The growing importance of technical services

As existing facilities grow older, service requirements increase. Equipment needs to be low maintenance and back in operation quickly after service and repair. Technology licensors are expanding their technical services with new digital tools, using digitalised expertise with real time insights and data driven analytics to boost chemical production and ensure that equipment operates reliably and efficiently, while maintaining product quality.

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Casale's digitalised expertise at customer service

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The operation of chemical plants is a highly complex task due to the intricate interaction between chemicals, reactions, flow dynamics, etc. and from the need to manipulate a large set of variables to reach production targets, while maintaining optimum efficiency. Plant performance and its associated operating costs are impacted by both external and internal factors, for example, changes in the composition of the raw materials, weather conditions, as well as the experience and expertise of the operators. Plant performance is measured in terms of key performance indicators, including the overall production, specific energy consumption, plant stability, emissions, etc.

The close relationship between process operation and mechanical reliability adds to the complex operation of chemical plants. Often, plants are highly stressed by the operating conditions, which are kept close to their limits to maintain profits. This is particularly true for old plants whose mechanical reliability and related performance must be carefully monitored. Therefore, it is of utmost importance to develop maintenance programs aimed at improving reliability. The operational data becomes a fundamental part of a more extensive analysis that not only supports the diagnostics of failures but also helps to understand the root causes during mechanical inspections.

Chemical plants generate a huge amount of data on a daily basis. The data is mostly used for DCS visualisation and archival purposes, and for helping field operations and control. Unfortunately, due to the lack of resources and time, prominent trends and data correlations are seldom analysed thoroughly, leading to suboptimal operation. Furthermore, in critical scenarios, expert advice is normally needed, if not mandatory.

To help plant operations, support maintenance and improve mechanical reliability, Casale has created a portfolio of digital products that takes full advantage of the existing plant data infrastructure:

- Casale Remote Engineering Service (CARES);
- Casale Operator Training System (OTS);
- Casale Model Predictive Control (MPC);
- Casale smart instrumentation.

Casale Remote Engineering Service (CARES)

CARES is a remote engineering service which provides assistance to plant operators and managers, supporting the achievement of their daily operational targets, improving process reliability and supporting mechanical inspections.

At the core of remote engineering services, Casale uses an automatic data reconciliation algorithm to convert measured data from the plant into physically-consistent values that respect global and local mass and energy conservation around units of operation, sections of the plant or the whole plant. An important feature to note is that the data reconciliation tool uses the same Casale proprietary models and thermodynamic packages regularly used for designing the plants: a critical feature that ensures the highest possible fidelity of the service.

The data reconciliation is much more than a process simulation, it is a tailor-made process model built up to reveal the real time performance of the plant, including full information of the critical process streams, which cannot be directly measured in the field, e.g. the full composition at the reactor outlet. Thus, calculated key performance indicators (KPIs) based on reconciled data offer great value to clients, providing an effective way to identify critical aspects of the plant operation and their temporal behaviour.

Data reconciliation also allows the identification of faulty readings and anomalies in the field instrumentation used to guide the process operation. Thanks to the power of the data reconciliation, abnormal deviations among reconciled quantities and field measurements are promptly detected and thus used to alert critical conditions into the plant. Essentially the identification of erratic readings of the instrumentation may suggest the underperformance of a plant section or the drift of parameters towards critical operating conditions and constraints.

For instance, in the case of urea plants, CARES provides value not only through the KPIs of the critical HP synthesis equipment,

but also alerts the operator of critical conditions which can impair the reliability and equipment life. The example of the HP stripper is typical: specific KPIs monitor the equipment performance such as the NH_3 stripping efficiency providing guidance for process optimisation, while at the same time the stripper temperatures are kept under strict surveillance to alert the attainment of critical thresholds for corrosion or anomalies in the reading of the temperature transmitter which may represents a risk for equipment integrity.

Moreover, the operating conditions of such critical equipment, such as the temperature and inlet/oulet composition of the process solution, provide valuable information used by CARES to complement mechanical inspections and the diagnosis of findings by supporting pro-active maintenance programs.

How does CARES help clients?

Using a combination of advanced analytics and expert advice provided by the customer care team, plant behaviour is analysed, focusing on the aspects that are most relevant to the client:

- **Boost plant productivity:** CARES provides continuous support to utilise the plant capabilities at its best and to achieve maximum production.
- **Improve plant efficiency:** CARES provides guidance for reducing emissions, energy consumption and to achieve plant stability.
- **Troubleshooting:** CARES offers support in identifying the root cause of plant upsets and unexpected shutdowns, providing solutions to improve reliability and increase the on-stream factor.
- **Improve understanding and confidence in plant operation:** Take the right action at the right moment. Feel confident and conscious of the plant behaviour. This is not an easy task. CARES provides valuable advice which allows improved knowledge and confidence of the plant operation and production process.
- **Identify plant limitations:** Identify equipment bottlenecks and operating procedures that are hindering plant performance.
- **Supporting pro-active maintenance and inspection programs.**

Expert advice is communicated to clients via a web dashboard available anywhere, anytime via a secure web page. The aim of the web dashboard is to provide a clear view of the plant and equipment performance using simple visual indicators (widgets) for the key performance indicators. The dashboard is not limited to displaying current values of the indicators but can also be used for trending and performance analysis: the user can inspect the timeline of the operation by selecting any date in the main interface window.

The dashboard service is completely customised according to customer needs. It is provided with a chat interface to maintain a direct link with the Casale customer care team and is complemented by periodic conference calls and written reports. The customer care team is also ready to support clients when problems occur. It is like having an expert on site every day. Fig. 1 shows screenshots (of a section) of the CARES dashboard and related KPIs.

Fig. 1: **Screenshot of the CARES dashboard showing examples of KPIs widgets**

Source: Casale

Benefits

Clients that use CARES have benefitted from the following:

- Direct operational advice and suggestions from the customer care team based on the behaviour of KPIs. Casale team experts comprise a broad spectrum of competences ranging from process to mechanical and instrumentation engineering.
- Critical insights of asset performance, leveraging Casale proprietary models that enable equipment parameters to be calculated that cannot be directly measured (e.g. catalyst health, catalyst activity, conversion efficiency, heat exchanger performance).
- Analysis of a full set of reconciled values for the different sections of the plant. Information that can be easily used to

tune or replace sensors that consistently exhibit large discrepancies between measured and reconciled values.

- Visualisation of performance and alert indicators of single units and plant sections by means of custom-made dashboards. Information that could be used by plant operators to reduce downtime and optimise equipment maintenance.
- Detailed reports summarising all the above and highlighting the limits of existing equipment.

How does CARES work?

Casale CARES can be visualised as a virtuous cycle, where raw plant data is processed in the Casale Data Center, where it is cleaned, corrected, structured and augmented to become a real source of information that can be used to improve plant operation. As shown in Fig. 2, Casale CARES is possible due to the interaction of different modules, including secure data transfer, analytics, monitoring, and reporting.

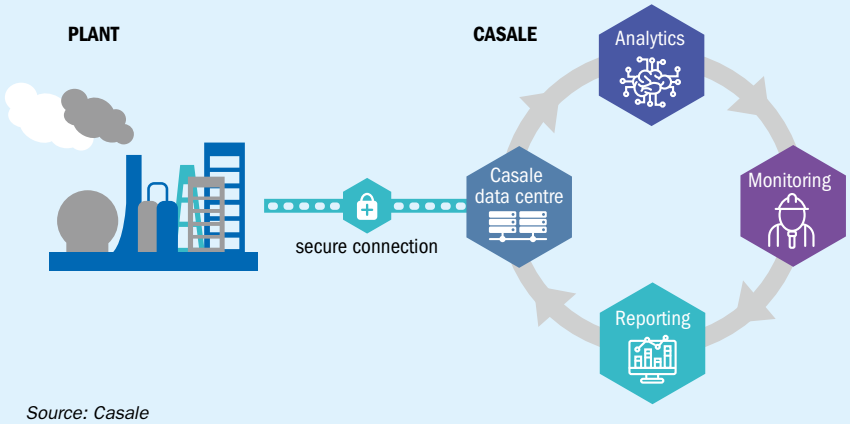
Secure data transfer

The first and essential step is to establish an automatic and secure plant data collection mechanism that transfers data from the client historian to the Casale data centre. Casale acknowledges that plant data is extremely precious, hence the established connection always satisfies the clients' security requirements. Casale often uses OSISoft PI Cloud Connect technology (see Fig. 3) to achieve secure data transfer and minimum infrastructure adjustments. This technology is based on a software-as-a-service platform that allows sharing data between the plant historian and Casale's data centre.

CARES analytics

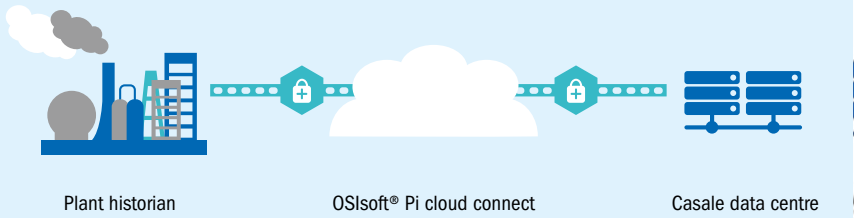
The CARES analytics module prepares data received from plant data. It detects and removes outliers and sets the variance of all measured quantities. Once the data is prepared, data reconciliation can take place of the streams and units of operation present in the section or plant being studied and with the determination of KPIs of critical and proprietary units. Fig. 4 shows an example of the reconciled values obtained for the synthesis loop of an ammonia plant. Lastly, plant behaviour is evaluated and a root-cause analysis of underperforming assets is carried out using machine learning techniques. All analytics can be triggered in batch or continuous mode.

Fig. 2: **CARES process cycle**



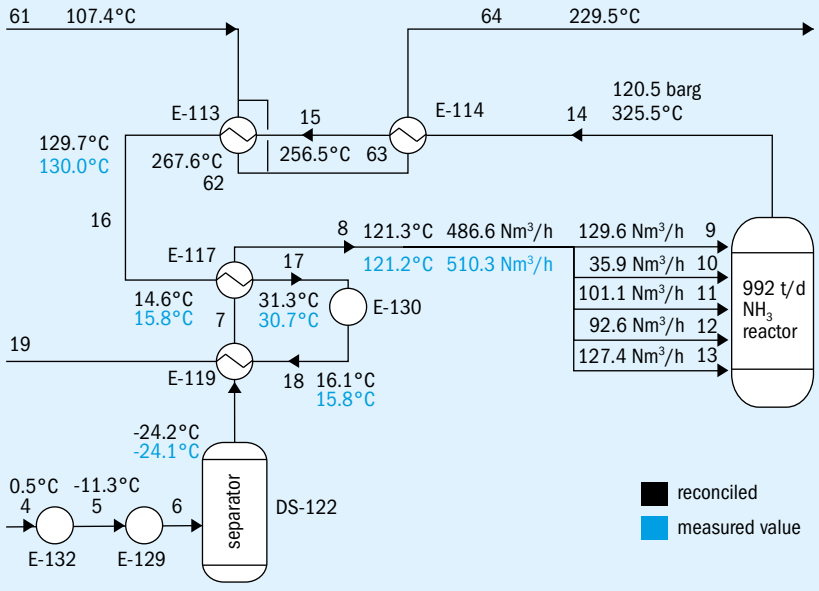
Source: Casale

Fig. 3: **Plant historian to Casale data centre connection**



Source: Casale

Fig. 4: **Data reconciliation of the synthesis loop in an ammonia plant**



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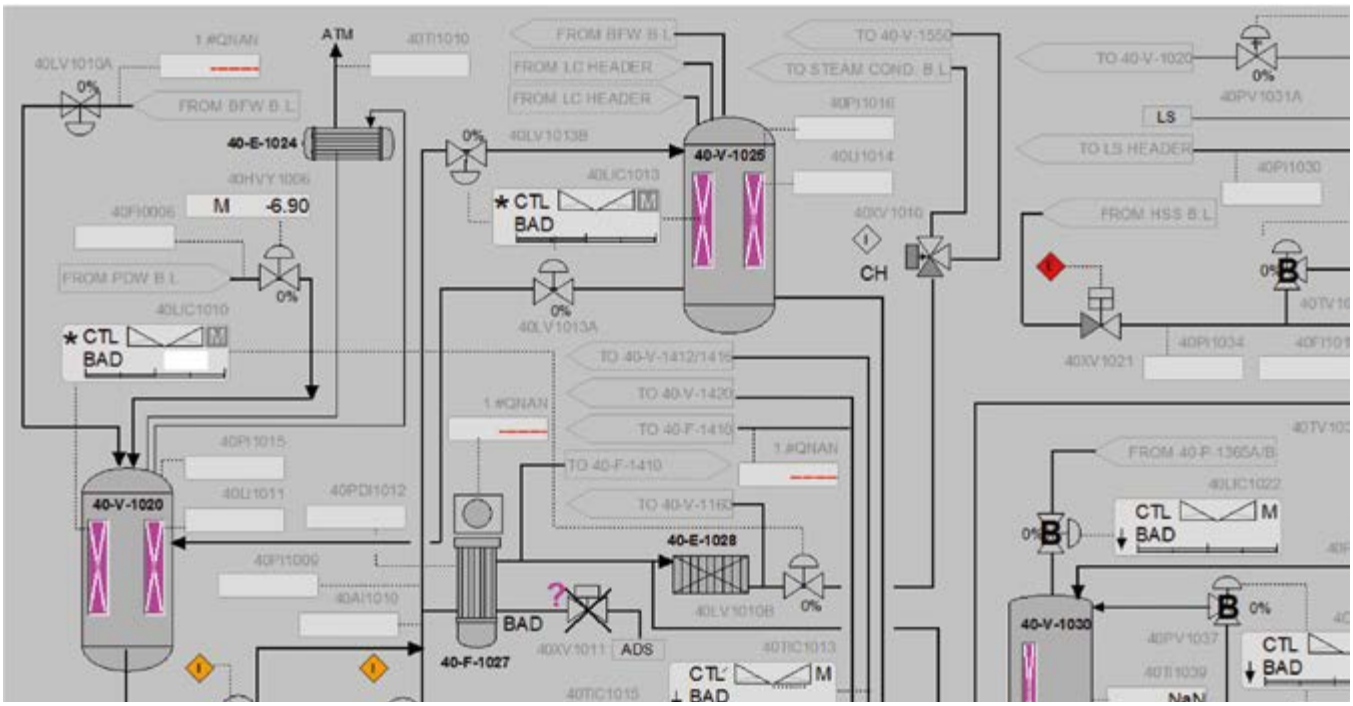


PHOTO: CASALE

Fig. 5: OTS screenshot of the melamine steam and condensate section. Casale and Honeywell have been working to deliver an OTS for the ammonia, urea and melamine plants for Metafrax complex in Gubakha, Perm region, Russia.

CARES monitoring

CARES is more than remote monitoring software, it is a true remote engineering service. Behind the scenes, a dedicated team of engineers will follow plant and asset performance. This is possible thanks to a specialised technical staff, that not only includes process engineers, who are a very important part of the structure, but also other subject experts dedicated to solving problems faced by clients, including instrumentation, machinery, reliability, and maintenance.

CARES reporting for valuable feedback

Providing effective feedback to the plant operational team is essential for a remote engineering service. CARES offers two types of reporting: a web dashboard, providing quick and effective plant performance visualisation, and periodic reports, presenting a detailed analysis of the performance of the assets and sections being studied during the last period. The reports also highlight identified states or bottlenecks that prevent optimal operation and stability of different sections of the plant.

Casale operator training system (OTS)

Training of operators is an essential requirement to improve plant performance, reliability, and safety. As a first step, operators learn how to operate the plant under normal conditions following design guidelines and field experience. However, to be prepared for unexpected or uncommon plant conditions, such as start-up, shutdown, incidents, safety procedures, etc. operators need special training to understand the behaviour of the plant under these conditions, as well as the associated risks. An OTS can help operators to quickly gain operational expertise on how their plant behaves under normal and special conditions, thereby improving the confidence and knowledge of operational teams. Casale's operator training system offers realistic high-fidelity plant simulations that cover many different scenarios and operating conditions. Moreover, the OTS allows operators to start learning how their plant works, even before the plant is running, improving the quality of operations from day one.

Existing commercial OTS providers offer excellent graphical user interfaces and dynamic simulation capabilities that perfectly mimic the operating experience of the control room. However, due to the inherent complexity of certain chemical technologies and operating conditions, standard thermodynamic packages and kinetic models used in these products, are not enough to accurately capture the physics of the associated chemical processes. To overcome this limitation, Casale can partner with any OTS provider to embed its know-how and proprietary models into the OTS, drastically increasing the accuracy of the response of the training simulator. As a result, clients receive high-fidelity plant models tested and validated by Casale. For example, Casale and Honeywell have been working in partnership to deliver an OTS for the ammonia, urea and melamine plants for the Metafrax complex in Russia (see Fig. 5).

Benefits include:

- reduced operational risks, downtime, failures, etc.;
- the best high-fidelity OTS can be obtained thanks to proprietary models to simulate the plants;
- operators can be trained even before start-up.

Casale model predictive control (MPC)

Plants are often operated in the "comfort zone" meaning that the key operating parameters controlling the performance are voluntarily kept below their optimum. This is mainly because even the most experienced operator is not able to adjust the parameters rapidly enough to respond to plant fluctuations or external changes and to avoid hitting physical constraints.

A model predictive control (MPC) system is an automation system that complements the DCS to overcome these problems by constantly tuning the set points of the different

control loops to stabilise the operation and push the plant to the optimum. As shown in Fig. 6, once stabilisation is achieved, it is then possible, using the MPC, to safely increase performance and to achieve higher production, or to reduce energy consumption. Depending on the client's needs an MPC system can be implemented on the whole plant or on a section of it.

Casale has partnered with the most important providers of MPC software to offer a dedicated MPC product for all Casale technologies. The product has been developed by adding Casale process expertise to the most evolved industrial MPC software, such as Honeywell, Yokogawa, Rockwell Automation, etc. and have been successfully applied to several chemical industrial sectors.

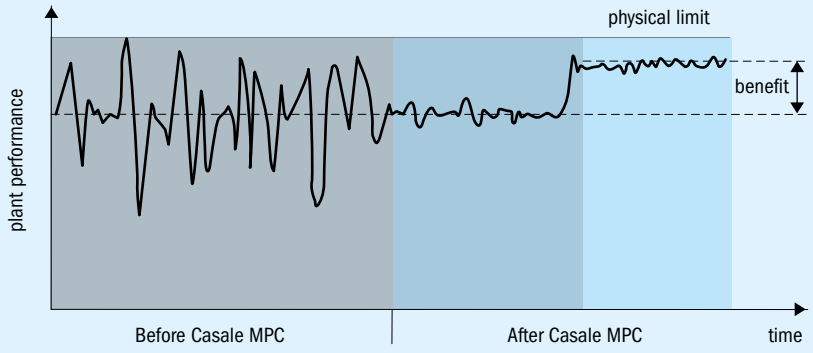
How does Casale's MPC solution help clients?

Most available MPC systems are a simple automation system, which applies purely mathematical algorithms to optimise selected plant parameters, named controlled variables (CV). These are considered the key players in the achievement of the optimum performance of the entire plant, thus they are strictly "controlled" and maintained at the optimum. This is possible due to continuous and smooth actions on manipulated variables (MV), which change the set point of controllers to correct the observed plant drift produced by external disturbances.

While this approach may seem sufficient, in practice it can only be applied to correct small plant perturbations for simple linear systems. Complex plants, such as those found in the fertilizer industry, can only be properly stabilised and optimised using custom thermodynamic and kinetic process models. This is because only through reliable models is it possible to identify and target the actual optimum of the critical controlled variables, which is not a steady figure (see Fig. 6), but dynamically changes depending on the real time capabilities of the whole plant. By using best-in-class MPC software, which incorporates Casale proprietary models, Casale's MPC product achieves even greater MPC performance. The optimum process performance is achieved utilising efficient and robust process models, which constantly monitor the operation of the critical sections of the plant.

For its urea technology, Casale has made great efforts to develop MPC software for process optimisation, which is now available in the market. Among different functionalities, the software allows the efficiency of the urea synthesis to be maximised by dynamically targeting the optimum N/C, H/C and operating pressure in the urea reactor. This is possible thanks to the power of the physical process model which supports the MPC operation by suggesting the optimum value of the critical controlled variables depending on the real plant capabilities and constraints.

Fig. 6: **Impact of a model predictive control over plant performance**



Source: Casale

What is the optimum set of conditions for the urea reactor? Qualitatively one may know that by increasing the N/C ratio and reducing the H/C ratio the reactor performance is improved. However, optimisation of the process is not an easy task. For instance, increasing the ammonia may lead to a pressure increase in the HP synthesis, a decrease of HP stripper and HP scrubber efficiency, and to the increase of pressure in the downstream urea recovery stage, and a partial loss of vacuum in the evaporation unit. Ammonia that cannot be handled by the plant will make the process unstable, leading to an increase in the emissions and raw material consumption. Lastly, the excess of ammonia contributes to an increase in utilities consumption for recovering and recycling the extra ammonia.

The above considerations highlight that the optimum N/C is not a steady figure for a given process technology but may change plant by plant and for a given plant may depend on several other conditions. For example, the operating procedure of the process may suggest operating the reactor at N/C 3.1 but this should only be used as a guideline. The optimum figure will depend on plant, the actual condition of the equipment, the environmental conditions, etc. Only advanced MPC software that embeds the process knowledge can target such an optimum N/C ratio at all times and depending on the real capabilities of the plant and related constraints.

Similarly, the optimisation of the water loops in the entire process is complex, since they strongly affect the value of the H/C ratio in the urea reactor.

It is well known that water is needed to control emissions, pressure, and the composition of recycled solutions. Water is provided to avoid crystallisation and keep the process stable, but any excess impairs the synthesis efficiency. Water is efficiently controlled by the Casale MPC acting on critical parameters in the process condensate treatment, urea recovery and recycling sections. The MPC constantly tunes the plant downstream to stabilise the composition of the recycle streams, targeting minimum water content and fulfilling constraints e.g. for crystallisation, pressure control and emissions.

The Casale MPC drives the plant to achieve the highest N/C and minimum H/C in the reactor to maintain:

- plant stability;
- synthesis pressure;
- HP stripper and HP scrubber efficiency (CO_2 stripping plants);
- NH_3 venting in continuous and discontinuous streams;
- crystallisation of the recycle streams;
- stability and performance of vacuum evaporation section (vacuum pressure);
- product quality.

Casale smart instrumentation

All of the innovative digital products mentioned above work better when complemented by a robust instrumentation system. Casale offers a range of reliable tools and novel instruments that can support daily plant operations (Raman urea analyser, tunable diode laser, refractive index meter, HP urea service guided wave radar level, etc.).

Casale has developed several hardware solutions providing value-added quantities that cannot be directly or reliably measured via standard instrumentation.

For instance, Casale has developed innovative solutions for level, pressure, and composition, which are especially targeted at urea synthesis, monitoring the performance of the urea reactor and other critical HP synthesis units such as the HP stripper and the HP reactor.

Customers can now benefit from the newly-developed guided wave radar level transmitter and the improved HP diaphragm seals pressure transmitter for the urea synthesis. It is very important to ensure reliability in the level and pressure control in order to stabilise the plant.

The composition of any HP process stream is even more important and can be monitored in real time by Casale's Raman urea process analyser.

Tunable diode laser (TDL) techniques are used for monitoring emissions in process vents.

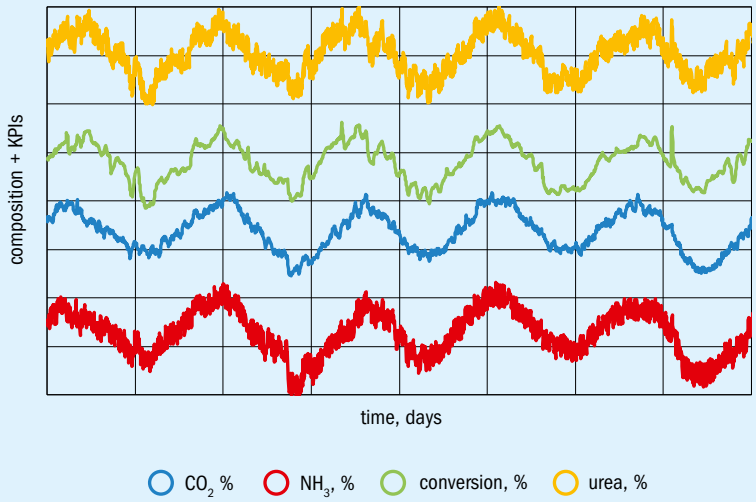
The availability of urea grade materials and tailor-made engineering for the urea process allows further techniques to be implemented, such as the on-line measurement of the refractive index in the recycle streams of the process to support the control of recycling water.

These are just some examples of smart instruments available today to support process operation. Casale offers tailor-made solution for any kind of need the process may have.

PHOTOS: CASALE

Fig. 7: Raman urea process analyser and special HP Raman probe.

Fig. 8: **Typical variation of composition and conversion during 9 days of production**



Source: Casale

Raman urea process analyser

The Casale Raman urea process analyser, a new powerful tool for on-line process analysis and control of urea plants, is a striking example of a smart instrument that can provide added value to digital services. Based on Raman spectroscopy, the composition of a process stream is determined by analysing a light spectrum created from a laser light source injected into the process stream via a special probe (see Fig. 7) The spectrum represents a fingerprint of the different chemical components present in the stream.

The Raman urea process analyser accurately measures the full composition of any high-pressure stream of the urea process in terms of NH_3%, CO_2%, urea% and H_2O% and provides KPIs of the urea synthesis, such as the N/C and H/C molar ratios, conversion and stripping efficiency. In this way, the analyser supports the everyday operation providing alerts for deviations of the most important parameters of the urea synthesis which can then be promptly corrected by the plant operators.

The Raman urea process analyser overcomes the limitations of traditional instrumentation for on-line analysis of the urea process, e.g. N/C monitoring systems, in which the N/C ratio is inferred from density measurements at the exit of the urea reactor. The analyser also automatically samples different locations of the urea synthesis section, i.e. reactor, stripper, condenser, scrubber, downstream lines, etc. resulting in savings due to the elimination of manual sampling. Other important benefits are the reduction of safety concerns related to sampling operations (in particular, due to the volatility of the involved components), and improvement in the quality of the results.

More importantly, the analyser provides real-time data. Lab analyses are normally p erformed according to standard procedures and require some hours to complete. In contrast, the Raman urea process analyser delivers real-time measurements of the composition of synthesis streams and related KPIs, capturing in this way the dynamics of the urea synthesis section. Fig. 8 shows the variation of the composition of a urea stream and related reactor conversion during several days of production.

The main benefits of the analyser translate into a reduction in the steam demand of the HP stripper by up to 5%, reduced emissions by up to 5 kg/tonne of ammonia and up to 3% increase in plant production. ■