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| cetlogo ***CHEMICAL ENGINEERING TRANSACTIONS***  ***VOL. , 2023*** | A publication of  aidiclogo_grande |
| The Italian Association  of Chemical Engineering  Online at www.cetjournal.it |
| Guest Editors: David Bogle, Flavio Manenti, Piero Salatino  Copyright © 2023, AIDIC Servizi S.r.l. **ISBN** 979-12-81206-04-5; **ISSN** 2283-9216 | |

The Digital Process Monitor (DPM):

digitalization for process and environmental excellence.

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The energy transition is leading companies to rethink their business models and the efficiency of their plants, making every savings in terms of energy consumption, emissions, improved plant availability and reliability more crucial than ever. Even the energy sector, and in particular the hydrocarbon processing industry -- well known for having been primarily a product-oriented industry with high margins -- is changing its vision as the striving for process and environmental excellence has become the only acceptable way to achieve a 'sustainable industry'.

The pursuit of operational excellence requires continuous process monitoring, together with qualified analysis of the collected data. In this framework, digital technologies can play a significant role in facilitating the adaptation of companies to this new and challenging industrial model.

Digital Process Monitor (DPM), introduced by Kinetics Technology (KT), part of Maire Tecnimont group, provides a Process Digital Twin which consists of an accurate process plant model, that, by incorporating the licensor’s knowledge, can provide continuous insights into plant performance. Process data are captured from the plant to feed a digital replica of plant processes, unlocking operational excellence through increased productivity and energy savings with a consequent reduction in the plant’s carbon footprint.

This paper provides an overview of the DPM’s features, focusing on the related benefits in terms of overall operational improvements and plant efficiency for KT licensed process units based on steam reforming technology for Hydrogen and Syngas production (HPU), and respectively on technology for the process of Gas Sweetening, Sulphur Recovery and Tail Gas Treatment (SRU). Today, DPM is at prototype stage, ready to be evaluated into real plant.

* 1. Introduction

The digital economy is becoming a major focus for many businesses, from conventional hydrocarbon processing to the domain of green chemistry.

Operating a plant is always challenging, and good management translates into improved safety and profitability. But unawareness of operators can be sometimes a critical factor potentially leading to loss of production, equipment damage and tarnished reputation; therefore, the adoption of digital tools, properly incorporating the know-how of the licensors, can be an answer to this pain point and a practical way to unlock the reduction of plant operating expenses (OPEX) by increasing margins for the plant owner.

In addition, it has been observed that the contribution of digital tools in assisting OPEX reduction allows the initial investment required for their implementation to be recouped, as well as the recurring annual cost to maintain them, within the first year of operation. Therefore, a payback time of less than one year implies that the annual OPEX savings are ongoing benefits unlocked by digital technologies for the plant owner.

* 1. Digital Process Monitor Description
     1. DPM at a Glance

The DPM is a new digital functionality developed by KT with the support of Tecnimont, together with Stamicarbon (both part of the Maire Tecnimont group) as technology partner and based on the similar DPM developed by Stamicarbon for its urea production technology. This collaboration has fostered a commercial and technological cross-fertilization that benefits the entire Maire Tecnimont group.

The DPM is a cloud-based solution. At its center is a first-principles plant model where all of the most important phenomena are rigorously simulated leveraging on KT’s unique know how as licensor, thereby guaranteeing the highest level of accuracy and adherence between the model response and the behavior actually observed in reality.

The model is fed with data derived from the plant's Distributed Control System (DCS) through a unidirectional data flow. The plant model unlocks valuable information that a DCS alone cannot provide, and with both automated procedures and the licensor’s intervention provides recommendations for board operators, through dedicated user interfaces, to enhance the plant's performance.

It will then remain the board operations' duty to implement the recommendations provided by the DPM by modifying process variables through the DCS so as to effectively enhance performance improvements.

* + 1. DPM Data Flow

Input data (online data from the plant’s DCS and offline data derived by measurement campaigns) are acquired by the DPM. A data validation algorithm allows plant operators to verify the quality of raw input data, so as to exclude unreliable ones. Validated data then feed the process model by generating simulated data and soft sensors, which consist in new process variables calculated starting from the DCS data properly manipulated.

As the quality of online measured operational data is usually not satisfactory for the performance evaluation of plants, because they are never error free, a data reconciliation algorithm has been implemented to improve measurement accuracy and achieve reliable operations.

Following reconciliation, data analysis takes place by leveraging on the comparison between process validated data derived from the DCS and reconciled process data calculated by the process model itself; the tool, with the support of KT specialists, is capable of generating advice to correctly operate the plant as near as possible to the optimum design conditions. This advice is summarized on dashboards which are the main interface with plant operators. It consists of a graphic representation of pre-defined KPI values and trends, the most critical plant parameters, and process variables affecting drastically the plant operation.

* + 1. DPM Dashboard

The DPM dashboards are the main interface for users and were designed by KT to provide operators with a quick and comprehensive overview of plant behavior. Literally, DPM dashboards let plant owners always have an overview of plant operation handy in their pocket: dashboards were designed to be visible on multiple devices such as laptops, tablets or smartphones. Data reported on dashboards are not only DCS data, but also helpful operating parameters (soft sensors) that cannot be derived directly from the DCS but are continuously calculated by the DPM model. Traditionally, these key parameters have not been available to operators for their immediate use, as they derive from an analysis of DCS data which can take hours to days, delaying any necessary remedial action. The DPM’s goal is to automatize this process, creating a live report of plant operation, minimizing the time between diagnosis and remedies in the event of an upset or deviation from optimum running conditions.

Below are some snapshots of prototype dashboards for HPU and SRU plants, with the aim of giving a comprehensive overview of DPM dashboard functionalities, regardless of the plant typology. However, content of dashboards is meant to be customized by KT to fit with specific requirements of plant owners.

Dashboards are designed to be composed of multiple sections:

* A main board giving an overview of plant operation / production, showing feedstock and product quantity and quality.
* Dedicated boards for each plant section, showing the main operating parameters and the key factors that will be closely monitored.
* Dedicated boards resuming KPI of the plant and showing possible savings.

An example of a KPI which cannot be detected directly by looking at the DCS is the Sulphur Recovery Efficiency (SRE). SRE is the main indicator of the operation of a Sulphur plant as it gives the percentage of Sulphur recovered (and thus produced as liquid Sulphur) from the inlet streams. SRE is calculated as shown in eq. 1.

|  |  |
| --- | --- |
|  | (1) |

Where:

* *S*IN Sulphur entering with feedstocks;
* *S*OUT Residual sulphur going to atmosphere at the end of the process.

Although deriving from a very linear reasoning, SRE cannot be detected directly from any DCS sensor, and must be calculated after a substantial data analysis. The DPM allows an operator to know at any time the SRE’s actual value.

For HPU plants, the dashboard construction philosophy is the same as for SRU plants, providing the necessary process monitoring boards together with KPI boards.

* 1. Advantages of DPM
     1. Licensor Modeling

One of the main advantages that makes KT’s DPM stand out compared to competitors is in the simulation engine. As licensor, KT is the most expert modeler of its own licensed technologies. KT models are not only based on consolidated thermodynamics models but are also improved over the years in order to best fit data acquired from several operating plants.

Another important feature that defines licensor advantages is the ability to precisely simulate proprietary items. KT uses commercial simulators customized for the unit operations with a proprietary design: for such equipment, proprietary models have been implemented in commercial simulators to create a customized “unit operation block”. Considering, for example, a SRU plant, which uses customized Unit Operation for Sulphur Condensers and a Thermal Reactor Waste Heat Boiler: these two pieces of equipment are not modeled as a regular heat exchanger but have their own dedicated simulation block which implements the KT models to simulate the complex of the chemistry/thermodynamics involved (e.g. chemical reactions for sulphur recombination).

This being said, DPM, leveraging on Licensor models, provides the strongest theoretical basis and so the most reliable prediction of a plant's behavior.

* + 1. Data Reconciliation

Data reconciliation is an important feature of KT’s DPM. Data reconciliation gives an automatic resolution for a problem that until now has been solved manually by the Licensor’s engineers.

As already said, the quality of online measured operational data is usually not satisfactory for the evaluation of the plant’s performance, because they are never error free, and even careful installation and maintenance of the hardware cannot completely eliminate this problem. In fact, after collection of plant data, the involved engineers always conduct an analysis to make raw data consistent (for example from H&MB perspective) so as to conduct a reliable assessment of plant behavior.

Data reconciliation is a data preprocessing technique which can improve the accuracy of measured data through process modeling and optimization, identifying potential anomalies in the input data. In other words, Licensor data analysis is provided to plant owner as a ready-to-use tool.

On the theoretical side, data reconciliation is summarized as a general optimization problem, solving an objective function. The objective function is a weighted sum of the relative differences between selected reconciled process data and the corresponding DCS process measured data as indicated by the formula shown below (eq. 2):

|  |  |
| --- | --- |
|  | (2) |

Where:

* N Number of variables selected for the objective function;
* XDCS DCS Data (measured validated data);
* XCALC Data reconciled calculated by Process Simulator;
* Wi Weight factor chosen by KT to reflect the importance of each process data considered in the objective function.

Minimization of the objective function is done by manipulating some of the variables involved in the reconciliation (typically coincident with the process data controlled by the DCS). The choice of the manipulated variables, among all the DCS recorded data, is performed by KT leveraging on licensor knowledge. The variables are manipulated inside a certain interval (standard deviation) which is also implemented by KT according to the type of process data processed. The mathematical problem is solved through the Bobyqa algorithm, which consists in a variation of Powell method for finding a [local minimum](https://en.wikipedia.org/wiki/Maxima_and_minima) of a function.

The mathematical approach of the problem is quite general, therefore the same approach can be extended to solve distinct types of minimization problems, such as the operating costs of the plant (even if such functionality is presently not available in KT DPM).

The numerical solver is independent from the simulation engine used, meaning that the tool can be eventually used for the reconciliation of the processes even different from KT licensed units.

* 1. Expected benefits for Plant Owner
     1. Reliability and Operational improvements

Using the DPM unlocks several advantages as far reliability and improved plant operation are concerned.

Continuous monitoring gives an improved overview of several features for HPU and SRU plants, some of which are listed below:

* critical transient events;
* combustion anomalies;
* hydraulic profile;
* soft sensors that represent unmeasured values.

For HPU, the DPM can additionally provide: the indications for optimizing the operating parameters related to multi-feedstocks (i.e. S/C, H2/FEED) for every mixture of feedstocks, even for cases not defined by available heat and material balances.

Short term benefits:

* the identification and analysis of critical transient events can lead to an increased reliability of operation, avoiding long operating transitions which often lead to an off-spec products or a significant environmental impact;
* the monitoring of combustion anomalies can maximize the prevention of undesired breach of emission limits;
* guidance for recalibrating field instruments when required by the DPM outcomes can improve the overall plant reliability.

Long term benefits:

* monitoring of the catalyst behaviour helps reach an optimized catalyst operation, leading to improved performance and lower polluting emissions; in addition, OPEX are reduced, as poisoning and catalyst ageing events can be detected early, extending catalyst life as much as possible.
* monitoring of hydraulic profile can give an early diagnosis on any fouling or soot deposition happening in the plant, thus helping prevent plant operation disruption due to high pressure losses or allowing a more optimized planning of turnarounds.
  + 1. OPEX saving estimation

The introduction of DPM leads to OPEX savings in several ways. A case study has been conducted on both HPU and SRU technologies licensed by KT.

A case study has been conducted for a HPU of 70,000Nm3H2/h production plant located in Europe.

The utility costs used in the case study are summarized in Table 1.

Table 1: Utility costs for European area, HPU case study

|  |  |  |
| --- | --- | --- |
| Utility | Price | Unit |
| Natural gas | 0.397 | €/kg |
| Make up fuel gas | 0.18 | €/kg |
| Boiler feed water | 0.00 | €/t |
| Cooling water | 0.00 | €/t |
| LP steam | 0.012 | €/kg |
| Export Steam | -0.019 | €/kg |
| Electrical power | 0.093 | €/kWh |

Table 2 and Table 3 compare the process parameters and the utility consumption of a real plant operation (i.e. without the help of DPM) with the same parameters that can be obtained by optimizing the operation through DPM. Results are based on 8600 hours of plant operation per year.

Table 2: Process Parameters, HPU Case Study

|  |  |  |  |
| --- | --- | --- | --- |
|  | UoM | w/o DPM | with DPM |
| Steam to carbon ratio | mol/mol | 3.9 | 3.7 |
| Excess of air | % | 15 | 10 |
| BFW delta T to steam drum | °C | -20 | 0 |
| Air delta T to burners | °C | -15 | 0 |
| Feed loss from vents | % | 1 | 0 |

Table 3: Utility Consumption, HPU Case Study

|  |  |  |  |
| --- | --- | --- | --- |
|  | UoM | w/o DPM | with DPM |
| Natural gas | kg/hr | 15550 | 15790 |
| Make up fuel gas | kg/hr | 4240 | 3340 |
| BFW | t/hr | 77.83 | 73.86 |
| cooling water | t/hr | 217 | 210 |
| LP steam Import | kg/hr | 300 | 250 |
| HP Steam Export | kg/hr | 52500 | 53280 |
| Electrical power | kWh | 2174 | 1663 |

***The result of the case study led to an estimated saving on OPEX up to 1,2 million Euro/year adopting DPM.***

A similar case study has been conducted for a SRU with capacity of 190t/d of removed sulphur located in Europe.

The utility costs used in the case study are summarized in Table 4.

Table 4: Utility costs for European area, SRU case study

|  |  |  |
| --- | --- | --- |
| Utility | Price | Unit |
| O2 | 0.19 | €/Nm3 |
| Fuel gas | 0.18 | €/kg |
| Boiler feed water | 0.00 | €/t |
| Cooling water | 0.00 | €/t |
| LP steam | 0.012 | €/kg |
| MP steam | 0.00 | €/kg |
| HP steam | 0.019 | €/kg |
| H2 | 1.5 | €/kg |
| Electrical power | 0.093 | €/kWh |

Table 5 compares the process parameters and the utility consumption of a real plant operation (i.e. without the help of DPM) with the same parameters that can be obtained by optimizing the operation through DPM. Results are based on 8600 hours of plant operation per year.

Table 5: Utility consumption, SRU case study

|  |  |  |  |
| --- | --- | --- | --- |
|  | UoM | w/o DPM | with DPM |
| O2 | Nm3/h | 0 | 0 |
| Fuel gas | kg/h | 296 | 307 |
| Boiler feed water | t/h | 27.9 | 27.3 |
| Cooling water | t/h | 482 | 482 |
| Export LP steam | kg/h | 7614 | 7031 |
| Export MP steam | kg/h | 0 | 0 |
| Export HP steam | kg/h | 17258 | 17509 |
| H2 | kg/h | 24 | 6 |
| Electrical power | kWh | 782 | 530 |

***The results of the case study led to an estimated saving on OPEX up to 385,000 €/year adopting DPM.***

* + 1. Carbon footprint reduction

The DPM also contributes to reducing the carbon footprint of plants based on KT licensed technologies since it allows optimization of:

* the consumption of natural gas and of makeup fuel gas (for HPU);
* the consumption of fuel gas and hydrogen (for SRU);
* the consumption of electricity;
* the steam exported at various pressure levels.

Considering the same case studies mentioned in the previous paragraph, the carbon footprint reduction has been calculated according to the following criteria and reasonable simplifications:

* 8600 yearly operating hours;
* the carbon footprint is calculated by assigning equivalent emissions factors only for the electricity and fuel consumptions, having all the other utilities optimized by DPM a negligible impact on the CO2 equivalent emission;
* the following CO2 equivalent emission factors are derived from “2BS-PRO-03 – Methodology for the calculation of GHG emissions – version 1.9”:
  + 127.65gCO2eq/MJ for Electricity
  + 67.59gCO2eq/MJ for Natural Gas & Fuel Gas

***The results of the case studies led to the following saving of emission of CO2 equivalent:***

* ***20,700t/y (~4% reduction of GHG emissions expected without DPM) for a HPU with capacity of 70,000Nm3H2/h (equivalent to ~621,000€/y saved considering a carbon tax of 30€/t);***
* ***2,300t/y (~18% reduction of GHG emissions without DPM) for a SRU with capacity of 190t/d of removed sulphur (equivalent to ~69,000€/y saved considering a carbon tax of 30€/t).***
  1. Conclusions

The energy sector is a very conservative business segment, but today there are two game-changers that can dramatically accelerate the changes already occurring in adjacent sectors such as insurance, banking, retail, etc. Digital transformation and the energy transition are two sides of the same coin, because the goal of decarbonizing existing and new industrial complexes can be effectively achieved only by leveraging on digitalization.

Going forward, at KT we will continue to develop and improve our newly created tools, which are part of Maire Tecnimont’s NextPlant’s[[1]](#footnote-2) digital platform, for managing the operational challenges in the hydrocarbon processing arena.

1. NextPlant is a portfolio of digital solutions and services that enables Maire Tecnimont Group’s companies to design "natively digital" plants starting from the engineering phase, thereby unlocking more value during plant operations. [↑](#footnote-ref-2)