Application of Expert systems to WWTPs in CSC

BY

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SYNOPSIS:

The operators of wastewater treatment plant receive various data and make adjustments based on experience. However, it is difficult for operators to monitor various data in real time constantly. In addition, there are numerous data that it is sometimes difficult to digest all the information and identify the problem in time. Therefore, CSC thought to collect all the related data and establish expert systems to predict future changes of the WWTPs in advance. The expert systems can assist operators to identify key factors in advance and take action in time to avoid unwanted results. The main factors affecting the target water quality are screened out according to the known theory and experimental results. The XGBoost algorithm is used to build a model, and the data source is selected through training and testing. Two expert systems have been build and applied to two WWTPs in CSC. One is applied to the biological WWTP and the target is controlling the ammonia nitrogen concentration in the effluent. After applying the system, the number of days that the ammonia nitrogen in effluent exceeding the internal control has dropped significantly to 1.3%. The other is applied to the industrial WWTP and the target is to optimize the chemical dosing and reduce the fee to at least 3%. After applying the model, the chemical dosing fee decreased 0.041 NTD/ton of treated wastewater and saved 4.8% of chemical dosing fee.

Keywords: Wastewater Treatment, Expert Systems

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1. Introduction

China Steel Corporation (CSC), located at Kaohsiung, Taiwan, was founded in 1971, with annual production around 10 million tons of crude steel. CSC is the largest integrated steel maker in Taiwan. Integrated steel production needs water for cooling, de-rust, lubrication, and dust washing. The source of raw water used in CSC is from Kaohsiung Fengshan Reservoir ([FSR] effective capacity 3.4 Mt), which provides 0.3 Mt of industrial water daily. Since September 2019, CSC began receiving 41,000 m^3 of reclaimed water daily from Fengshan Creek Reclaimed Water Plant which reclaims water from Kaohsiung City's domestic sewage. With effective water management, recycling industrial wastewater in CSC itself, and using the reclaimed water from Kaohsiung City's domestic sewage, the daily raw water consumption for production has reduced to 75,375 m^3 in 2021. In CSC, process water recycling rate has reached 98.4 %, and the water intensity was reduced to 4.6 m^3/tCS in 2021.

The other main task of CSC is water pollution control. The CSC wastewater treatment facility with 79,600 m^3/day capacity treats wastewater to effluent standards and discharges to the ocean through a 60-meter channel. In addition, a 40,000 m^3 runoff wastewater collecting pool with 36,000 m^3/day capacity for the raw material yard treats runoff wastewater from heavy rain to the effluent standards. In 2021, the total discharge was 14,202,000 m^3 (Figure 1). The average Chemical Oxygen Demand (COD) concentration was 44.2 mg/L, suspended Solids (S.S.) concentration was 5.3 mg/L and ammonia was 6.8 mg/L (as nitrogen). These three water quality are all much lower than statutory effluent standards which are 100, 30, and 20 mg/L, respectively.

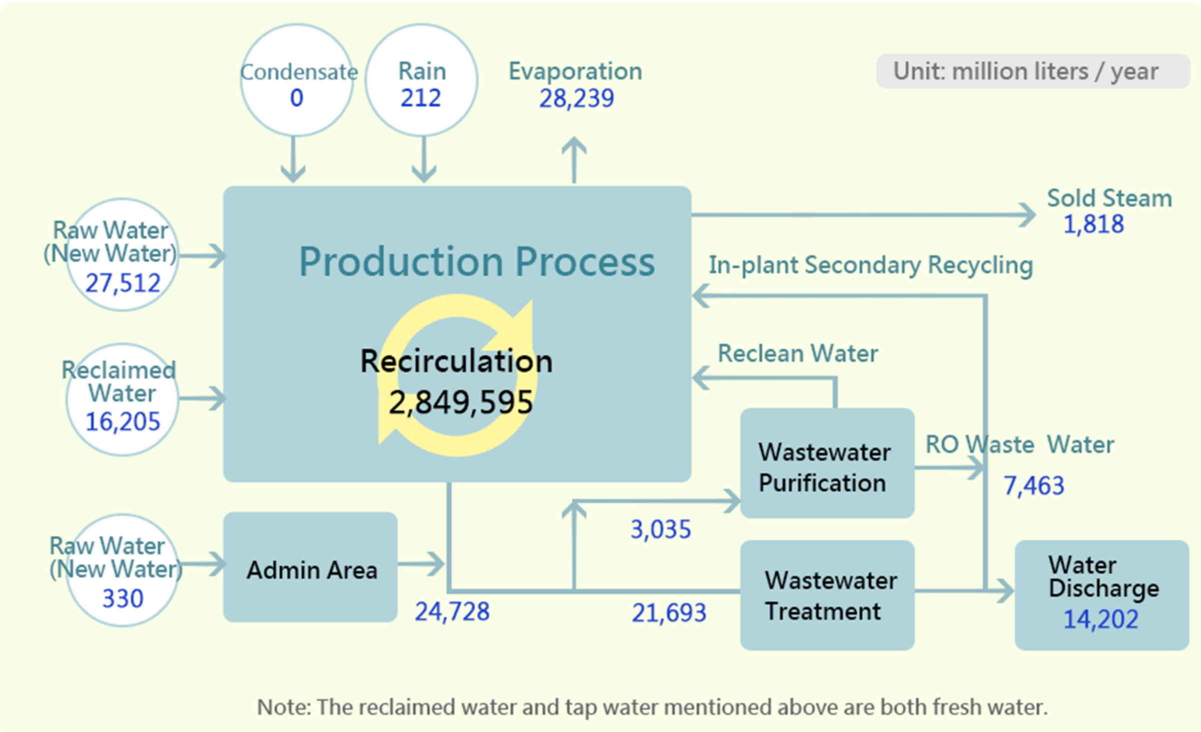

Figure 1 Water balance in CSC in 2021

There are various data and operating parameters in WWTP and the operators make adjustments based on their experience. However, it is difficult for operators to monitor various data in real time constantly. In addition, sometimes it is difficult to identify the problems in time due to huge amount of input data. CSC thought to build expert systems to predict future changes in advance and assist operators to identify key factors that may lead to abnormality of WWTP in time. Two expert systems were built in Biological and Industrial WWTP respectively.

Biological WWTP used to only have one main function which is to remove COD. In order to fit the new regulation of ammonia nitrogen, the Biological WWTP was reconstructed in 2015~2016. After the reconstruction, the biological basins are modified and function to remove ammonia was added to the system. However, the total hydraulic retention time (HRT) was only 38 hours, which made the system quit susceptible to water quality fluctuations of influent. One third of the times, the effluent would exceeded the internal control of ammonia which is 10 mg/L (as nitrogen). The system treats organic matter and ammonia by biochemical reactions of the microbes. There are many monitoring parameters in different biological basins and sometimes it’s difficult for the operators to identify problems in short amount of time. The research team established an expert system to help operators maintaining optimal operation.

The main variables are selected according to the theoretical and experimental results. The Xgboost algorithm is used to build a model, and the optimal data source is selected through training and testing. SHAP (SHapley Additive exPlanations) was used to sort out the importance of each variables. The expert system would give suggested value of each variables. The operators would know which variable plays the most important role to affect ammonia in effluent and know which direction to adjust. Since the launch of the expert system on 110.08, the number of days that the ammonia nitrogen concentration in effluent exceeded the internal control value has dropped significantly to 1.3%, which has achieved remarkable results.

The industrial wastewater system uses sedimentation process to remove suspended solids, chromaticity, turbidity, and other substances in the wastewater. The coagulant and flocculant are added and pH is control in order for the flocs to be formed properly. In order to ensure the quality of the effluent, the excess amount of chemicals are usually added to the system. It’s a waste of chemical dosing and sludge treatment fees. The sedimentation effect depends on the particle size of the formed flocs. In order to observe the floc size, the operators need to be on site in person to watch the floc formation. The operators then adjust the dosing concentration base on their experience. Sometimes, it is difficult to detect abnormality or problems in time. The research team established an expert system to help operators maintaining optimal operation.

The research team built up a camera in substitute of human eyes to capture the floc forming in real time. There is a build in image analysis software to convert the images into quantitative number. There are 20 parameters been measures. Together with chemical dosing concentration, pH and water volume flow rate, a model was built using Xgboost algorithm. SHAP (SHapley Additive exPlanations) was used to sort out the importance of each variables. The expert system would give suggested values specifically to chemical dosing concentration, pH and water volume flow rate. The operators could operate base on the suggestion. The target of this project is to optimize the chemical dosing and reduce the fee to at least 3%. After applying the model, the chemical dosing fee decreased 0.041 NTD/ton of treated wastewater and saved 4.8% of chemical dosing fee.

2. Materials and Methods

2.1 Data collection and selection in Biological WWTP

The whole treatment processes of Biological WWTP have been reviewed and all the monitoring targets have been discussed between, operators, domain experts, and data scientists. The main factors affecting the ammonia concentration in the effluent of the Biological WWTP were screened out base on the known theory and experimental results. 78 factors including 63 factors which are assayed daily in lab and 15 factors which are monitored by online detectors were selected. The AVEVA PI (Plant Information) System was used to collect and stored the data.

2.2 Data Processing and establishment of expert system in Biological WWTP

Three algorisms including, XGBoost, random forest, and deep learning were used to process the data. Three sets of data source including, data assayed daily in lab, data monitored online, data from both lab and online were tested to build models. Through training and testing, the data source which the factors are assayed daily by the lab and a model which was built using the XGBoost algorithm was selected. Lastly, the importance of the factors to affect the ammonia concentration in the effluent of the Biological WWTP are ranked using SHapley Additive exPlanations (SHAP).

2.3 Set up floc capturing camera in Industrial WWTP

Three different brands of cameras were tested to capture the flocs in the slow mixing tank. The basin floccam made by DURASENS, LLC is the only one which can captured the flocs in slow mixing tank during both day and night. The floccam can capture live video of flocs and is equipped with software to convert the image to 20 quantitative parameters including average floc size, volume, number of flocs, and floc size distribution etc. The basin floccam can continuously give measurement in real time and allows operators to know the overall flocculation performance.

2.4 Data collection and selection in Industrial WWTP

The whole flocculation dosing processes of Industrial WWTP have been reviewed and all the monitoring parameters have been discussed between, operators, domain experts, and data scientists. The target is to reduce the chemical dosing fee and the concentration of suspended solid of effluent still need to meet the effluent standard. 20 quantitative parameters from the floccam together with the other 10 factors, including chemical dosing concentration, pH, and water volume flow rate of influent were selected. All the parameters and factors are all monitored online. The AVEVA PI (Plant Information) System was used to collect and store the data.

2.5 Data Processing and establishment of expert system in Industrial WWTP

Three algorisms including, XGBoost, random forest, and deep learning were used to process the data. Through training and testing, a model which was built using the XGBoost algorithm was selected. The sampling frequency of each parameter is every 5 minutes. The target of the model is the suspended solid concentration of the effluent. Take the hydraulic retention time into account, the model is set to predict the concentration of suspended solid in the effluent 25 minutes later. The suggested chemical dosing concentration and pH were also calculated and shown on DCS.

3. Results

3.1 Application of expert system to Biological WWTP

The biological WWTP in CSC processes 7,200 m^3 wastewater per day of coke oven wastewater. Coke oven wastewater contains 80% of the COD and 90% of the ammonia produced from the entire CSC plant. The composition of coke oven wastewater is complicated and mainly includes phenolics, thiocyanate, ammonia, and cyanide. The biological WWTP originally was designed only to treat COD. As regulation of ammonia nitrogen became stricter, the biological WWTP was modified in 2016 to remove ammonia by adding function of nitrification and denitrification (Figure 2). The system currently can process both COD and ammonia in the same WWTP and the hydraulic retention time only has 38 hours. The newly added ammonia removal function and relatively short HRT make the system more vulnerable to the fluctuations in the coke oven wastewater.

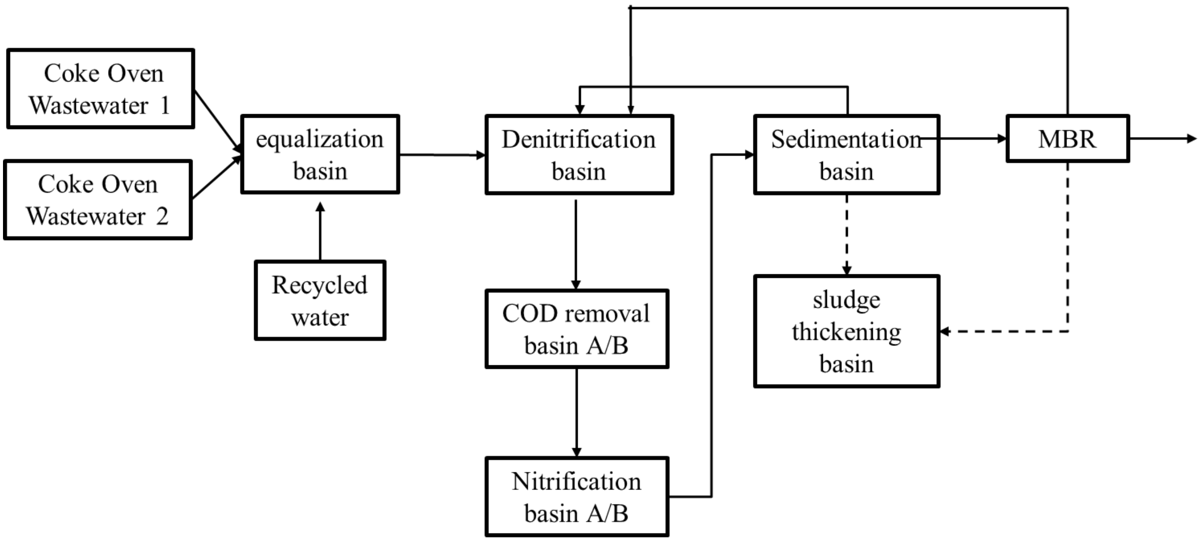

Figure 2 Flowchart of treatment processes in Biological WWTP

Adjustments of manufacturing processes at coking plants or changes in coal material often led to fluctuations in the quality of coke oven wastewater. The biological system cannot metabolize and remove organic compounds in time, and the residual organic compounds inhibit the nitrification reaction. The ammonia nitrogen of the effluent of Biological WWTP would exceed the internal control and the discharge water of CSC would be under risk of exceeding the effluent standards.

The biochemical WWTP was originally operated by the experience of operators. However, the factors that would affect the system are comprehensive and would interfere with one another. Sometimes, it is not easy to find out the key factors in time when the system fails. In order to maintain the optimal operation of the biological WWTP, a research team including operators, domain experts, and data scientist cooperated to establish an intelligent monitoring and diagnosis expert system through data analysis.

All monitoring parameters of biological WWTP are checked and there are 175 detection points manually or online. The main factors that are likely to affect the concentration of ammonia nitrogen in the effluent are screened out according to the theory, previous researches, experimental results, and experience of the operators. 78 factors including 63 factors which are assayed daily in lab and 15 factors which are monitored by online detectors were selected. After data cleaning, missing value processing, three algorithms including random forest, Xgboost, and machine learning were tested. Through training and testing, the data source which the factors are assayed daily by the lab and a model that was built using the XGBoost algorithm was selected. Lastly, the importance of all the factors were ranked using SHapley Additive exPlanations (SHAP). Once the expert system get a new set of data, the system would rank the variable factors according to its importance to the ammonia nitrogen concentration of effluent and also give suggested value of the factors (Figure 3). The operators can adjust base on the suggested values.

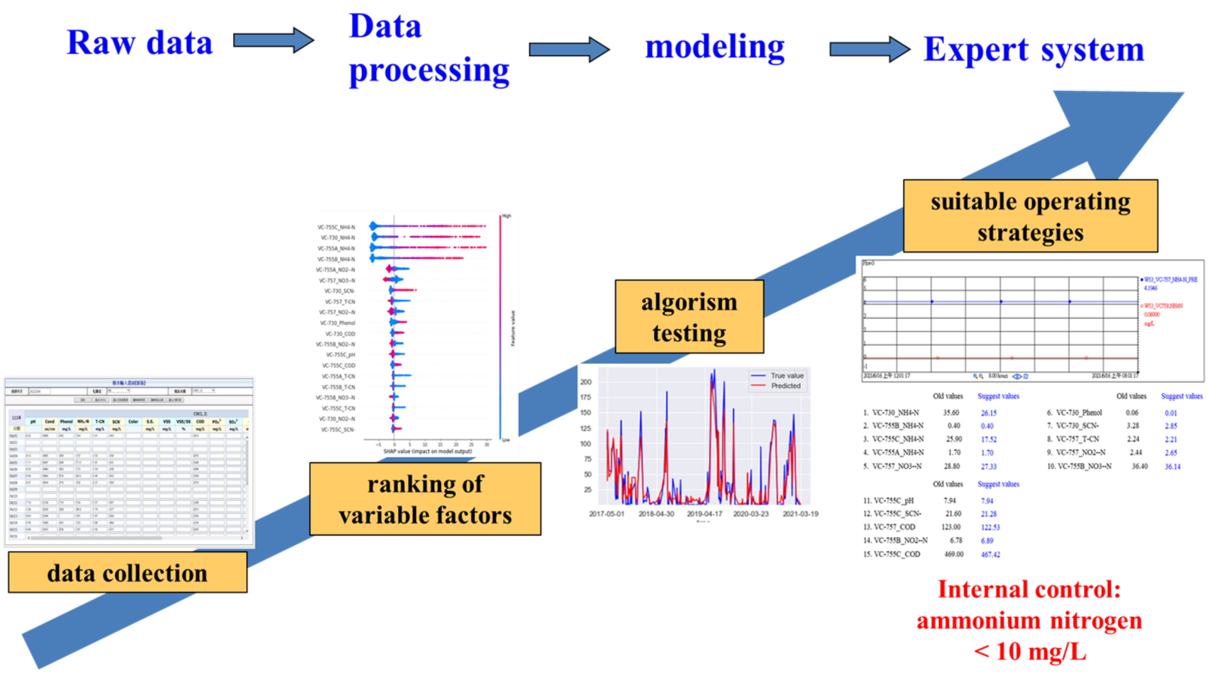

Figure 3 Flowchart to build a expert system

The monitoring and diagnosis expert system of Biological WWTP was launched in 2021.08. Through this system, the operators could identify the key factors that affect the ammonia nitrogen concentration in the effluent and make adjustments according to the suggestions by the model. The predicted values of ammonia nitrogen in the effluent of Biological WWTP have been consistent with actual measurements. Together with the troubleshooting plans, the number of days that the ammonia nitrogen in the effluent exceeding the internal control has dropped significantly to 1.3%.

3.2 Application of expert system to Industrial WWTP

The industrial WWTP uses the coagulation, flocculation, and sedimentation to remove the suspended solids and turbidity in the industrial wastewater (Figure 4). The sedimentation depends on the particle size of flocs and the dosage of the coagulant and flocculant. Jar test is normally used to evaluate the suitable reagents and optimal dosage. The operators use their experience to judge whether it is necessary to adjust the chemical dosage based on the fluc size observed with personnel's eye balls, the turbidity in the water, and the effluent condition.

CSC's current chemical dosing system controls the dosing amount base on the water volume flow rate of the influent automatically and maintains a fixed dosing concentration of the coagulant and flocculant at the same time. When the water quality of the wastewater is relatively stable, the described way to operate can still ensure the discharge water to fit effluent standard. However, when the water quality of the wastewater changes dramatically, the dosing concentration could not be adjusted accordingly and immediately. The operators often add excess amount of coagulant and flocculant in order to ensure the water quality of the discharge water. The WWTP would produce more sludge due to excess amount of chemical dosing. Together, there will be a waste in chemical dosing and sludge handling fee.

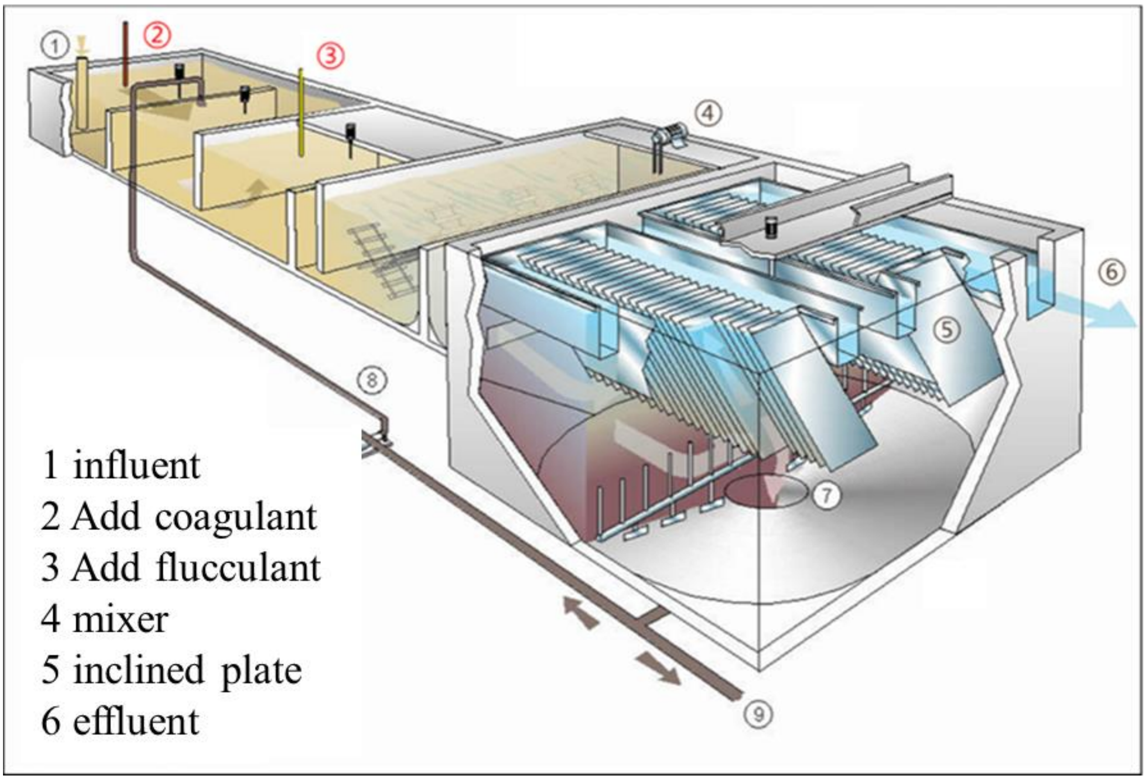

Figure4 Process of industrial WWTP

An image analysis system to detect the particle size, density, and shape of flocs in real time is planned to be built in substitute of human eyes. Combined with the data including the turbidity, water volume flow rate, pH and other monitoring parameters of influent and effluent, we are hoping to built a intellectual chemical dosing controlling system that can not only predict the suspended solid concentration in the effluent but also give the operators the optimal pH and dosing concentration of each chemicals.

Three different brands of cameras were tested to continuously shoot the water surface and to observe the image capture status of flocs in the slow mixing basin of industrial WWTP for 24 hours. The basin floccam made by DURASENS, LLC is the only one which can capture the flocs in slow mixing tank during both day and night. The floccam is equipped with software to convert the image to 20 quantitative parameters including average floc size, volume, number of flocs, floc size distribution and so on. A one-month stability test was conducted to evaluate how the weather, sunlight, oil in water, and the frequency of lens cleaning required to affect its data processing. Data were collected under different chemical dosing conditions.

The stability test showed that the abnormal formation of flocs observed by operators, changes in the shape and size of flocs caused by adjusting the dosing or switching of the coagulants could be successfully captured by the floccam and the corresponding data could be obtained (Figure 5). On the other hand, it was also found that there were problems such as sinking of the buoy that carrying the camera, interference of sunlight, rain, and dirt, and the breakage of the vertical fixed rod. The problems has been solved and the whole body structure of floccam has been strengthen and improved. In addition, the stability test also showed that the cleaning frequency of the equipment needs to be twice a week.

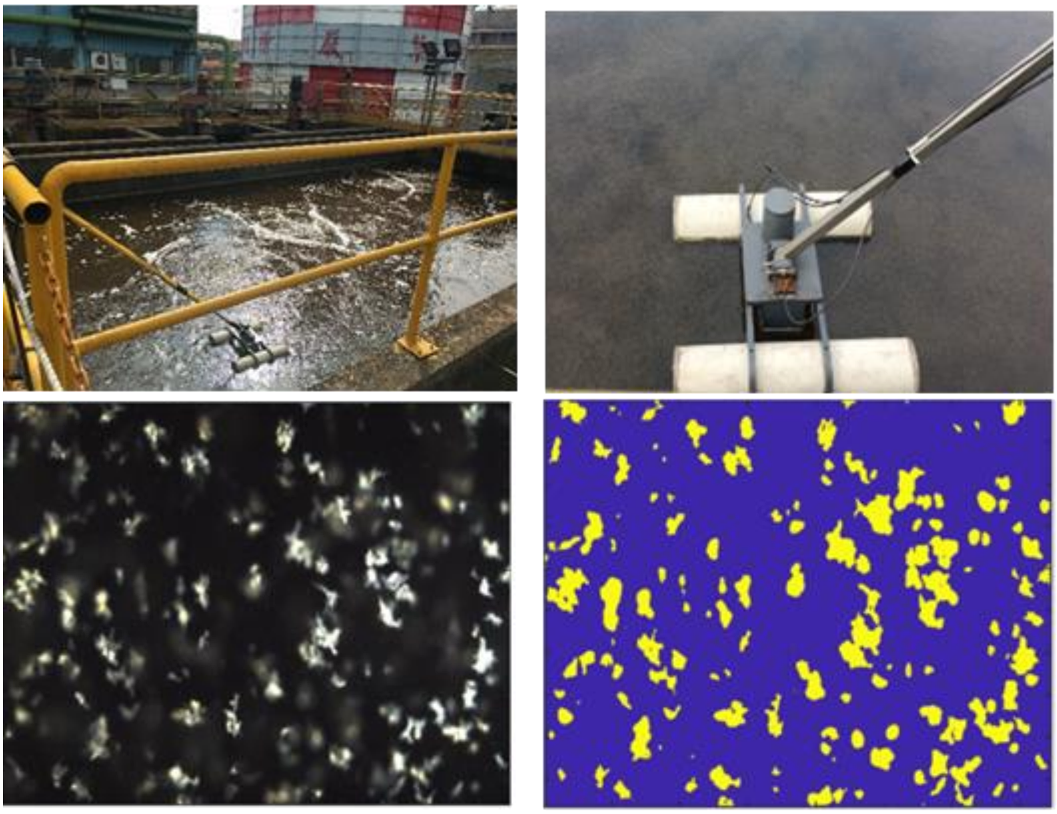

Figure 5 Floccam on slow mixing basin and images captured by it

All monitoring subjects of Industrial WWTP are checked and there are 25 online detecting points. There are 20 parameters provided by floccam. The other 5 factors are water volume flow rate, turbidity of influent, coagulant concentration, flocculant concentration, and pH. After Data cleaning, missing value processing, three algorithms including random forest, Xgboost, and machine learning were tested. Through training and testing a model that was built using the XGBoost algorithm was selected. The target of the model is the suspended solid concentration of the effluent which need to be less than 30 mg/L. Take the hydraulic retention time into account, the model is set to predict the concentration of suspended solid in the effluent 25 minutes later. The suggested chemical dosing concentration and pH were calculated and shown on DCS (Figure 6). The operators can adjust base on the suggested value.

The monitoring and diagnosis expert system of Industrial WWTP was launched in 2021.01. Through this system, the operators could adjust coagulant and flocculant dosing concentration together with pH according to suggested value by the model. The predicted values of suspended solids concentration in the effluent of Industrial WWTP have been consistent with actual measurements. The WWTP was well controlled by the expert system and the effluent quality is stable. The average suspended solid concentration is 5.35 mg/L, and the maximum value is 13 mg/L, which is lower than the 30 mg/L effluent standard. On the other hand, the coagulant and the flocculant used per unit of wastewater was decreased by 4.1% and 22.4%, respectively. The total chemical dosing fee was decreased by 4.8% which is meeting the initial target (reducing 3%).

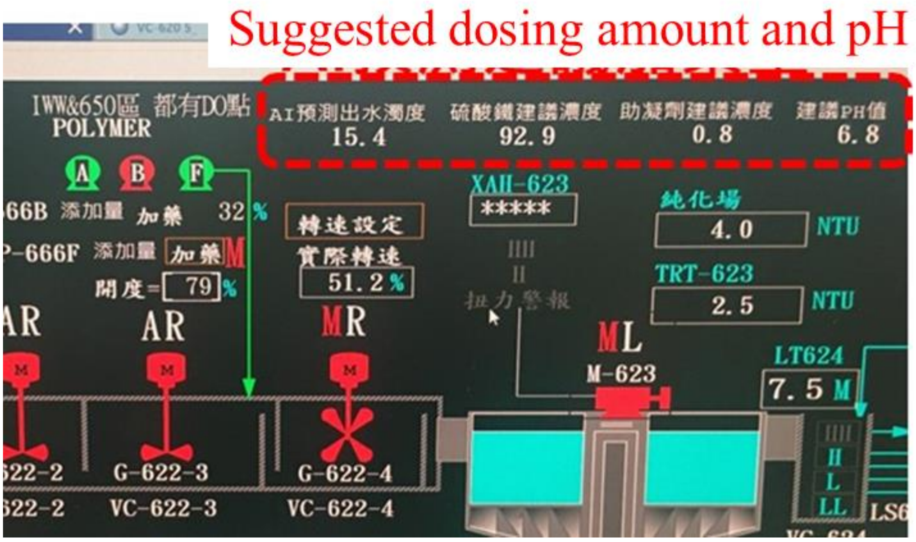

Figure 6 Predicted S.S. concentration and suggested chemical dosing concentration on DCS

4. Discussion

The expert system was built in biological WWTP and it was designed to pick up the key factors that would affect the ammonia nitrogen concentration in the effluent. The system would give suggested value of the key factors and the factors would be ranked according to their importance. The system would also give predicted ammonia nitrogen concentration of the effluent. The operators would know whether the biological function of the WWTP is going good or bad direction. The expert system could help the operators to identify problems and give them suggestions. Since the launch of the expert system, the number of days that the effluent ammonia nitrogen exceeded the internal control value has dropped significantly to 1.3%.

The expert system was built in industrial WWTP and it was designed to optimize the chemical dosing and reduce the fee to at least 3% and keep the suspended solid concentration below the effluent standard at the same time. A camera called floccam was built to substitute human eyes in order to capture the flocs in the slow mixing sink. The floccam equipped with software that can covert image to quantitative data and give 20 parameters. The data from the floccam together with data of chemical dosing, water volume flow rate, and pH were used to build the expert system. The system would give predicted suspended solid concentration of the effluent, suggested chemical dosing concentration, and suitable pH value. Since the launch of the expert system, the average suspended solid concentration is 5.35 mg/L, and the maximum value is 13 mg/L, which is lower than the 30 mg/L effluent standard. On the other hand, the coagulant and the flocculant used per unit of wastewater was decreased by 4.1% and 22.4%, respectively. The total chemical dosing fee was decreased by 4.8% which is meeting the initial 3% target.

The data of both WWTP will be continuously collected, accumulated and stored in the AVEVA PI (Plant Information) System. The expert systems of both WWTP would be fixed and modified every 6 months. The research team and operators would have regular communication and discussion to improve both systems.

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