam turbine. On the other hand, for shorter outage periods with fast re-start ability, the condenser hotwell needs to be kept filled with condensate. This limits the applicable preservation method to vacuum preservation or a combination of a hot standstill and optimised shutdown procedure by application of the Alstom CECD diagnostics tool. Whereas vacuum preservation requires continuous generation and consumption of steam (for example by operation of an auxiliary steam generator) to feed the gland seals and also non-interrupted operation of the vacuum pumps, a hot standstill combined with CECD does normally not require any additional installation or continuous consumption of steam or large amounts of electricity. With CECD the shutdown procedure and the changes in humidity in the area of the turbine exhaust neck are measured and the root causes for the humidity changes are identified and analysed. By modification of the shutdown procedure and several measures during standstill, the turbine and condenser neck can be kept dry for an entire weekend standstill.

One possible source leading to the increase of the relative humidity could be the draining of the boiler drain collection tank. The boiler condensate that develops during the standstill collects in a tank; as soon as the filling level of the tank is reached, the tank is automatically discharged into the condenser hotwell. As a result, hot water up to around 85 °C enters the hotwell causing an increase in humidity in the LP turbine exhaust. One possible modification would be to avoid discharging the condensate into the hotwell during the standstill period (Figure 2). An increase inside the LP casing could also be caused by vapour that comes from the vacuum flashbox and gets into the cold condenser (Figure 3). This problem could be mitigated by keeping one condensate pump at minimum flow and the vacuum pumps turned on during standstill periods in order to exchange the hot condensate at the vacuum flash box with cold condensate. Spraying the hot condensate over the cold condenser tubes provides an additional cooling effect as long as the cooling water pumps are running. However, the spray nozzles should be operated with care, as they could produce mist leading to an increase in relative humidity at the turbine neck.

If the CECD package is applied to the steam turbine and the relative humidity in the exhaust neck of the LP turbine can be kept below 40 % relative humidity during the entire lay-up time, Alstom allows reducing the consumption of Equivalent Operation Hours (EOH) from 50 to 25 per standstill/start-up.

If the plant is shutdown frequently and the duration often exceeds a weekend outage, this preservation method can be combined with dry preservation by installation of a permanent adsorption dryer and automa-

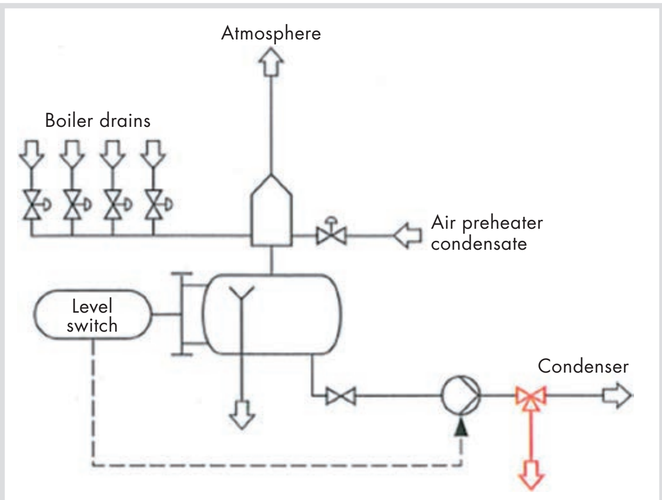

Fig. 2. Boiler condensate collection tank with possibility to discharge the collected condensate during standstill.

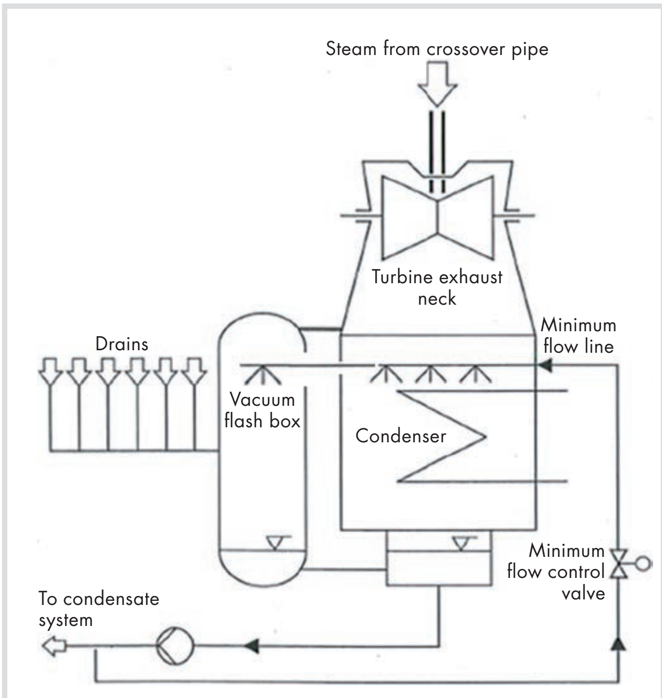

Fig. 3. Cooling down of a vacuum flash box content by operation of the condensate pump in minimum recirculation mode.

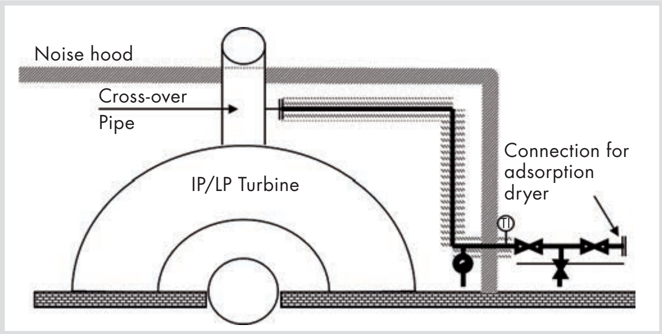

Fig. 4. Automatised preservation of a steam turbine for short and long standstill periods.

tised as shown in Figure 4.

Whenever needed, the adsorption drier can be put into operation by the signal coming from the humidity probe from the CECD installation, the gate valves open and the dry air is blown into the cross-over pipeline between the IP and the LP turbines. Special types of gate valves for sure need to be installed to assure tightness at overpressure as well as under vacuum conditions. Very often, a recommendation from the turbine suppliers is to keep the turbine in turning-gear operation at least until the turbine has cooled down to a certain temperature to avoid distortion of the rotor due to different cooling rates in the upper and lower half of the split casing. Operation of the rotor in turning gear, however, works against the dry air flow to the IP turbine. As long as the IP turbine's temperature is above 100 °C condensation and thereby caused corrosion cannot happen anyway. After the IP turbine has cooled down to below boiling point, the turning gear should be switched on only for a short time per week to re-establish the lubricant film in the bearings and the entire lube oil system.

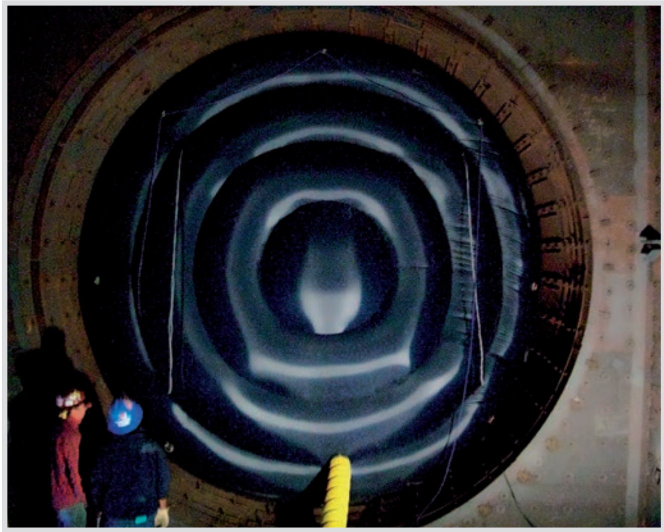

Fig. 6. Duct balloon installed between the gas turbine flue gas outlet and the HRSG. Figure used with the courtesy of G.R. Werth & Associates, Inc.

For the rest of the time, the turning gear should be switched off, so that the dry air can blow into the IP turbine from the cross-over pipeline in reverse steam direction.

If the outage is even extended to much longer periods, in addition to the above, the hotwell should be emptied. Also the cooling water needs to be drained out of the condenser tubes to avoid settlement of dispersed solids or biological growth of aquatic life forms inside of the tubes. To avoid corrosion attack at the condenser tubes, water residues after drainage of the condenser shall be removed by blowing through with compressed air and/or flushing with clean water, ideally demineralised water. This is shown in Table 2, where the criticality of the water quality that might concentrate in salt content by dry-out of water residues based on different water sources and for different commonly used condenser tube materials is estimated.

Another good example for conflicting recommendations and a potential mitigation is shown in Figure 5. The suppliers of condensate pumps with pot-pump casing design usually request for wet preservation of the pump to avoid damage to the slip rings. In addition they might even require operation of the pump for at least one hour every 14 days. This does not match with the recommendations given by the turbine suppliers to establish dry preservation of the turbine and the condenser, if the outage time lasts longer than a few days. Emptying of the pot pump casing usually is not possible without dismantling of the impeller.

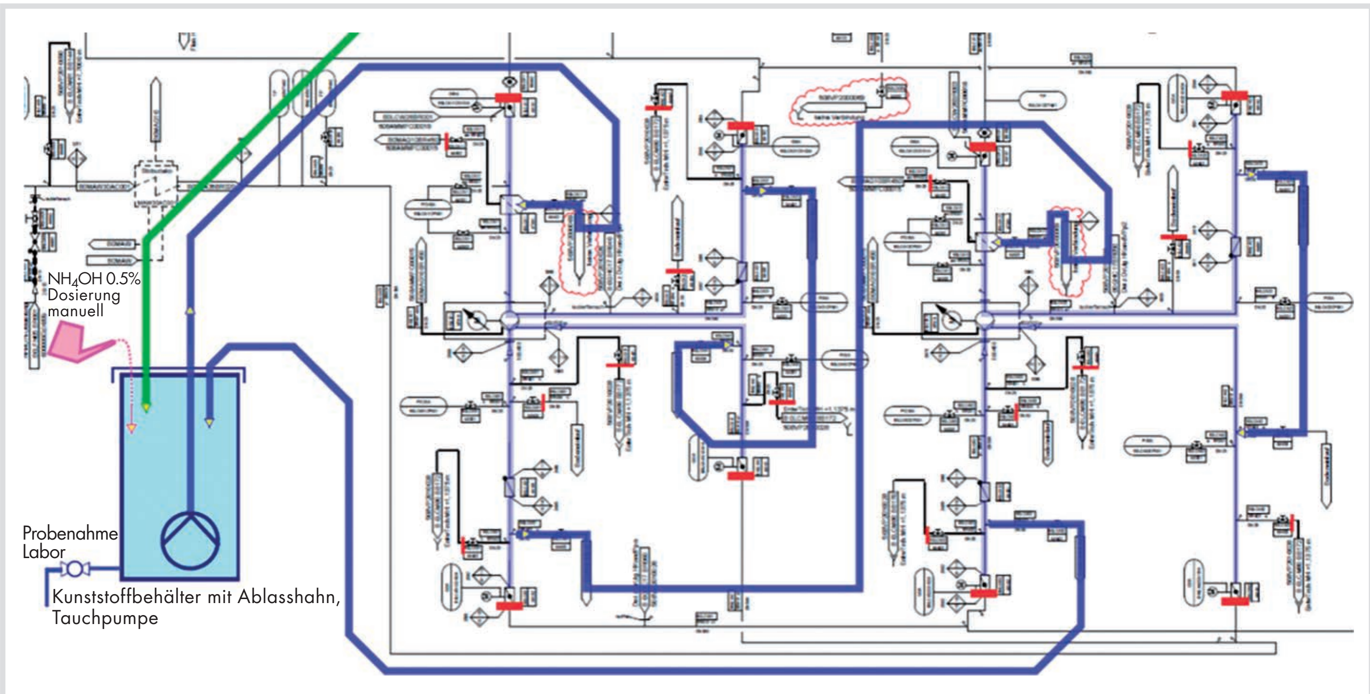

Fig. 5. Creation of a temporary wet preservation loop to protect the slip rings of the condensate pumps from dry-out.

Tab. 2. Impact of water quality on the corrosion stability of condenser tube material due to dry-out effects.

	Demin water/ condensate	Drinking water	River water/ cooling tower water
Assumed concentration of sodium chloride (mg/l)	0.0584	58.4	250
Resutling conductivity (µS/cm)	0.18	125	625
Acid conductivity (µS/cm)	0.43	423	2,200
Remaining water residue after dry-out SS304 (resistance limit Cl^- 100 mg/kg)	0.035 %	35%	Not stable
Remaining water residue after dry-out SS316 (resistance limit Cl^- 1500 mg/kg)	0.0025 %	2.5 %	12.5 %

To keep the slip rings of the pump wet and the pot pump casing filled, a temporary wet preservation loop can be established by connecting temporary hoses to the vent/drain lines upstream and downstream of the pump. The loop is completed by a small collection tank and a submersible pump of low capacity to circulate the water. This system is filled with demineralised water or condensate and the pH is adjusted with ammonia to some pH 10. If the duration of the standstill is not too long (several months), there is no need to protect the tank against oxygen ingress from the atmosphere.

Preservation of the flue gas side of the GT, the HRSG and the once-through cooler (OTC) for the compressed combustion air is another challenge, that on the one side is easy to cope with and on the other side also reveals some conflicts:

For cost reasons most combined cycle power plants have no bypass channel that routes the exhaust flue gas from the gas turbine exhaust neck directly into the stack without passing through the HRSG. For the same reason stack dampers and dampers or jalousies in the filter house of the air intake system are not installed. As a consequence, the gas turbine, the HRSG and the OTC are cooling down quickly due to natural draught caused by the stack.

During weather changes or even caused by day and night temperature gradients, condensation might happen on all cold surfaces of the entire air intake and flue gas path. Dependent on deposits (mainly after oil firing), sulphuric acid containing electrolytes may form and heavy rusting and corrosion can happen.

A good and easy to establish mitigation is the use of duct balloons as shown exemplary in Figure 6. These inflatable air cushions can stop the draught and isolate the flue gas path from ambient conditions and weathering. Adsorption driers of small capacity can be connected to the gas turbine or the OTC to keep the entire system dry.

References

[1] VGB-S-036-00-2014-08-DE "Konservierung von Dampfturbosätzen", VGB PowerTech, Essen, 2014.

[2] VGB-R 116e "Preservation of Power Plant Systems" VGB Power Tech, Essen, 2009.

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