MIRROR PLANT for Innovating Plant Operation

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Using plant models throughout the plant lifecycle is proposed for improving plant operation. MIRROR PLANT, a virtual plant simulator, can perfectly simulate the dynamic behavior of plants. MIRROR PLANT has finished verification testing at a Mitsui Chemicals, Inc. commercial plant, and is being prepared for its release. Throughout the plant lifecycle, MIRROR PLANT focuses especially on the plant's operations phase. MIRROR PLANT not only supports plant operators but also helps technical staff to change plant operation conditions for their optimal operation. This paper compares features and applications of MIRROR PLANT and other plant model products. Unlike conventional Yokogawa products, MIRROR PLANT provides high-level plant service related to users' production processes.

INTRODUCTION

At the Technology Exhibition 2005 held for the 90th anniversary of its foundation, Yokogawa announced a plant operation concept that effectively uses a plant model to fuse virtual and real worlds and overcome the restriction of time and space. At the moment of the announcement, it was still in the research and development phase, and called "tracking simulator". Upon the completion of field tests at Mitsui Chemicals Inc., Yokogawa renamed it MIRROR PLANT in anticipation of its commercialization [(1), (2)].

The MIRROR PLANT, a plant simulator jointly developed by Yokogawa and Omega Simulation Co., Ltd, works concurrently with a real plant. The MIRROR PLANT, built in a computer, can follow temporal changes in the process and precisely simulate behaviors of the real plant by identifying model parameters online. The MIRROR PLANT in virtual space enables plant safety operation based on future predictions, which would be impossible with conventional plant operations. It also achieves optimal operations even in processes with temporal changes, such as heat transfer changes of heat exchangers and deterioration of catalysts.

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THE BUSINESS ENVIRONMENT SURROUNDING THE PROCESS INDUSTRIES IN JAPAN AND ITS CHANGES

As shown in Figure 1, process industries such as the oil and petrochemical industries in Japan are surrounded by a harsh business environment. This includes a strong yen, high crude oil prices, high corporate taxes and labor costs, cheap competitive goods due to trade liberalization, power shortages after the Great East Japan Earthquake, and environmental issues such as CO_2 emission reduction. Against such trials, several management strategies for maintaining business continuity in Japan are being adopted as major countermeasures. These include integration of industrial complexes, specialization in functional materials specific to the chemical industry, and activities for improving production efficiency through production innovation and production reforms. Meanwhile, strategies concerning foreign activities such as business alliances with overseas manufacturers and the construction of overseas Japanese owned plants are being taken.

Although assets of many plants in Japan have been completely depreciated and those plants can be operated on running costs alone, their scales are small compared with plants constructed by overseas manufacturers in recent years, and their global competitiveness cannot be kept up without improvements to their production efficiency.

Amid such changes in the process industries in Japan, there is an increasing demand for upgrading plants in Japan to become mother factories. Previously, a mother factory aimed at technology development and transfer. However, management aspects such as locational conditions and securing employment in Japan have been more emphasized in recent years. Although state-of-the-art equipment should be installed in mother factories, capital investment is frequently unavailable due to intense global competition. As a result, there have been actions taken in order to virtualize mother factories [3].

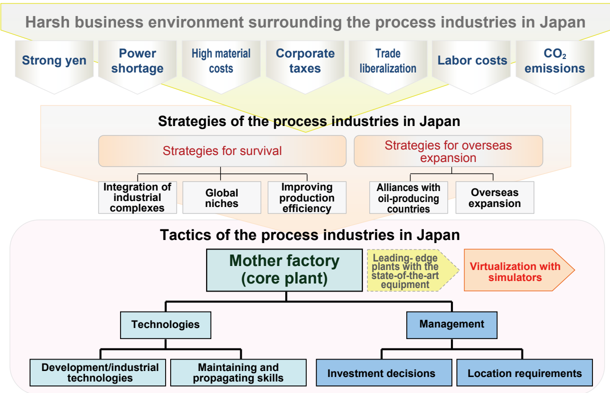

Figure 1 Challenges facing the process industries in Japan and some responses

ROLE OF THE MIRROR PLANT IN A PLANT LIFECYCLE

The role of the MIRROR PLANT in a plant lifecycle from the design, construction, and operation to the closure of the plant is explained below.

Challenges during the Production Phase

Generally, the life span of a plant is about 40 to 50 years. As shown in Figure 2, the production and operation phase is the longest in a plant life cycle. As described earlier, during the long production phase, technologies advance and the economic and social environments surrounding the plant can change greatly. To keep up with these changes, plants have to be run in different conditions from those assumed during the design stage. While manufacturing the same product, plant operation often needs to be drastically changed. For example, economic conditions force a plant to switch from full-load production during periods of high economic growth to variable amount production. Environmental concerns force a plant to use LNG as fuel rather than heavy oil. In addition to changes in external conditions, the processes themselves also change during the long production phase. Conditions in a process may change: for example, catalytic activity and heat transfer conditions of heat exchangers.

In general, plants are designed under specific process conditions, and temporal changes in the process are not considered. Therefore, actual plant operation after the construction may deviate from the assumptions at the design stage due to repeated changes in operating conditions and temporal changes in the process.

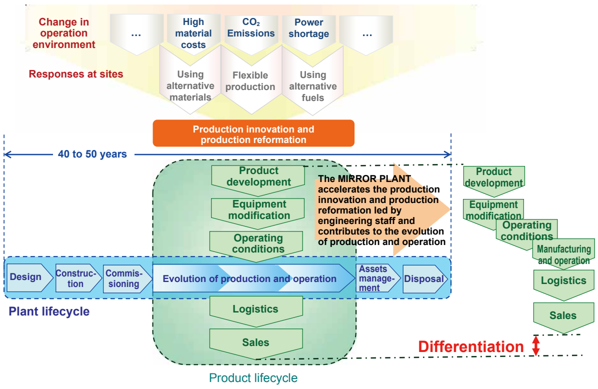

Figure 2 Effective use of the MIRROR PLANT in a plant lifecycle

Role of the MIRROR PLANT in the Production Phase

Different from the operator training simulator (OTS) which covers operations from the start-up to shut-down of a plant, the MIRROR PLANT focuses on the production phase in the plant lifecycle. The MIRROR PLANT uses a physical model based on principles and fundamental rules to simulate the process behavior, identifies model parameters online, and provides an operational environment that can foresee plant behaviors by using visualization and predictive functions.

Meanwhile, as shown in Figure 2, the product life cycle is involved in the production phase, the longest phase in the plant lifecycle as described in the previous section; thus it must also be considered. It includes production with changes in raw materials or fuels, and the production of new products requiring plant modifications. Engineering staff at the production site manage these changes in the process and operating conditions. But their investigations are usually static and mainly focused on equipment, and rarely include controllability. The MIRROR PLANT is a dynamic simulator which applies a physical model based on principles and fundamental rules. It enables a quicker release of new products by reflecting changed conditions into the model and concurrently designing more optimal operating conditions.

The MIRROR PLANT can support applications covering the tasks of plant operators as well as engineering staff.

APPLICATIONS SUPPORTED BY PLANT MODELS

There are various products that make use of plant models, such as the operator training simulator, which provides operators simulated experiences of unsteady operations such as the start-up and shut-down of plants; the model predictive control (MPC) which handles multiple variables; the real time optimizer (RTO) which finds the optimal set point based on a steady-state process simulator, and so on. Table 1 compares the features of the MIRROR PLANT and other products using plant models. The MIRROR PLANT can accurately simulate the behavior of a plant by updating the model online. The predictability based on this model differentiates the MIRROR PLANT from other products. As the MIRROR

PLANT expresses the non-linear dynamics of plants by using a physical model based on principles and fundamental rules, it can precisely predict the near future results of changes in conditions within a certain operating range.

Table 1 Comparison of features of the MIRROR PLANT and other products using plant models

Item \ Product	MIRROR PLANT	OTS Training Simulator	MPC Advanced control	RTO Steady-state simulator
Type of model and its feature	Physical model (non-linear, white box)	Physical model (non-linear, white box)	Transfer function model (linear, black box)	Physical model (non-linear, white box)
Applicable application	Normal operation	Normal operation unsteady operation	Normal operation	Normal operation
Expressiveness of dynamics	Yes	Yes	Yes	No
Synchronization with an actual plant (online model update)	Yes (tracking, and dynamic reconfiguration)	No	Yes (online gain adjustment)	No
Visualization of the inside of a plant	Yes	Yes	No	Yes
Future prediction	Good (possible to predict substantial changes in operating points)	Impossible	Limited (only for changes near operating points)	Impossible

Table 2 compares the applications applicable to the MIRROR PLANT and those applicable to other products using plant models. Applying a dynamic simulator, the MIRROR PLANT can calculate and predict the final steady state of the process after changes in operating conditions. It must be noted that the MIRROR PLANT can perform fine optimization taking various factors into consideration such as deterioration of catalytic activity, because it can track temporal changes in the parameters by using online model updating technology. Yokogawa has also developed applications such as plant diagnosis and abnormality avoidance operations by using predictive features of the MIRROR PLANT.

Table 2 Comparison of applicable applications of the MIRROR PLANT and those of other products using plant models

Application \ Product	MIRROR PLANT	OTS Training Simulator	MPC Advanced control	RTO Steady-state simulator
Decision assistance for operating conditions	Applicable	Not applicable	Not applicable	Applicable
Model predictive control	Not applicable	Not applicable	Applicable	Not applicable
Operation optimization	Applicable	Not applicable	Applicable (by combining MPC, RTO)	
Analysis and evaluation of controllability	Applicable	Applicable	Not applicable	Not applicable
Operation training	Applicable	Applicable	Not applicable	Not applicable
Plant diagnosis	Applicable	Not applicable	Not applicable	Not applicable
Abnormality avoidance operation	Applicable	Not applicable	Not applicable	Not applicable

FOR HIGH VALUE-ADDED SERVICES FOR PLANTS

The MIRROR PLANT aims to deliver innovative solutions to problems at a production site by interacting with the user processes through the plant model. The MIRROR PLANT is not simply a packaged product. At the outset, it can build and evaluate a plant model while working together with users. After that, Yokogawa and Omega Simulation will support the users in identifying and resolving subsequent on-site issues. In this regard, the MIRROR PLANT is a novel type product among Yokogawa's line-up.

New Process Systems Engineering (PSE) Framework

As a pioneer manufacturer of DCS, Yokogawa has so far solved user problems mainly by using DCS. As shown in Figure 3, Yokogawa has provided highly reliable production systems to achieve 24-hour full operation, and wide-area monitoring systems to reduce energy consumption and manpower at production sites.

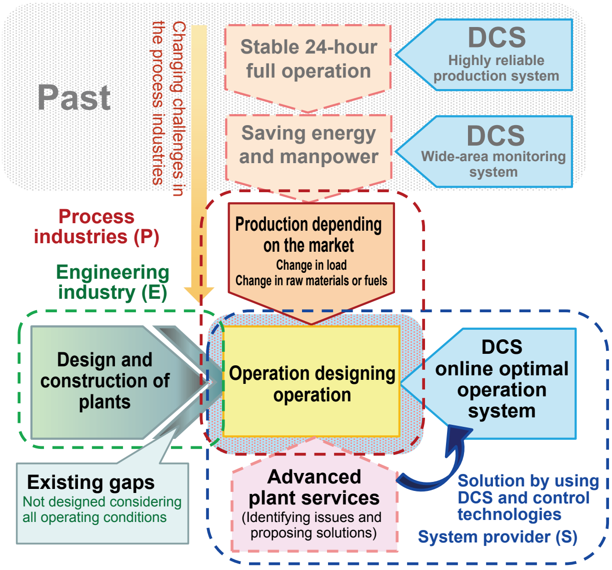

Figure 3 New PSE Framework

As mentioned earlier, the process industries in Japan are now in a harsh business environment, and it is difficult to maintain maximum output production as in the past. Instead, operations depending on market conditions are required. Yokogawa still believes that current problems of plants can be solved by using DCS as a main system, but unlike previous resolutions, system providers (S) must closely cooperate with the process industries (P). A multi-purpose dynamic simulator (MPDS), which uses a dynamic model throughout all phases from design to plant operation, is advocated. However, design models used in the engineering industry (E) are not applicable to actual operations yet (4). System providers should establish high value-added services for plants in order to share problems with users, set improvement targets, implement solutions to achieve them, and support to maintain the improved situation even after the solution of problems. As a system provider, Yokogawa will solve user problems by using DCS and control technology. We consider that we have entered a new era in which a new PSE framework is required.

Services Provided Through Plant Models

Plant models are closely related to operations control, one of Yokogawa's business domains. Figure 4 shows an example of a continuous agitation reactor tank. The heating jacket is omitted in this figure.

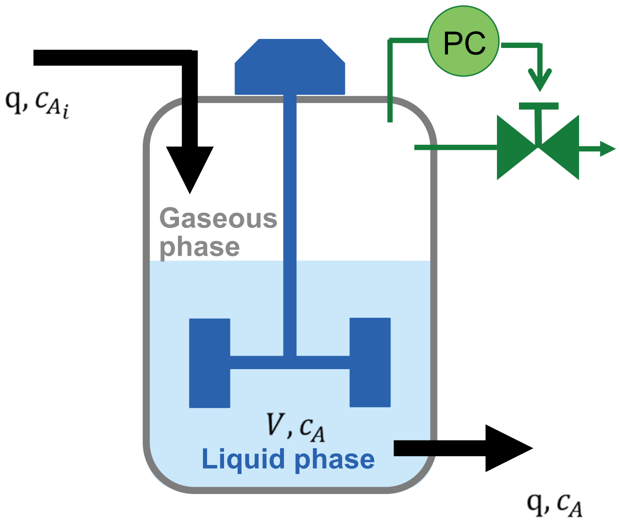

Figure 4 A continuous stirred reactor tank

A model formula used in the design for materials in this system is as follows:

$$V\frac{d(c_A)}{dt} = q\left(c_{A_i} - c_A\right) - Vkc_A$$

where, q is the feed flow rate, C_{Ai} is the concentration of the raw material feed, C_A is the concentration of the reactant after heating and reaction, V is the volume of the liquid phase reactant and k is the reaction rate. This formula holds when the contents are uniformly agitated in the reactor vessel to proceed the reaction. In addition, the pressure of the gaseous phase reactant in the tank must be constant. Therefore, to keep this formula valid, pressure control to maintain the pressure constant is indispensable. That is, control plays an important role in achieving the ideal behavior assumed in the process design.

The MIRROR PLANT expresses plant behaviors by using a physical model based on principles and fundamental rules. Factors which may disturb processes can be found by checking the data measured in the plant against the plant model and by investigating site factors hindering assumptions that the model formula holds. For example, if the effect of pressure fluctuations on the reactor system cannot be quantified, the control target cannot be precisely determined.

After the process is stabilized, the operating point is shifted to the optimal point. The optimal operating point often exists in the vicinity of critical regions for processing: near the explosive region or just inside of the limit of the product specifications region. The MIRROR PLANT can verify and optimize safety during the transition to a new operating point, and the stability at the operating point and the control system.

A high value-added service for plants to stabilize and optimize processes cannot be provided by the MIRROR PLANT alone. It should coordinately cooperate with DCS and other services currently offered by Yokogawa, such as engineering services for implementation of advanced process controls, and the plant analysis service.

CONCLUSION

The MIRROR PLANT applies a simulator technology developed in Japan. Yokogawa believes that the MIRROR PLANT will be a support tool for establishing competitive plant operating technologies which will help plants in Japan to continue doing business in the extremely severe business environment.

The field tests of the MIRROR PLANT at a user site have already been completed, and it is in the operational stage now. Although specific results cannot be disclosed for confidentiality reasons, great improvements have been shown at the field test site. Yokogawa and Omega Simulation are jointly preparing for its commercialization. As described in this paper, the MIRROR PLANT has various applications and can be used in many effective ways when applying models that accurately simulate plant behaviors.

Improvement activities such as small group activities and company-wide quality control (CWQC) activities are actively carried out in plants every day. People in factories may think that palliative approaches towards issues have all been tried. A lot of knowledge and skills are supposed to be accumulated in a plant. To make full use of them and transform them into useful technology, fragmented knowledge and skills that are often hard to quantify must be combined into logical technical strategies. It is important to respond to changes in the external environment during the long plant life cycle, and it is also important to remember that people involved in plant operations are replaced. We believe that using the MIRROR PLANT as a framework to systematize technology instead of accumulating know-how in persons is an optimal approach.

Nowadays, users often face problems that they cannot solve on their own. Through the development of the MIRROR PLANT and its field tests, Yokogawa now has staff who can build the MIRROR PLANT itself introduced in this special issue. While the MIRROR PLANT is still in preparation for commercialization, Yokogawa anticipates that many users will consider its implementation.

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