Featured Articles

Utilization of AI in the Water Sector

Case Study of Converting Operating History Data to Values

Ichiro Embutsu, Dr. Eng.
Koji Kageyama, Dr. Eng.
Satomi Tsuji
Norihiko Moriwaki, Ph. D.
Yukiko Ichige

OVERVIEW: Global demand for water has been increasing as urban economic activity expands. A significant amount of energy is required to obtain clear water, and the reduction of this energy requirement is a major concern for water utilities. Since the qualities of raw water vary greatly in water processing systems, such systems are constructed out of combinations of multiple unit processes designed to handle each of these qualities. For this reason, there are many cases where explicit models based on physical and chemical phenomena are not sufficient for implementing appropriate operation and control, and so expectations have grown for the utilization of implicit knowledge that is inherent in the operating history data. Hitachi is deploying its Hitachi AI Technology/H technology to social infrastructure, and will continue contributing to water supplies that are both safe and reliable by proactively applying the system to water treatment systems.

INTRODUCTION

THE global water environment market shows promise and is poised to grow from 36.2 trillion yen in 2007 to 86.5 trillion yen in 2025[1]. Of this, just under 90% is comprised of water supply and sewage systems, between 40% and 50% of which is management and operation. The over 10% remaining is taken up by seawater desalination, industry, and recycling segments which are expected to grow tremendously.

Hitachi is promoting its Social Innovation Business in a bid to reform social infrastructure by fully utilizing information and communication technologies (ICT), and its provision of solutions for the water industry is playing a key role in these efforts. Specifically, by supplying products, systems, and services, Hitachi is working to provide solutions for customers' issues in areas such as water conservation, flood control, water supply and sewage systems, securing water resources (desalination and water recycling), and wastewater treatment, etc.

The biggest concern of water utilities introducing solutions such as these is how to minimize business costs while maintaining the regulated level of water quality. Most of all, along with streamlining and the reduction of manpower requirements related to the operation of water processing systems, Hitachi is giving priority to energy-saving solutions as a major focus of its research and development, since expectations for them are high.

The technology of artificial intelligence (AI) has seen new progress in recent years, and is expected to be effectively applicable to water treatment systems as well. This article introduces these efforts.

ATTEMPTS AT UTILIZING AI IN THE WATER SECTOR

Water supply and sewer systems, seawater desalination systems, and other water treatment systems differ greatly from other typical industrial systems in that fluctuations cannot be avoided in the qualities of the raw water that they process (river water, sewage, seawater, etc.). In order to deal with these changing raw water qualities, water treatment systems are comprised of multiple unit processes including sedimentation, biological treatment, membrane filtration, and others. The physicochemical phenomena that occur within these unit processes are systematized and formulated based on previous knowledge, and although this is controlled automatically to a great extent, it depends on the know-how and skill level of operators. Sometimes flexible responses are required, and it is important to provide solutions that can deal with these types of cases.

The history of attempts to apply AI is relatively long in the water sector, and even Hitachi experimented with applying the know-how of operators involved with water treatment systems and the causal relationships inherent in operating history data to operation and control in the 1990s. For instance, Hitachi applied fuzzy logic-based expert systems, which can be considered to be one type of AI in the broader sense, along with neural networks to coagulant chemical injection operations at water treatment plants, and demonstrated at the actual plant level that these technologies can be used to handle operation during both normal and abnormal situations, including high-turbidity raw water[(2), (3)].

Due to advancements in AI technology and improvements in machine power that have been occurring in recent years, the environment is in place for utilizing more massive amounts of operating history data than before. The next chapter describes in detail how Hitachi is considering the application of AI technology with a focus on the seawater desalination sector.

CASE STUDY EXAMINING DESALINATION SYSTEM OPERATION AND CONTROL

Target System: Water Desalination & Reclamation System

Fig. 1 shows an example of a representative process flow using the "water desalination & reclamation system" integrated seawater desalination and sewage treatment system. This system recycles treated sewage and other types of water while at the same time utilizing the concentrated water (brine) generated in the final filtration process as dilution water for its seawater desalination system, thereby achieving low-cost desalination that saves energy while reducing the burden placed on the environment. The system can be broadly divided into a sewage and industrial drainage recycling system and a seawater desalination system. The sewage and industrial drainage recycling system biologically treats the sewage in a membrane bioreactor (MBR), and then filters the output through a sewer system reverse osmosis (RO) membrane device to get water for reuse. With this water, it is possible to achieve water quality that is at the level of drinking water or industrial water.

The seawater desalination system filters seawater through ultrafiltration (UF) and then mixes the resulting water with the concentrated water in the sewer system RO membrane device, and then filters the output through a seawater RO membrane device to get purer water, after which the seawater RO membrane device's concentrated water is released into the ocean as drainage water. When compared with general seawater desalination systems, this system offers the following four advantages:

(1) It can effectively utilize the sewer system RO membrane device's concentrated water output from the sewage recycling system, thereby reducing the amount of drainage water.

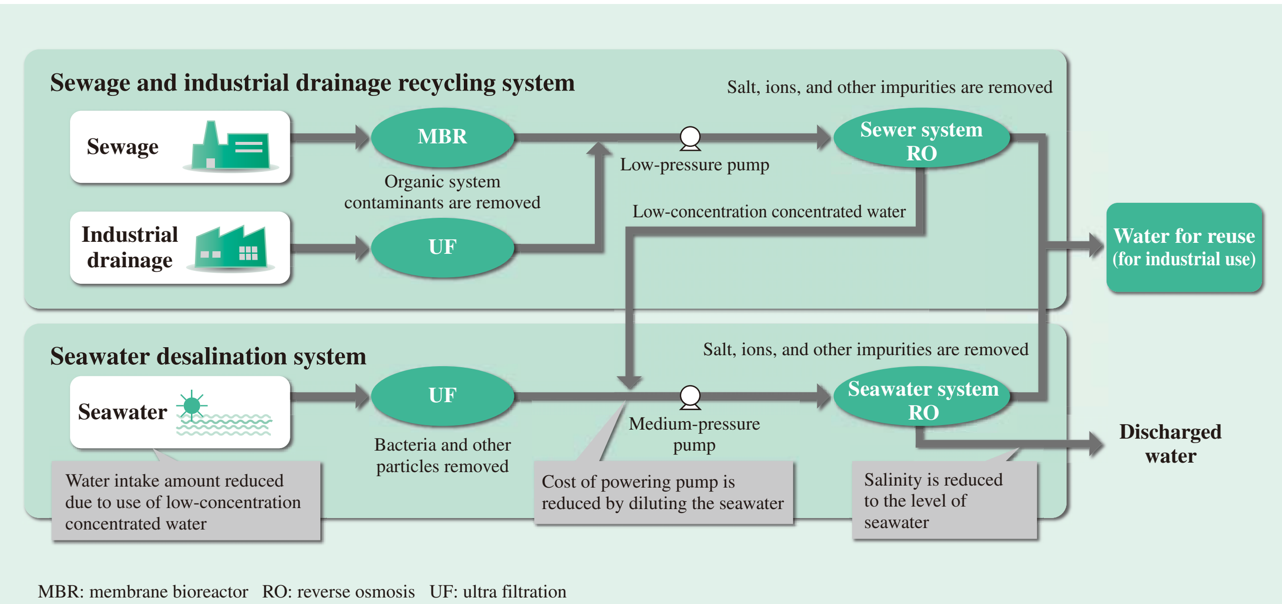

Fig. 1—Water Desalination & Reclamation System Process Flow Example.
The figure shows a representative configuration example integrating seawater desalination and the recycling of sewage and other input.

(2) It can reduce the quantity of seawater intake required to produce a given amount of production water (fresh water), thereby reducing the size of water intake facilities while at the same time lowering the cost of power required for water intake.
(3) By mixing seawater with the concentrated water from the sewer system's RO membrane device, it reduces the osmotic pressure of the treated water in the seawater system's RO membrane device, thereby lowering the cost of powering the filtration pumps necessary for desalination.
(4) The salinity of the concentrated water of the seawater system's RO membrane device is reduced to roughly the level of seawater.

On the other hand, a seawater desalination system based on RO membrane devices does suffer from the same problem of fouling, which is widely known to increase the cost of power to run the filter and to decrease equipment utilization. Although there is established knowledge regarding the mechanisms that cause fouling[4], at present, effective suppression methods still rely in part on trial and error. It is for this reason that Hitachi attempted to acquire knowledge regarding operation and control methods that can suppress fouling by applying AI technology to operating history data from the past.

Applied AI Technology: Hitachi AI Technology/H

In order to acquire new knowledge regarding the suppression of fouling, Hitachi is applying AI technology it has developed called Hitachi AI Technology/H (hereafter referred to as H). This technology offers functions that exhaustively derive and visually represent correlations from large amounts of numerical data (indices) generated by combining huge amounts of data[5]. In this way, the system can extract from among the many different types of indices those that have useful correlations with objective variables, and use this information to create specific measures that are highly effective with respect to the objective variables.

By inputting and analyzing operating history data from the water desalination & reclamation system, Hitachi is attempting to come up with control methods based on new causal relationships that have been overlooked in the past. This includes, for example, the expected ability to extract candidate process parameters that correlate meaningfully with the seawater system RO membrane device's inlet pressure, which increases when fouling occurs.

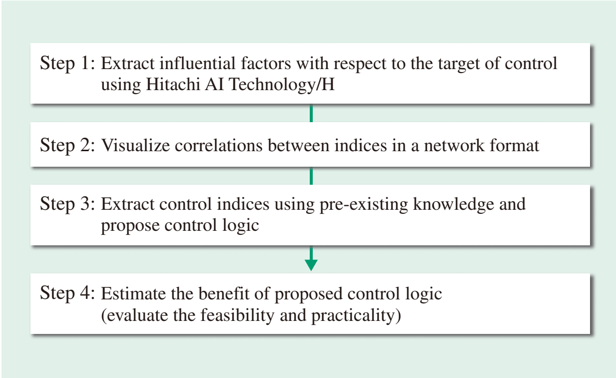

Fig. 2—Analysis Flow for Consideration of Control Logic.
H was applied in a four-step analysis.

Used Data and Analytical Methods

This analysis used operating history data acquired through "Water Plaza Kitakyushu," which was contracted to the Global Water Recycling and Reuse Solution Technology Research Association (GWSTA) as a project for the New Energy and Industrial Technology Development Organization (NEDO). Hitachi used the acquired data by selecting data at one-hour intervals without irregular operations in order to create an analytical data set comprised of one objective variable and 43 explanatory variables.

The analytical method was implemented based on the four-step process shown in Fig. 2, with the goal of extracting the influencing factors affecting inlet pressure at the seawater system RO membranes that could indicate the degree of fouling, and which could be used as a basis to consider methods of fouling suppression control. For this reason, the analysis was conducted using the seawater system RO membrane inlet pressure as the objective variable.

First, Hitachi extracted influencing factors from this data set using H, and then extracted explanatory variables (influencing factors) based on these results that had meaningful correlations with the objective variable. The relationships between the extracted influential factors and the objective variable were then visualized using a network format. Phenomenological pre-existing knowledge regarding fouling was then used to extract control indices and devise control logic. Finally, the devised control logic was used to estimate the expected fouling suppression benefit, and both feasibility and practicality were evaluated.

Analysis Results and Consideration of Control Methods

The results of the analysis using H with seawater system RO membrane inlet pressure selected as the

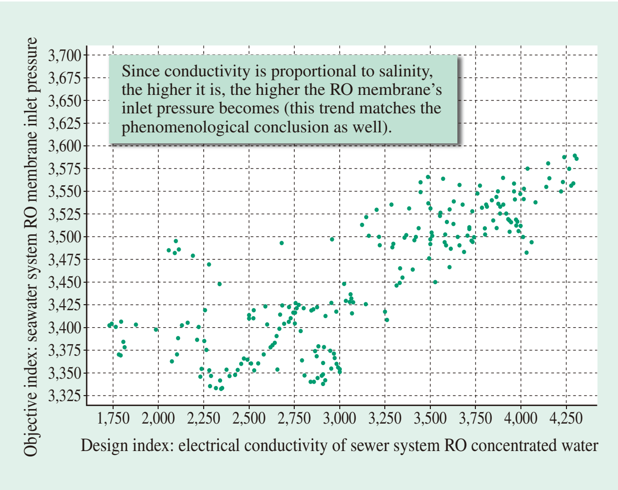

Fig. 3—Correlation Chart between Water Quality Parameters Extracted by H and Objective Variables.
The results imply a trend where the higher conductivity is, the higher RO membrane inlet pressure becomes.

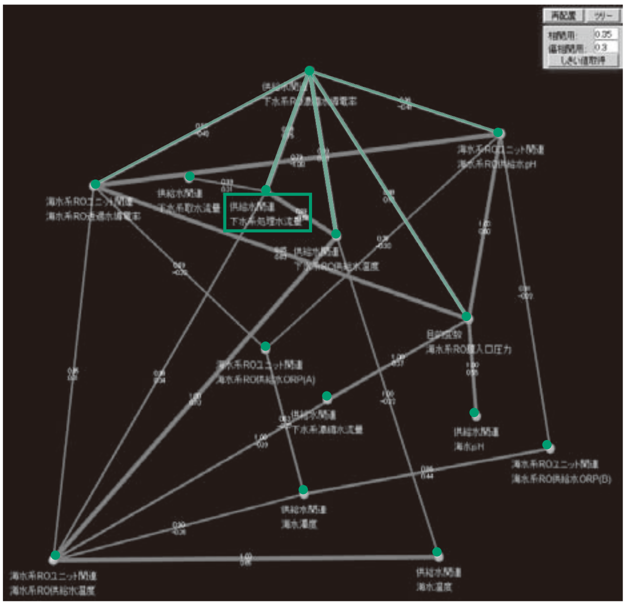

Fig. 4—Example of Visualization in Network Format of Correlation between Indices Related to Sewer System RO Membrane Concentration Water Electrical Conductivity Based on Results of H Analysis.
The controllable factors can be extracted by visualizing correlative relationships.

objective variable produced correlation coefficients with 43 explanatory variables. Of these variables, Hitachi focused on one related to the quality of the sewer system RO membrane's concentrated water, which accounted for approximately half of the water supplied to the seawater system's RO membranes. As shown in the scatter plot in Fig. 3, a direct correlation existed with respect to the objective variable. Increasing electrical conductivity is thought to be associated with increases in salinity and other factors, and the connection with the increasing inlet pressure of the seawater system's RO membranes agrees with the phenomenological analysis as well.

Furthermore, Fig. 4 shows the results of visualizing the relationships of other variables with the conductivity of the concentrated water from the sewer system's RO membranes, based on the network analysis function applied between indices. When viewed from the perspective of changing conductivity and then verifying results, the flow rate of water through the sewer system process was derived as a variable factor. The related operating history data also showed that specific increases in conductivity were triggered by changes in the flow rate of water through the process.

Of the knowledge attained from the analysis described above, the knowledge of what was seen as an effective method for suppressing increases in the inlet pressure of the seawater system's RO membranes, which was the objective variable (causal relationships between variables), can be summed up with the following inferred causal relationship: suppressing the electrical conductivity of the concentrated water from the sewer system's RO membranes will suppress the electrical conductivity of the mixture of the concentrated water from the sewer system's RO membranes with seawater, which will then suppress the osmotic pressure of the mixed water, thereby suppressing the inlet pressure (absolute value) of the seawater system's RO membranes and/or the inlet pressure's increase over time. A conceivable control plan based on this is, (1) controlling the mixed water electrical conductivity. Conceivable subordinate control plans include, (2) controlling the electrical conductivity of the sewer system RO membrane's concentrated water, (3) controlling the blend ratio, and (4) controlling the seawater intake. The specific control methods derived are shown in Fig. 5.

Hitachi estimated the suppression benefit with respect to increases in inlet pressure at the seawater system's RO membranes based on these control methods (details such as the method of estimation are omitted here). Estimates showed that operation and control that restrained the flow rate of the sewer system process for the approximately ten days of the evaluation period resulted in a total pressure increase (integrated value) of approximately 6% of the 1.47 MPa that would occur without this control, producing a figure of only 0.09 MPa. Analysis of a breakdown of this benefit showed a direct benefit

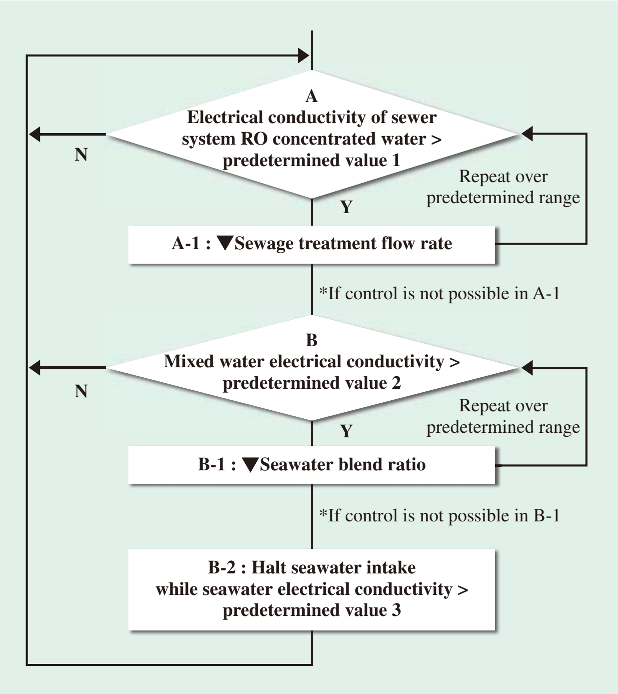

Fig. 5—Control Method Flow for Suppressing Fouling.
This control method was derived based on knowledge extracted using H.

of approximately 3% due to a reduction in osmotic pressure through lowered conductivity. The benefit of suppressing the increase in irreversibility of filtration pressure (that is, fouling suppression) was also shown to be approximately 3%.

Since the cost of powering a high-pressure pump can be considered to be proportional to the filtration pressure, this means that the cost of power is expected to be reduced by approximately 6%. At present, when it comes to the operation of seawater desalination plants, a variety of different on-site efforts have incrementally reduced operating costs a steady rate of several tenths of a percent. The proposed control methods are judged as providing a significant benefit in terms of reducing running expenses without generating additional costs or requiring new equipment or chemicals.

CONCLUSIONS

The water desalination & reclamation system is a process that integrates both sewage recycling and seawater desalination, and Hitachi is aiming to expand its adoption both domestically and internationally. By applying Hitachi AI Technology/H to the fouling problem shared by all water treatment systems that use filtration membranes, it was possible to extract the knowledge necessary for considering control methods.

In addition to seawater desalination plants, this technology can be applied to any other plant as long as past operating history data is available. Hitachi will continue working to expand the application of this technology to other plants, including water supply and sewer systems as well as other water treatment plants.

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REFERENCES

(1) Ministry of Economy, Trade and Industry, “Challenges and Specific Measures for International Development of the Water Business,” (Apr. 2010) in Japanese.
(2) I. Embutsu et al., “Rule Extraction from Neural Network—Application for the Operation Support of Coagulant Injection in Water Purification Plant—,” Transactions of the Institute of Electrical Engineers of Japan D, Vol.111, No.1, pp. 20–28 (Jan. 1991) in Japanese.
(3) I. Embutsu et al., “Integration of Multi AI Paradigms for Intelligent Operation Support Systems,” Water Science & Technology, Vol.28, No.11 (Dec. 1993)
(4) J. S. Vrouwenvelder et al. “Biofouling of Spiral Wound Membrane Systems,” Journal of Membrane Science, Vol.346, Issue.1 (Jan. 2010)
(5) N. Moriwaki et al., “AI Technology—Achieving General-Purpose AI that Can Learn and Make Decisions for Itself,” Hitachi Review **65**, pp. 35–39 (Jul. 2016).

ABOUT THE AUTHORS

Ichiro Embutsu, Dr. Eng.

Process Engineering Research Department, Center for Technology Innovation – Materials, Research & Development Group, Hitachi, Ltd. He is currently engaged in the research and development of water treatment and control systems for water supply and sewage. Dr. Embutsu is a member of The Society of Environmental Instrumentation Control and Automation (EICA), the Japan Society on Water Environment (JSWE), and The Institute of Electrical Engineers of Japan (IEEJ).

Koji Kageyama, Dr. Eng.

Process Engineering Research Department, Center for Technology Innovation – Materials, Research & Development Group, Hitachi, Ltd. He is currently engaged in the research and development of water treatment and control systems for water supply and sewage. Dr. Kageyama is a member of EICA.

Satomi Tsuji

Global Center for Social Innovation – Tokyo, Research & Development Group, Hitachi Ltd. She is currently engaged in research into the use of human big data for organizational management. Ms. Tsuji is a member of the Society of Project Management (SPM).

Norihiko Moriwaki, Ph. D.

Intelligent Information Research Department, Center for Technology Innovation – Systems Engineering, Research & Development Group, Hitachi, Ltd. He is currently engaged in the research and development of human information systems and artificial intelligence. Dr. Moriwaki is a member of The Institute of Electronics, Information and Communication Engineers (IEICE), The Japan Society for Management Information (JASMIN), and the Association for Information Systems (AIS).

Yukiko Ichige

Business Development Department, Global Water Solutions Division, Water Business Unit, Hitachi, Ltd. She is currently engaged in business development and task management of water solutions for the global market. Ms. Ichige is a member of The Robotics Society of Japan (RSJ).