Case Examples of MIRROR PLANT for Chemical Process

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MIRROR PLANT is an online plant simulator that estimates the current state of an actual plant online by using real-time data from the distributed control system (DCS). Dynamic simulation has been used offline such as the Operator Training System (OTS) so far, however, MIRROR PLANT can be used online, enabling the simulator to be used in unconventional ways. MIRROR PLANT is already running in actual chemical plants as a real-time "digital twin" and has contributed to the operational support and improvement of plant operations. This paper describes a case example of MIRROR PLANT used in the main chemical plant of Mitsui Chemicals, Inc.

INTRODUCTION

Digital Twin is a model, created in virtual space, of actual products and production facilities on which trial production and verification are performed. This idea has been widely used in the manufacturing industry in recent years. Digital Twin is useful for improving operational efficiency such as reducing rework in the real world because the cycle of trial production and verification can be carried out in advance in the virtual environment. Moreover, thanks to the spread of the Internet of Things (IoT), it is possible to input various field information required for modeling into the data server. With these advantages, the use of Digital Twin is spreading in various domains.

In chemical processes, dynamic simulators are used offline for process design, analysis, and operation training. If a simulator can update models to reflect the state of the actual plant while taking in field information, it will be used more widely as a real-time Digital Twin.

Existing plant simulators offer much useful information that is not obtained by a DCS, such as stream compositions and the internal state of towers and vessels. If such simulators can be improved sufficiently to be placed online, it would be possible to determine manipulation and operating conditions based on the real-time composition of the process and the state quantities of towers and vessels, which are not monitored by analyzers. This would make plant operation safer and more efficient. Moreover, plant tests and operation verification could be performed in a highly precise virtual environment for designing, verifying and improving DCS control systems.

MIRROR PLANT is an online dynamic simulator that uses Visual Modeler (Omega Simulation's simulator) as a calculation engine(1). While acquiring real-time DCS data, MIRROR PLANT identifies the performance parameters of a device online, and follows and expresses the state of an actual plant. MIRROR PLANT displays the current internal state of a plant as well as its future behaviors based on time-forwarding calculations, providing operators with much useful information and helping keep a plant running stably and safely.

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This paper introduces a joint development project with Mitsui Chemicals, Inc. We performed a field test in its main plant to confirm how well MIRROR PLANT supports operations and cooperates with an operator training system (OTS).

OUTLINE OF MIRROR PLANT

The configuration and functions of MIRROR PLANT used in this project are as follows.

Outline of Configuration

MIRROR PLANT acquires real-time DCS data via an OLE for process control (OPC) server. Figure 1 outlines the system configuration.

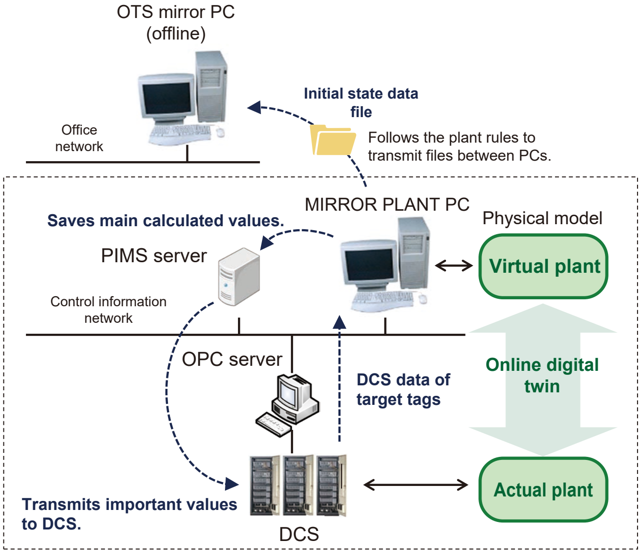

Figure 1 Outline of system configuration

Figure 2 outlines the functions of MIRROR PLANT in this project, which consists of a mirror model that calculates the internal state of plants and an analytical model that executes various applications. MIRROR PLANT has two methods of using real-time data to adjust a model to an actual plant: tracking, and data reconciliation with dynamic compensation(2). The latter method is used for adjusting model parameters in response to process changes over a long time, such as deterioration of catalysts and fouling, whose influence reaches far and wide. Since there are no such elements in the process, this method is not applied to this project.

In this project, the configuration has an offline analytical model. This makes it possible to offer operation training that uses the actual operational state saved in MIRROR PLANT and offline optimization case studies.

Outline of Functions

The basic functions of MIRROR PLANT are listed below. The functions required for the target process are implemented in this project; the details are described in another paper(3) and are omitted here.

- Plant internal state visualization
  Keeps displaying the composition at crucial plant elements such as reactors and distillation columns.
- Periodic prediction (20× time-forwarding simulation)
  Predicts plant behaviors 30 minutes ahead at 90-second intervals.
- Case study for transient state prediction
  Predicts behaviors in the future when flow rates, temperatures, or other parameters are changed.

The offline functions of MIRROR PLANT (OTS mirror) are listed below.

- Operation training
  Allows offline operation training starting from the initial state data saved in the HDD of MIRROR PLANT PC.
- Case study (offline)
  Allows offline case study starting from the initial state data saved in the HDD of MIRROR PLANT PC.

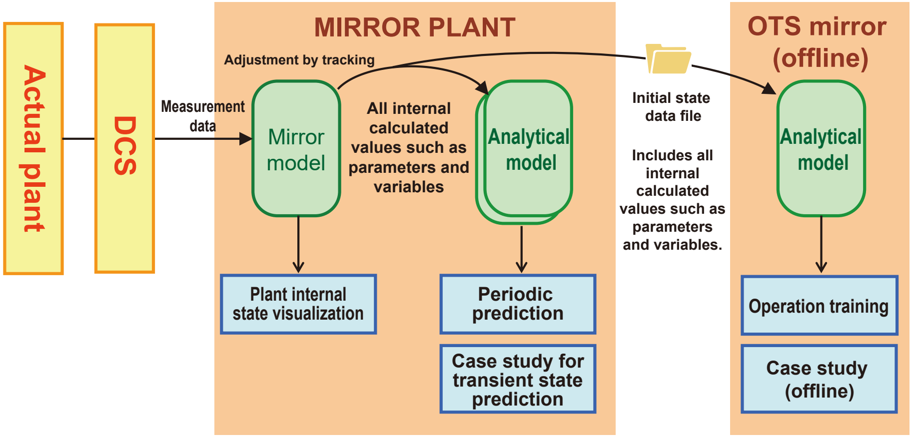

Figure 2 Outline of functions

CASE EXAMPLES OF MIRROR PLANT

Outline of the Target Process

MIRROR PLANT is applied to a continuous chemical process that consists of reaction, separation, distillation, and recycling processes. Figure 3 outlines the target process. When any unusual operating condition occurs at an operation unit, it is difficult to determine how much it will affect other plant elements and how long it will take to return to the normal condition because there are multiple recycle lines for unreacted raw materials, solvents, and crude products. Some operation control indexes need sampling for composition analysis. In this case, it is difficult to determine the control index in real time under unusual operating conditions. Raw material A is used in multiple plants, and emission gas (including unreacted raw material A) is collected from other plants and used in the target process. The flow rate and composition of collected emission gas fluctuate depending on the operating conditions of other plants. Therefore, this process requires fine adjustment of operation against disturbances.

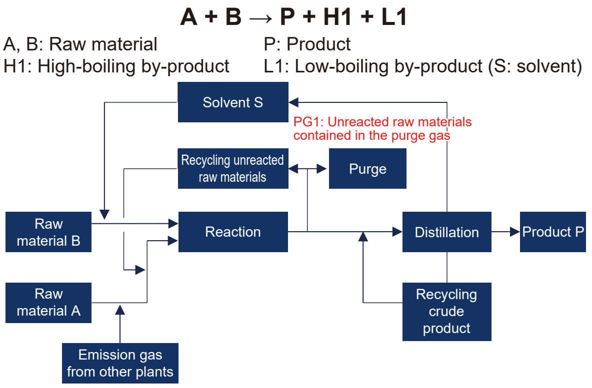

Figure 3 Outline of the target process

Plant internal state visualization

This section describes a sub-project in which a basic function of MIRROR PLANT, plant internal state visualization, is applied.

Reaction and recovery processes

In the target process, unreacted raw materials and by-products are contained in the gas emitted from the reaction process. Unreacted raw materials are recovered at multiple recovery columns, and the remaining gas containing by-products is emitted from the overhead. Figure 4 shows the process flow. The concentration of unreacted raw materials contained in the overhead gas (PG1) is an important index of operation.

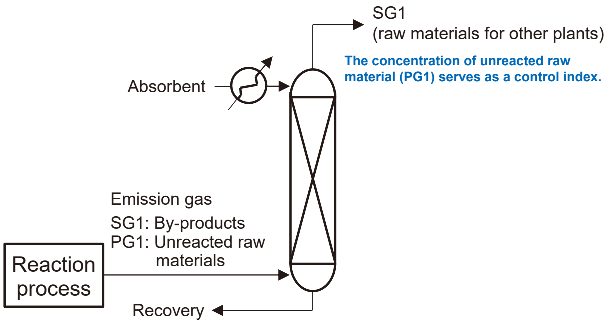

Figure 4 Process flow around the recovery tower

Increased PG1 means waste of raw materials, and also increases the load to be processed in downstream plants. This increase can be suppressed by adding more absorbents and cooling the process further. However, this has a trade-off relationship with the operation cost; suppressing PG1 concentration increases utility costs. Moreover, the seasonally changing temperature of absorbents affects the concentration of PG1 even under the same operating conditions. If the process is operated with PG1 adjusted to the optimum level, costs can be reduced. However, it is difficult to determine the real-time PG1 value, and thus the recovery process was conventionally operated with a fixed load.

MIRROR PLANT can calculate and display PG1 concentration, which enables operators to monitor its level in real time. Figure 5 shows the calculated PG1 trend in a summer month in 2017 and the same month in 2018. In 2017, the recovery process was operated with a fixed load. In 2018, the process was operated by referring to the real-time composition determined by MIRROR PLANT. Clearly, MIRROR PLANT helped stabilize the PG1 level compared with the conventional approach. Although optimization is left to be judged by field operators since the optimum point varies depending on the environment, waste of materials was greatly

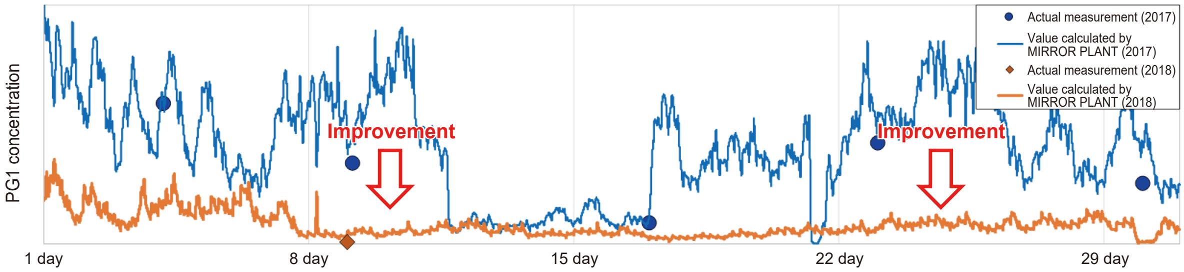

Figure 5 Calculated PG1 trend

reduced thanks to the stabilized PG1.

Purification process

In the target process, three distillation columns are used for the purification process: a low-boiling cut tower that separates the product from low-boiling by-products, a high-boiling cut tower that separates the product from high-boiling by-products, and a distillation column that purifies the product. Figure 6 outlines the flow.

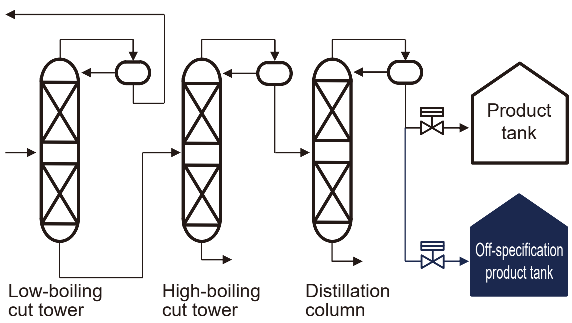

Figure 6 Process flow of distillation columns

When the product containing impurities (low-boiling materials) is found to flow from the low-boiling cut tower into the following process due to unusual operating conditions, the route is changed from the product tank to the off-specification product tank before the product containing impurities flows out from the distillation column. After the unusual operating condition is resolved, the route is switched back to the product tank.

There is a time lag between the time when an unusual operating condition occurs and the time when the influence appears in the discharged product. Even after the unusual operating condition is resolved, the route is not switched back to the product tank until the product containing impurities completely flows out from the distillation column and the holdup at the bottom of the condenser. Conventionally, it was impossible to grasp the composition of the product discharged from the distillation column in real time. Therefore, switching back to the product tank was performed at a sufficiently later timing to ensure the product quality. In contrast, visualization of the product composition by MIRROR PLANT enables operators to monitor it in real time.

Figure 7 shows the trend of calculated impurities in the product composition around the time when an unusual operating condition occurs. Since MIRROR PLANT enables operators to monitor the product composition in real time, the route can be switched back to the product tank as soon as the product composition returns to the normal level. In this sub-project, we successfully shortened this span, which greatly reduced product loss.

Displaying calculated values on the DCS screen

This section explains another sub-project in which the values calculated by MIRROR PLANT (mirror calculated values) are displayed on the DCS screen.

(1) Display on the DCS screen

An outline of the system configuration is shown in Figure 1. The mirror calculated values at major plant elements are output to the customer's plant information management system (PIMS). In the target plant, required information (including data of other plants) among the data collected by PIMS can be displayed on the DCS screen. Since the mirror calculated values on PIMS can be handled like actual plant data, the calculation results of important composition are transmitted by using the same system to the DCS. In the DCS, not only are the values and the trend displayed but also upper and lower alarms can be set. While checking in real time, operators use the composition values as an operation index. This is the major reason why improvements described in earlier sections were successful.

(2) Determining the degree of deviation

To use mirror calculated values as the index for actual operation, MIRROR PLANT must express actual plant behavior accurately. Therefore, MIRROR PLANT includes a function to check the degree of deviation.

This function subtracts "mirror calculated values" from "DCS values" at multiple key points and uses the results to manage the compatibility of the points between MIRROR PLANT and the actual plant.

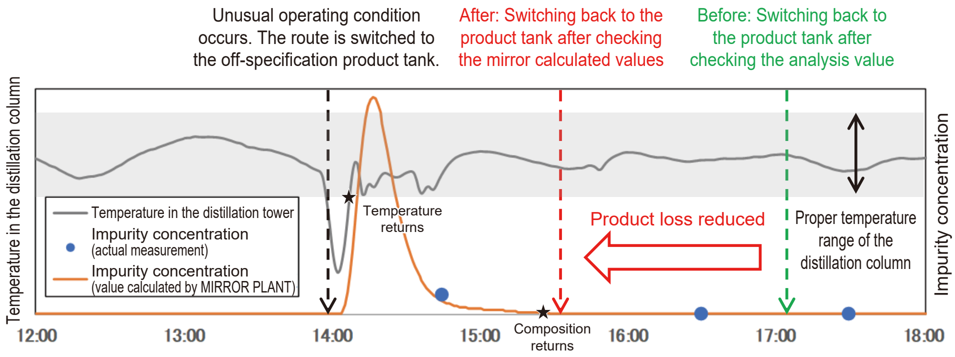

Figure 7 Trend of calculated impurity concentration

Large degrees of deviation can be attributed to the two factors described below. In either case, it is not desirable to use mirror calculated values as the index of actual operation, in which case MIRROR PLANT warns the operators.

(1) Due to troubles in field instruments and meters, the DCS does not reflect the operational state of the actual plant.
(2) By-pass operation with manual valves and some other changes added to operation cannot be grasped by the DCS, and so the state simulated by MIRROR PLANT deviates from the operational state of the actual plant.

Stabilizing the process

This section describes a sub-project in which a new control system is introduced by using a sophisticated mirror model.

The target process is two distillation columns connected in series. The two columns separate Product P from Solvent S. Figure 8 shows the process flow. The overhead liquid of the second (downstream) tower is returned to the first (upstream) tower and recycled. If any fluctuation occurs in one tower, it affects the other tower and comes back to the original tower. This means that a fluctuation causes another fluctuation as well as aggravates itself, resulting in strong interference between the two towers.

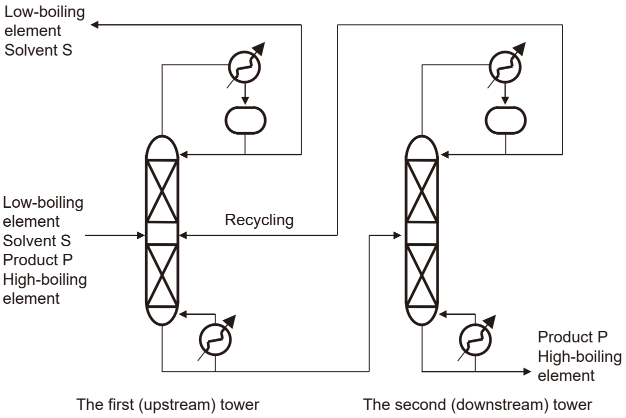

Figure 8 Stabilization target of the distillation process

Generally, a plant test is carried out to change the process within the tolerance and its response data are used to determine the parameters of a controller. In the target process, the two towers have their own operation control criteria and there is strong interference between the two towers. Therefore, it is difficult for safety reasons to perform a plant test that changes multiple items.

MIRROR PLANT can perform such a test without any risk and its time-forwarding calculations deliver results quickly. In this sub-project, MIRROR PLANT performed various step response tests for the first tower, which is particularly important for operation. The contents and procedures of the test followed the flow of the actual plant. We calculated the transfer function of the control temperature against operation variables and disturbance elements and used its gain and time lag to create parameters for the feed forward (FF) control. We also chose, from among multiple disturbance elements, FF elements that have high correlations with the control target. Figure 9 outlines the FF control. We examined the control parameters in advance and the control loop based on the simulation results and implemented both in the DCS as they were. The examined control system was introduced in the actual plant and automatic control was achieved over the range specified by field operators. There was no need to tune parameters. The operation frequency analysis showed that the examined control system successfully reduced operations by more than 90% around the target distillation column.

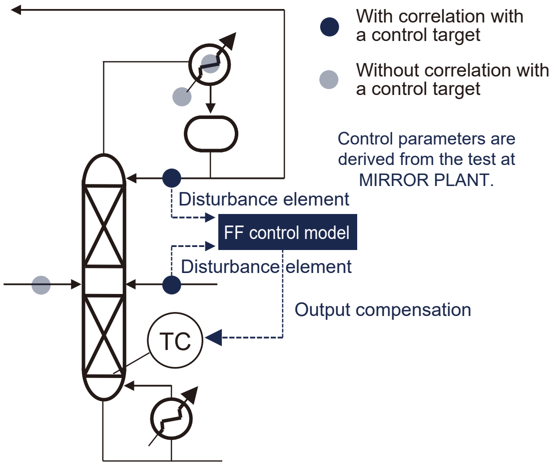

Figure 9 Outline of FF control

Cooperation with OTS

In another sub-project, we built a system in which MIRROR PLANT and OTS work together. The existing OTS uses default conditions as the starting point for simulation and thus does not reproduce the current operational state of an actual plant. After making MIRROR PLANT work with OTS, it is possible to perform training and case studies that use actual operating conditions and updated model parameters.

The system configuration and functions are shown in Figures 1 and 2. The initial state data generated by MIRROR PLANT can be used on OTS because MIRROR PLANT and OTS have the same model. Note that the control state to be reproduced is limited to PID control. Since there is no sequence element in the training for stabilizing disturbances and the case study of changing the load, sequence information is omitted. The scenarios of training reflect the requests of field operators.

When OTS receives the initial state data that MIRROR PLANT generated at a certain timing, trainees can use the operational state data at that timing on OTS. Since the initial state data file can be handled by PCs, it is transferred by ordinary functions of the Windows operating system. The file transfer between PCs follows the security policy of the plant.

There are two methods of saving snapshots (plant state at a certain time), each of which has the features described below.

(1) Overwrite saving

Saves snapshots in a cycle of 90 seconds. Since old data are overwritten, the data always represent the latest plant state. This method is useful for training and case studies on the current state of the plant.

(2) Fixed cycle saving

Saves snapshots in a cycle of 15 minutes. All data are stored in HDD and not overwritten. This method is useful for reproducing the plant state at a specific time and date, such as when an operation trouble occurs. Training, case studies, and search for the optimum operation can be performed efficiently.

As described earlier, improved control systems promote efficiency and automation. However, veteran staff are concerned that young operators may miss the chance to gain experience of operation. By expanding the usage of OTS, MIRROR PLANT covers training and skill succession and helps plant operation.

CONCLUSION

This paper introduced a project in which the functions of MIRROR PLANT were applied to an actual chemical process. In the case of operation support, MIRROR PLANT helped reduce material loss, utility costs, and product loss. MIRROR PLANT also worked with OTS to offer practical training by reproducing the current operational state of the actual plant. This delivered intangible advantages such as plant safety and the succession of operator skills.

Periodic prediction is a basic function of MIRROR PLANT. Although prediction results can be displayed to operators, such prediction has yet to be used in daily work on site. Operators want to predict the behavior of the downstream process and raw material recycling when the concentration of raw materials fluctuates in the reaction process. We are building a system for forecasting and providing operating guidance in the case of unusual operating conditions.

In this joint development project with Mitsui Chemicals, Inc., we confirmed that MIRROR PLANT effectively supported operations and cooperated with OTS. Since the project was completed, customers have started to focus on making use of MIRROR PLANT in daily work, and we have been expanding its usage.

In chemical plants, numerous improvements are repeatedly made to strengthen competitiveness. As a result, process operation is becoming more complex and sophisticated, making it difficult to clearly identify the extent of impacts such as disturbances, time lags, and fluctuations. Meanwhile, fine-tuned operation is essential to satisfy safety and quality requirements. In terms of systems and technology, soft sensors and model prediction control (MPC) are often chosen because there are many examples of installation in actual plants. For soft sensors based on a statistical model, however, it is difficult to respond to operating conditions that deviate from the learned range. In addition, it is difficult to perform enough tests for introducing MPC in plants where severe control criteria exist. MIRROR PLANT is expected to bring great benefits in terms of operation support and improvement to chemical plants under these conditions. Through this joint development project, we were able to expand knowledge and engineering know-how on chemical processes. Leveraging these, Yokogawa will expand the use of MIRROR PLANT in other chemical processes.

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