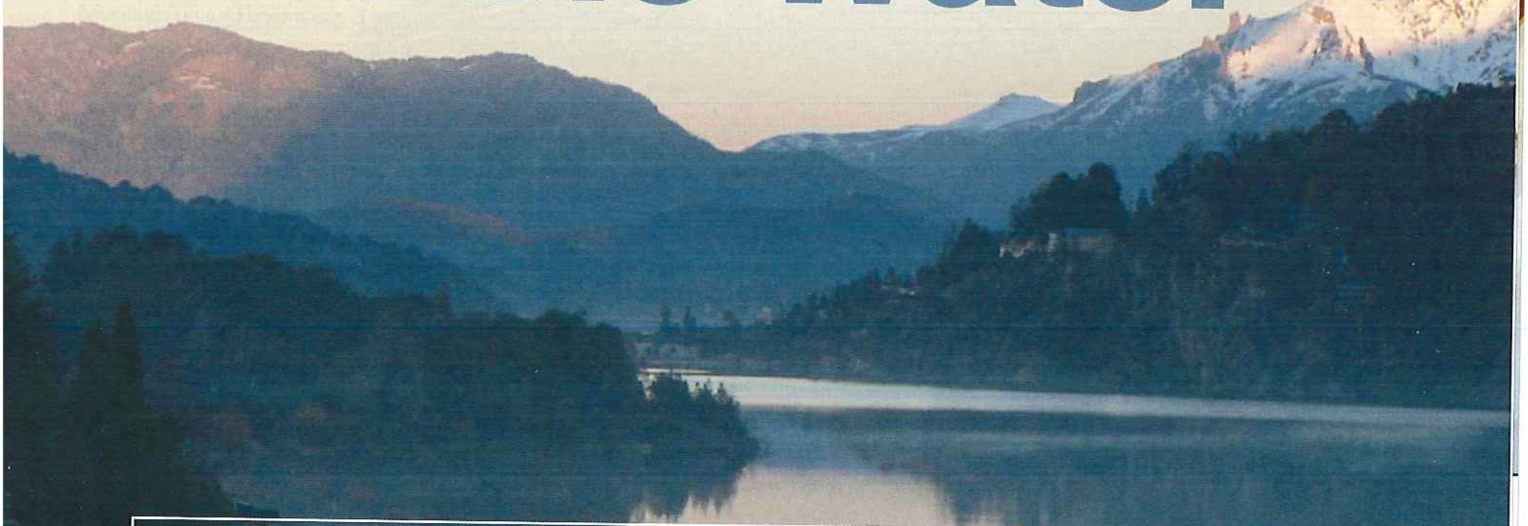
Something in the water



F. Callero and R. Martini, ABB, Italy, and M. Abela, D. Giannobile, Isab Energy Services, Italy, discuss the challenges that face industrial water treatment, and the advanced process control measures that can be implemented at an IGCC plant to overcome them.

Local environmental regulations force industrial plant operators to treat process wastewater in order to comply with discharge limits. Most industrial plants and utilities have process units devoted to wastewater where those are treated by means of physical or chemical methods. On the other hand, the goal of many industrial plants is to maximise productivity and optimise operation cost; hence, the concept of 'watergy' is becoming a fundamental one for plant managers. This expression describes the envelope which includes water management and energy and is becoming more and more popular in the industrial market.

This article will describe how advanced automation technologies support an IGCC wastewater treatment plant to comply with regulations and, at the same time, to optimise operations and increase energy efficiency. In particular, it will describe how, by means of model predictive control (MPC), an effective pH control was achieved in a wastewater stripping column, minimising the usage of steam for stripping operation. Herein, a brief description of plant and process will be provided, highlighting operation and control challenges, followed by a brief description of project goals and technologies implemented to deal with the problems. Conclusions will show some results and achievements in term of process manageability and energy efficiency improvements.

IGCC

Isab Energy IGCC plant, integrated with an upstream SDA refinery unit, converts approximately 120 tph of heavy residual oil, provided by the nearby refinery, into more than 500 MW of electric power and can be divided in three main areas (Figure 1):

- Solvent deasphalting unit (SDA) treats the heavy residues from the refinery: the deasphalted oil (DAO) is sent back to the refinery, while the asphalt is fed to the gasification unit.
- Gasification transforms the asphalt into syngas; this section includes different units, encompassing units for sulfur, carbon, acid gas and heavy metal recovery, which are removed prior the combustion.
- Combined cycle unit (CCU) includes two trains for power generation, each of them with a gas turbine, a HRSG and a steam turbine.

Overall process water treatment

In the gasification section (Figure 2), syngas is processed in different units before arriving at the CCU, in order to remove unwanted compounds or matters which are recoverable for further purposes. In these conditioning units large amounts of utilities are used. Wastewater treatments are necessary to process the water utilities before discharge in order to comply with local environmental regulations. Wastewater main sources are hence represented by soot water coming from the gasification unit.

This is first sent to the carbon recovery unit where the ashes and carbon content is abated; after this treatment, a crucial step is represented by the heavy metal recovery unit were all the pollutants are removed and stored as metal cake for disposal. Residual wastewater purified from metals and solids is then sent to the wastewater pretreatment unit which represents the scope of this application.

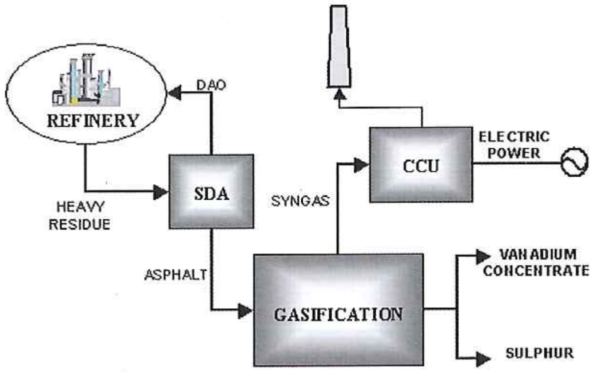


Figure 1. IGCC plant scheme.

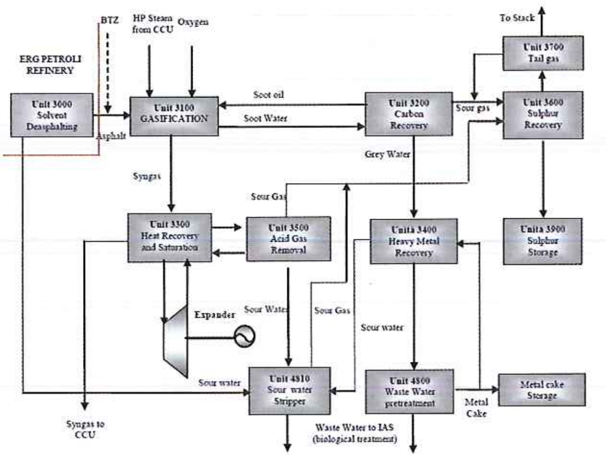


Figure 2. Gasification flow diagram.

$$x(k+1) = Ax(k) + B_u\,(u(k) + w(k)) + B_d\,d(k)$$
$$z(k) = Cx(k)$$
$$y(k) = Cx(k) + v(k)$$

Figure 3. Where: x is the state vector; u is the process input or control effort vector; d is a vector of measured disturbance variables, also known as feedforwards; w, v are noise vectors; z is the vector of process variables; y is the vector of process variables with measurement noise; A, Bu, Bd, and C are process matrices; and k is the time in number of sampling intervals.

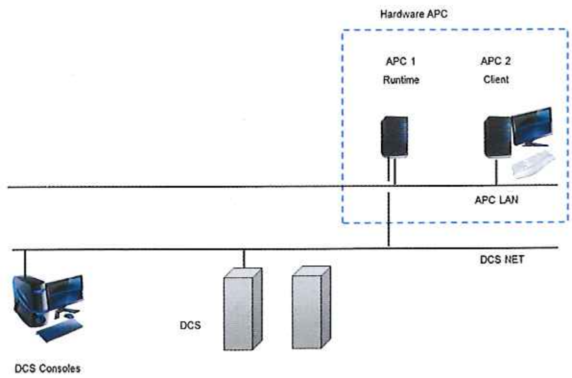


Figure 4. HW architecture.

In this unit, water coming from different processes is treated with chemicals and stripped with steam. At the end, treated water is then sent to the secondary water treatment unit external to the IGCC plant.

The secondary process is based on biological treatment by aeration in specific tanks.

Wastewater pretreatment unit

The unit consists mainly of a stripping column, where the water is separated from ammonia by means of thermal separation. In order to perform an effective separation, the wastewater inlet stream is added with soda (NaOH)[1], whose quantity is regulated by a devoted pump. The stripper thermal balance is guaranteed by a pump around which the water exchanges heat with steam in a specific reboiler; steam coming from low pressure network is controlled and adjusted in ratio with the actual wastewater column inlet. The column top stream, rich in ammonia, is successively sent to other process units, while the bottom stream represents the pretreated water which is sent to sour water treatment unit.

One of the major challenges in this process is related to the effective control of the stripping column, whose objective is to maintain the value of the pH and residual ammonia content of the outlet water within predetermined ranges. Maintaining the correct level the pH of treated water is crucial for two main concurrent factors:

- Prevent formation of carbonates, which can precipitate and lead to the need of unit maintenance due to clogging and fouling processes or, even worse, major failure in water pumps: $NaOH + CO_2 + H_2O$--à $(CO3)^{2-}$ ↓.
- Guarantee an effective ammonia stripping: NH_4^+ (l) + OH^-(l) + QàH_2O+ NH_3 (g).

This process is controlled by two main operating parameters:

- The quantity of soda that is introduced before the stripper.
- The steam/load ratio at the reboiler.

Both the steam/load ratio and the soda have a direct effect on process variables of the system (pH and residual ammonia content), which is further characterised by a slow response dynamic.

The previously existing control strategy, based on DCS control scheme, showed poor control performance. In particular, the following issues emerged:

- The DCS configuration had the pH control in closed loop which cascaded to the soda trimming (before the stripper section).
- pH control used sensors located upstream to the stripping column and close to soda injection but this measurement has a very low reliability/availability and is affected by periodic clogging, resulting in very rare and short operation in closed loop. pH was therefore monitored and controlled using measurements downstream to the column having much higher availability but with very slow dynamics. The slow dynamics and long delays, along with the nonlinear nature of pH/soda relationship made it nearly impossible to properly tune the pH control loop using the downstream pH measurement.
- pH control is affected by several unmeasured disturbances, related to small sour water streams, which are collected together with the main inlet.

The control of the NH_3 residual content was assigned to a manual operator control, as a consequence the pH measurement showed excessive swings, together with an excessive usage of low pressure (LP) steam. Current challenges in process control lead to

Variable description	Type target
Controlled variables	
Residual ammonia from stripping column	Min limit
Downstream pH (measured downstream) of stripping column	Setpoint with band
Top column pressure	Max limit
Upstream pH measurement	Min/max (when available)
Manipulated variables	
Soda al 10% inlet	
Ratio steam/load at stripping column	Minimise

Table 1. Controller configuration

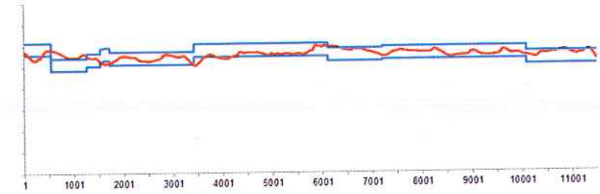


Figure 5. Results from pH control over a 1 week period (band = 0.3).

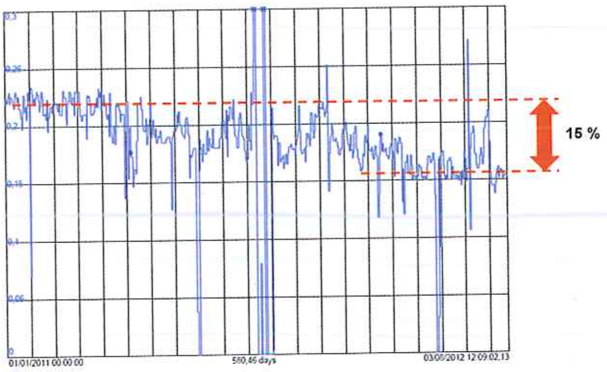


Figure 6. Specific steam usage unit since MPC activation.

the decision to engineer and install an advanced controller based on MPC.

Space state technology

The multivariable controller used to implement this application is OptimizeIT Predict & Controller software, based on state space technology. This technology allows to properly handle rejection of unmeasured disturbances, especially when available upstream measurements (faster) can be used to anticipate future changes in downstream measurements (slower).

For a long time, the control literature has described modern control algorithms based on a flexible type of multivariable model. The model was based on linear differential equations that mapped the relationships between process inputs and process outputs through use of intermediate variables, called the state vector. This type of model was called a state space model. MPC algorithms came along after state space models were introduced, but did not use this type of model.

State space models became linked to optimal control theory for aerospace applications and did not include many of the practical control objectives that were part of the design basis of MPC. The result was that state space models were ignored for a long time by the process industries, but recent enhancements in new algorithms have changed that. The equations that represent a discrete time state space model are presented in Figure 3.

In this case, the MPC controller uses an explicit estimation of state vector X to compute the future moves on manipulated variables.[7]

MPC at the water pretreatment unit

The MPC solution implemented in the water pretreatment unit has been seamlessly integrated into the existing automation hardware configuration, as presented in Figure 4. The application is based on dynamic process models taking into account the relation between controlled variables (CV), manipulated variables (MV) and disturbances (FF). Those relations have been extrapolated by observing the historical process data gathered from plant DCS as well as by means of a data collection campaign coupled with devoted step tests when possible. Step tests were performed in strict cooperation with plant operation and always keeping in account process stability and targets. Evaluation of relations between controlled variables, manipulated variables and disturbances gave the possibility to deploy models representing the core of MPC.

The solution applied is the ABB OptimizeIT Predict and Control (P&C), a software package for multivariable control based on state space modeling technology. The tool communicates with the existing plant control system, the ABB Melody DCS, through the use of an OPC connection thanks to the existing OPC Server DA.

The project represents a second step of APC system's implementation strategy related to the etire IGCC plant.

The first step featured APC solutions in some of the key process units, such as SDA unit, AGR unit and gasifier units.[3]

A third step was executed in 2012, covering an MPC acting as global IGCC coordinator to control power export control and also a controller dedicated to gasifiers water management.

Advanced controller configuration and operation

The APC technology was essential for achieving an effective pH control in the wastewater stripping column, so too for simultaneously achieving compliance with regulation, optimising operation and increasing energy efficiency.

In detail, the purpose of the APC application is to automatically move the manipulated variables (i.e. soda and steam/load ratio) in order to:

- Keep the pH near the required setpoint, avoiding the precipitation of carbonates that may affect the overall process also due to the deterioration of equipment and maximising the efficiency of the stripping column.
- Keep top stripping column pressure below a minimum value in order to ensure stable operation.
- Keep the value of the residual ammonia below a maximum, minimising the need for the low pressure (LP) steam for stripping.
- Keep the pH for the upstream measurement in range when this measurement is available. When this variable is active, the controller uses it as an additional feedforward in its state space model to predict future changes in the downstream pH following changes in the upstream pH.

Table 1 shows the configuration of the controller, covering the main controlled variables (CV) and control mode, manipulated variables (MV) and type target where applicable.

In order to preserve safe operation and stable and process conditions at the controller configuration stage, a number of settings and limits have been implemented on both DCS and P&C controller side.

Results

The advanced controller has been in operation since late 2010 and has led to significant benefits both on process operability and economic returns.

Figure 5 shows the pH control results over a one week period with indication of the limits. pH control with APC showed a reduction in variable standard deviation of approximately 45% compared to the case with normal DCS control.

The implementation of APC allowed the plant to operate with lower steam usage. As plant operators gained confidence in the controller, additional space was given to the steam ratio setpoint, allowing a progressive reduction of the specific steam usage.

Figure 6 shows the specific steam usage over roughly one year, with an overall reduction of approximately 15%. This resulted in large steam savings, whose potential value can be estimated in the range of €300 000/y. Further to this, the customer experienced additional benefits in terms of reduction of operator's activities and daily tasks, which resulted in additional time that could be dedicated to other tasks.

Conclusion

In conclusion, the final results prove that APC is a valuable technology for supporting plant owners and managers in the implementation of the 'watergy' concept:[5] This term is becoming more and more important for industries having to deal at the same time with crucial factors like environmental and operational sustainability, as well as process and energy efficiency.

APC has led to a significant increase in treatment performance, allowing a better pH control at the stripping column for ammonia removal. At the same time, it was possible to achieve significant savings in steam consumption and tangible economic benefits. This second successful step of APC implementation at an IGCC plant has paved the way to further application for the completion of plant unit optimisation.

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