Application of Expert systems to WWTPs in CSC

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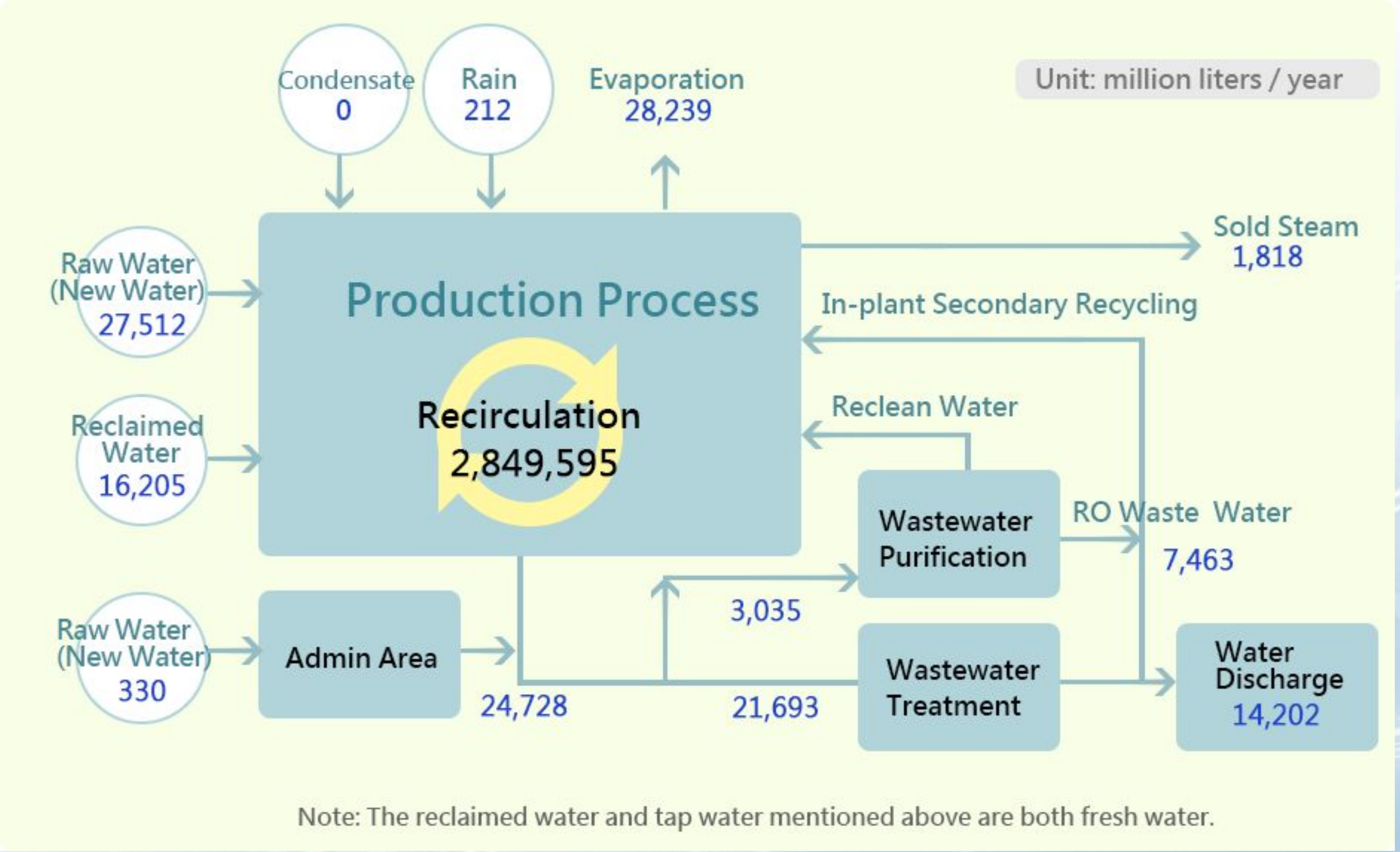
Outline

1. Introduction
2. Expert system in Biological WWTP
3. Expert system in Industrial WWTP
4. Summary

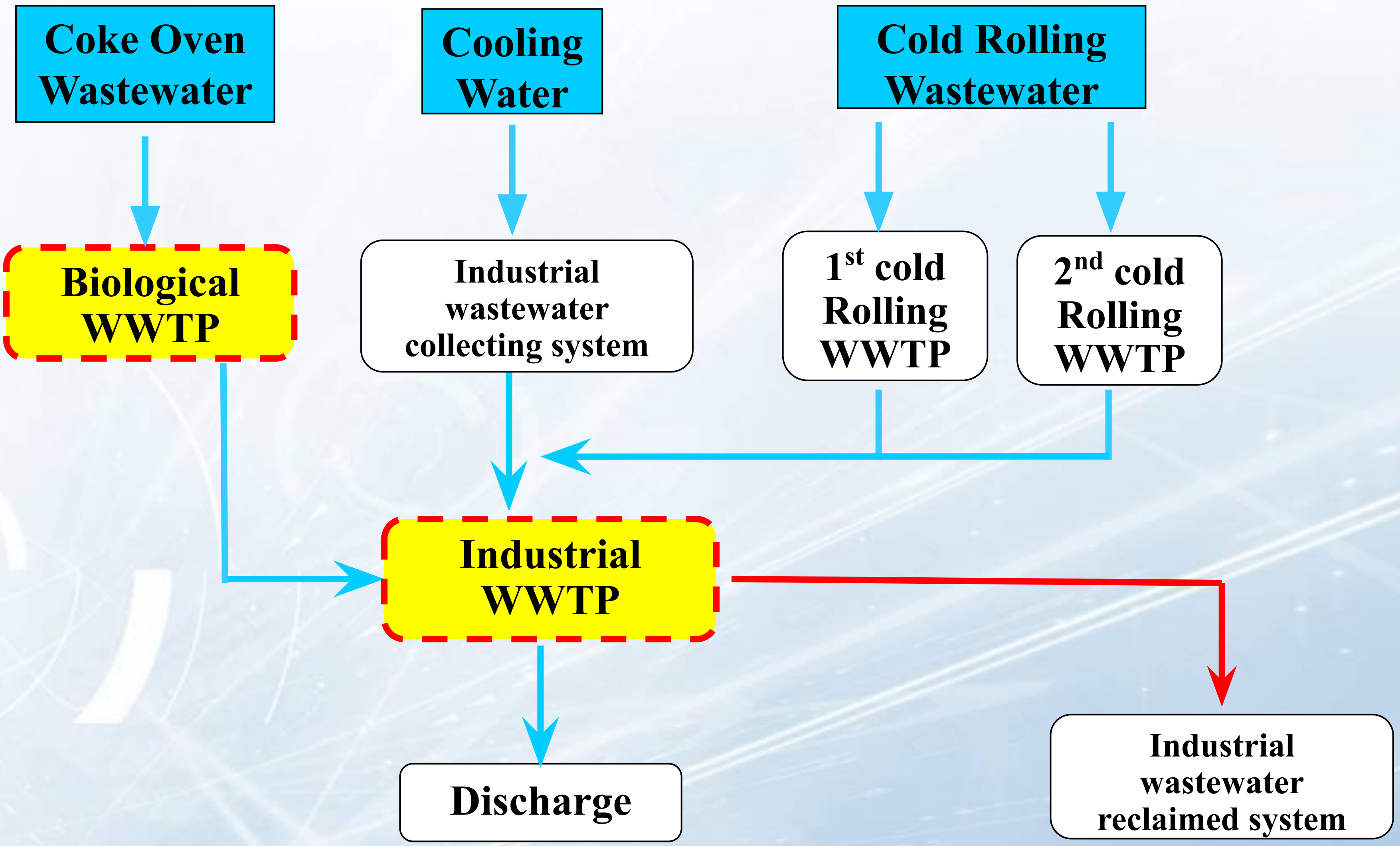
1.1 Introduction of CSC

1) China Steel Corporation (CSC), located at Kaohsiung, Taiwan, was founded in December 1971.
2) It is the largest steel company in Taiwan with annual production (in terms of crude steel) around 10 million tons.
3) The domestic market takes roughly 65% of CSC's production and the exports take 35%. The major export destinations are Mainland China, Japan, and Southeast Asia.

1.2 Water balance in CSC

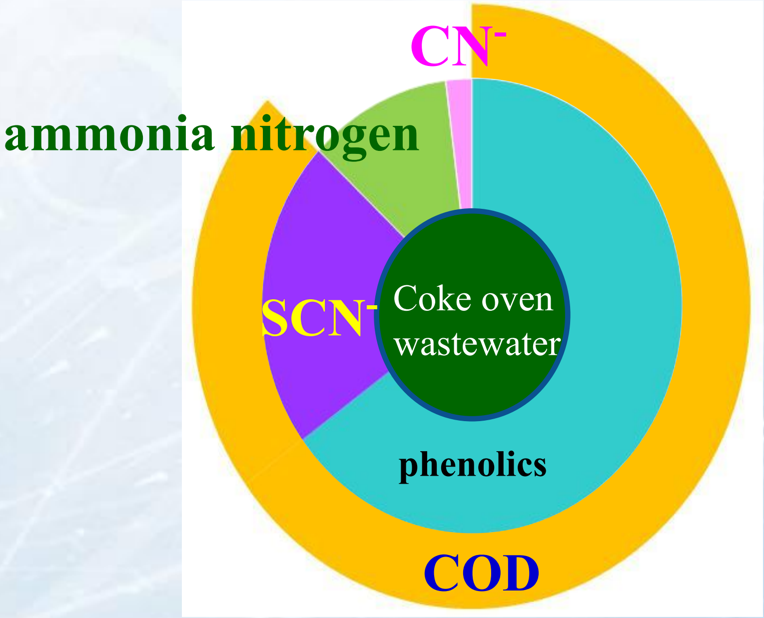


1.3 Wastewater treatment in CSC



2.1 Composition of Coke Oven Wastewater

1) Coke oven wastewater contains 80% of the COD and 90% of the ammonia nitrogen produced from the entire CSC plant.
2) The composition of coke oven wastewater is complicated and mainly includes phenolics, thiocyanate, ammonia nitrogen, and cyanide.



2.2 Problems and difficulties

Eutrophication caused by ammonia nitrogen

Ammonia nitrogen of discharge water needs <20 mg/L before 2017.11.01

Biological WWTP used to only treat COD

Ammonia nitrogen of effluent: 400~500mg/L

↓

Reconstruction

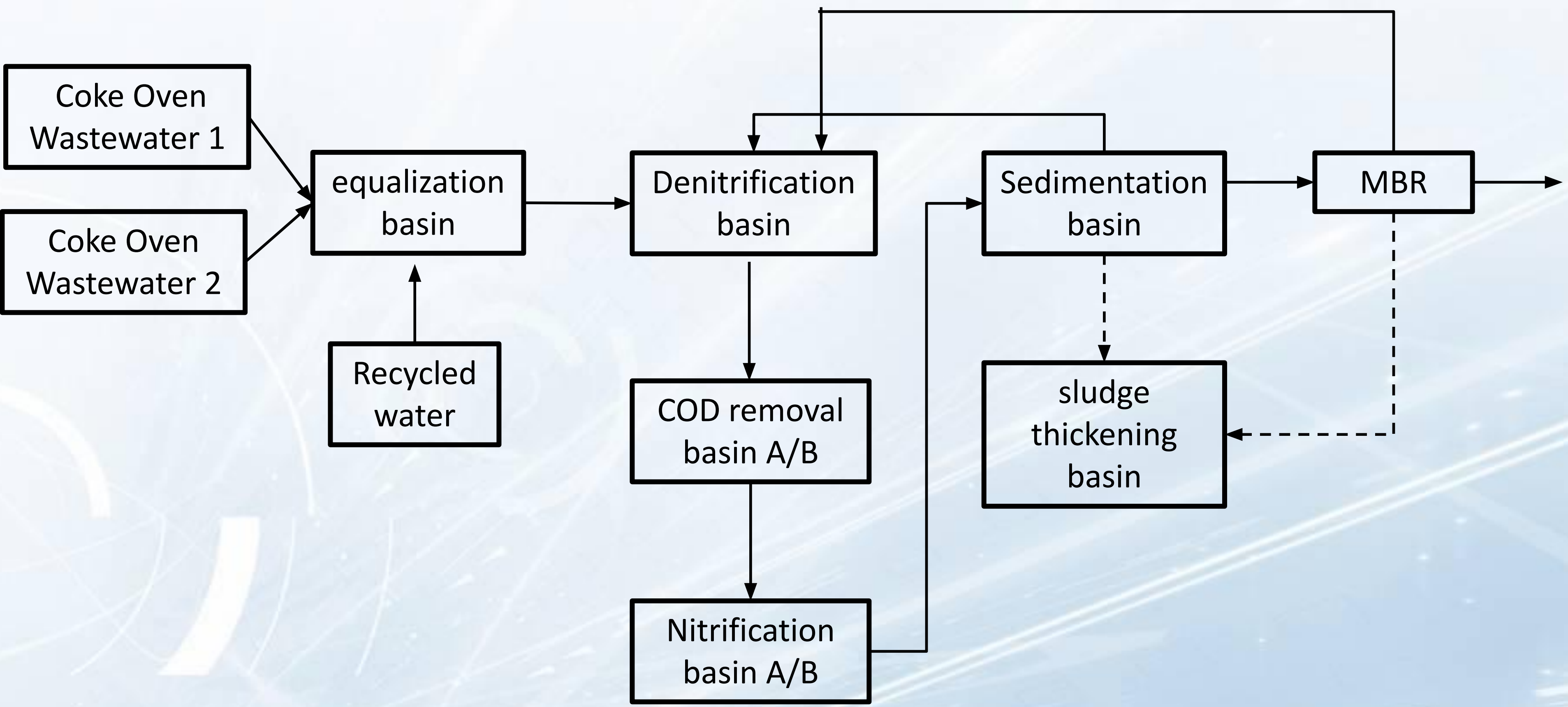
↓

Ammonia nitrogen of effluent: <10 mg/L

Reconstructed in the original WWTP

- **HRT is only 38 hrs**
- **the system is more vulnerable to the fluctuations in the coke oven wastewater**
- **the residual organic compounds inhibit the nitrification reaction**

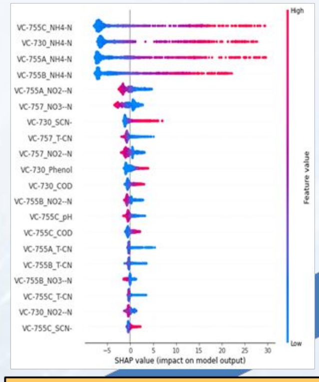
2.3 Biological WWTP treatment process after reconstruction



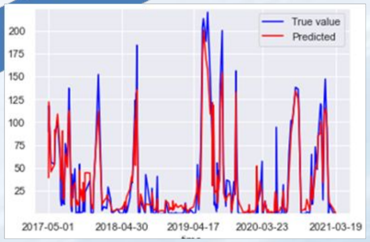
2.4 Flowchart to build a expert system

Raw data → Data processing → modeling → Expert system

data collection

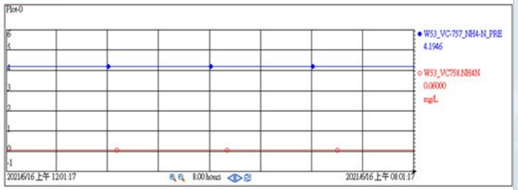


ranking of variable factors



algorism testing

suitable operating strategies



	Old values	Suggest values		Old values	Suggest values
1. VC-730_NH4-N	35.60	26.15	6. VC-730_Phenol	0.06	0.01
2. VC-755B_NH4-N	0.40	0.40	7. VC-730_SCN-	3.28	2.85
3. VC-755C_NH4-N	25.90	17.52	8. VC-757_T-CN	2.24	2.21
4. VC-755A_NH4-N	1.70	1.70	9. VC-757_NO2--N	2.44	2.65
5. VC-757_NO3--N	28.80	27.33	10. VC-755B_NO3--N	36.40	36.14

	Old values	Suggest values
11. VC-755C_pH	7.94	7.94
12. VC-755C_SCN-	21.60	21.28
13. VC-757_COD	123.00	122.53
14. VC-755B_NO2--N	6.78	6.89
15. VC-755C_COD	469.00	467.42

Internal control: ammonium nitrogen < 10 mg/L

2.5 Evaluate and screen relative parameters

Monitoring target	Parameters assayed in lab
Coke oven wastewater1	pH、conductivity、phenol、ammonia、CN^-、SCN^-、COD
Coke oven wastewater2	pH、conductivity、phenol、ammonia、CN^-、SCN^-、COD
equalization basin	pH、conductivity、phenol、ammonia、CN^-、SCN^-、COD
COD removal basin	pH、conductivity、phenol、ammonia、CN^-、SCN^-、COD 、S.S.、NO_2^-、NO_3^-
Nitrification basin A	pH、ammonia、CN^-、SCN^-、S.S.、COD、NO_2^-、NO_3^-
Nitrification basin B	pH、ammonia、CN^-、SCN^-、S.S.、COD、NO_2^-、NO_3^-
Denitrification basin	pH、conductivity、ammonia、CN^-、S.S.、COD、NO_2^-、NO_3^-
Effluent	pH、conductivity、ammonia、CN^-、COD、NO_2^-、NO_3^-

Monitoring target	Parameters monitored online
equalization basin	Temperature
COD removal basin	pH、temperature、pure oxygen flow rate
Nitrification basin A	temperature、dissolved oxygen、pure oxygen flow rate
Nitrification basin B	temperature、dissolved oxygen、pure oxygen flow rate
Denitrification	temperature、dissolved oxygen、pure oxygen flow rate

63 factors which are assayed daily in lab and 15 factors which are monitored by online detectors were selected

2.6 Inventory of all monitoring parameters and controlling strategies

Monitoring parameters

item	monitoring frequency
15 online parameters	continuously
63 parameters which are assayed daily in lab	Mon~Fri
S.S.; VSS	1 times/week

Controlling strategies:

issue	Controlling strategy
CN^- of influent >10mg/L	Add $FeSO_4$ into the basins to form Prussian blue $Fe_4[Fe(CN)_6]_3$ to remove toxicity
metabolism of biomass decreases	Add nutrient salts and vitamins to stimulate metabolism
decrease of biomass	Implant sludge from other biological WWTP

S.S.: suspended solids; VSS: volatile suspended solids

2.7 model selection and testing

	(1)	(2)	(3-1)	(3-2)
data source	lab	online	lab＋online	lab＋online
parameters	63	15	63+15	63+15
data amount	1240	1240 1 data set /day	34201 1 data set/hr	1240 1 data set/day
Training R^2	0.92	0.89	0.95	0.93
Testing R^2	0.91	0.39	0.95	0.9

1. (3-1)seems better than (1). However it’s caused by data processing and the lab data is used too repeatedly overfitting phenomenon.
2. SHapley Additive exPlanations analysis showed that the correlation between 15 online parameters and ammonia nitrogen in the effluent is relatively low.

(1) was chosen and the model is built using XGBoosting algorism

2.8 Importance of parameters analysis

Ranking	parameter	Importance
1	NH_3-N of Denitrification basin	0.172
2	NH_3-N of COD removal basin	0.155
3	NH_3-N of Nitrification basin A	0.153
4	NH_3^- of Nitrification B basin	0.145
5	NO_2^- of Nitrification A basin	0.030
6	NO_3^- of effluent	0.028
7	SCN^- of COD removal basin	0.024
8	CN^- of influent	0.019
9	NO_2^- of effluent	0.019
10	Phenol of COD removal basin	0.016

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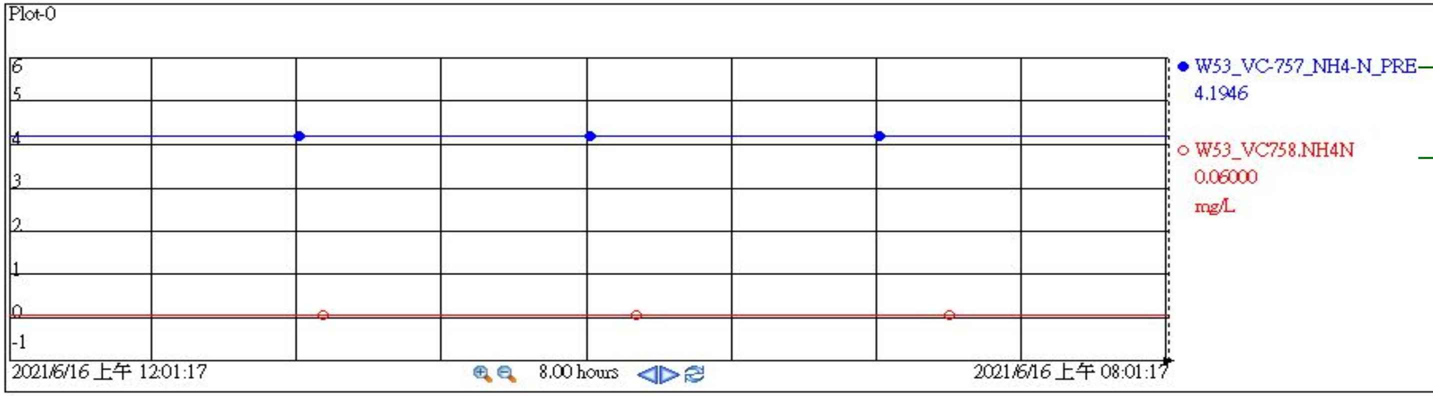
The importance of parameters to affect the ammonia concentration in the are ranked using SHapley Additive exPlanations

2.9 Results to Operators



Predicted NH_3-N

Actual NH_3-N

Detected number in lab ←

	Old values	Suggest values
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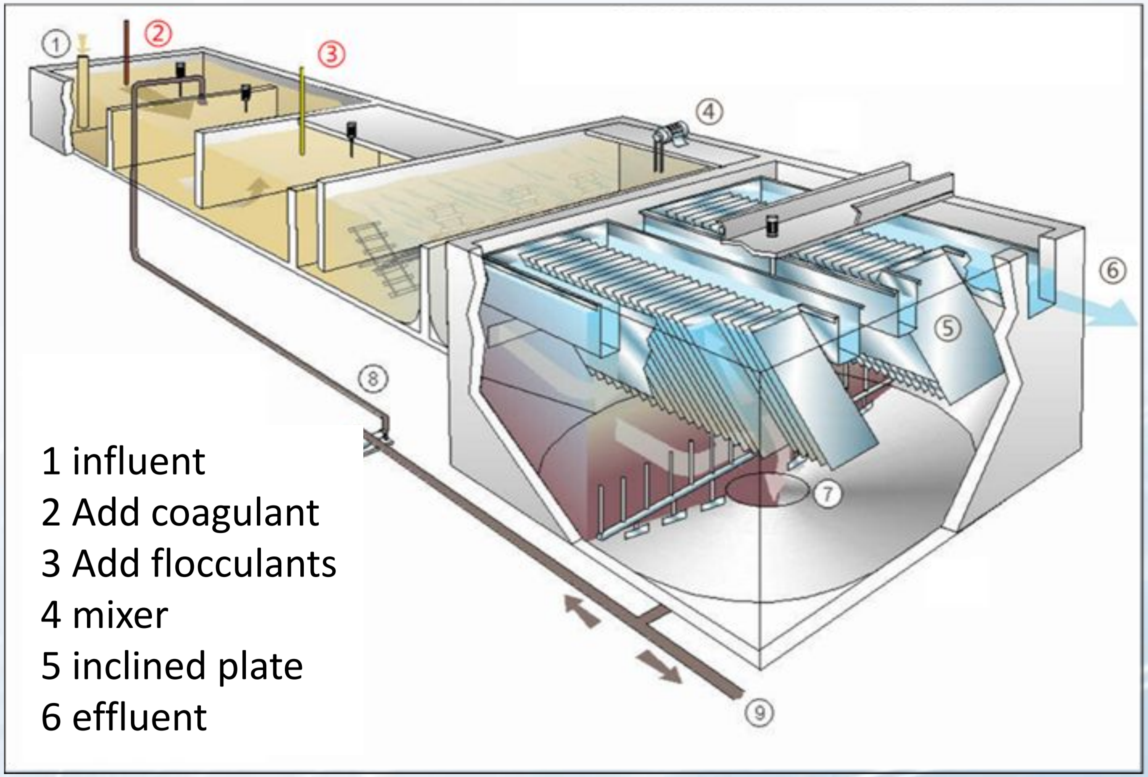
Target: NH_3-N < 10 mg/L in effluent

The number of days that the ammonia nitrogen in effluent exceeding the internal control has dropped significantly to 1.3%

3.1. Process of industrial WWTP



Coagulation, flocculation, and sedimentation are used to remove the suspended solids and turbidity.

3.2 Problems and difficulties

1) The sedimentation depends on the **size of the flocs**. The human **eye** is used to judge and the **chemical adding dosage** is base on **operator's experience**.
2) **Excess amount** of chemicals are usually added in order to ensure water quality of the discharge water. There will be a waste in **chemical dosing** and **sludge handling** fee.

Insufficient dosage
No flocs formation

Optimal dosage
flocs formation

3.3 Development approach

Plan (2%) 2020Q1

Floccam instillation (10%) 2020Q2

2020Q3

Data gathering (45%) 2020Q4

2021Q1

Modelling (80%) 2021Q2

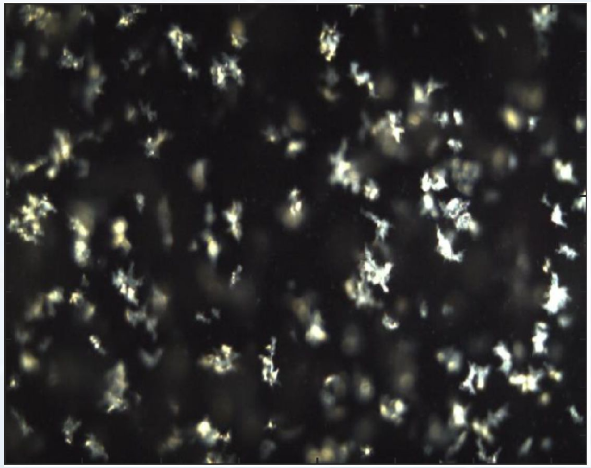
Model built in to DCS (90%) 2021Q3

Model Validation (100%) 2021Q4

Target: optimize the chemical dosing and reduce the fee to at least 3%

3.4 Floc capture and data collection

1) **Floccam instillation:** flocs are captured and the images are converted to 20 quantitative parameters.
2) **Data Collection:** floccam data together with 10 other factors, are all monitored online and the AVEVA PI (Plant Information) System was used to collect and store the data.



Flocs captured by floccam

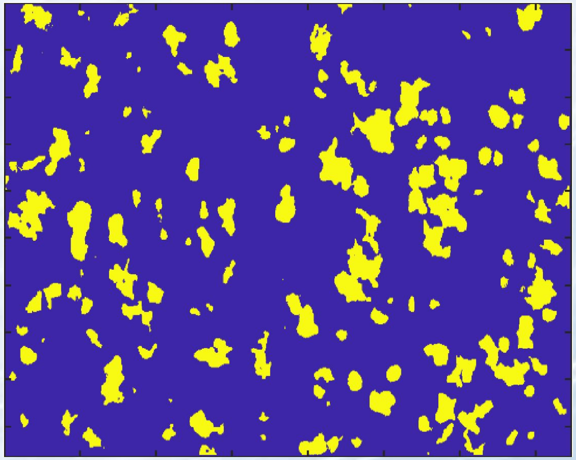


Image analysis-
Floc and background

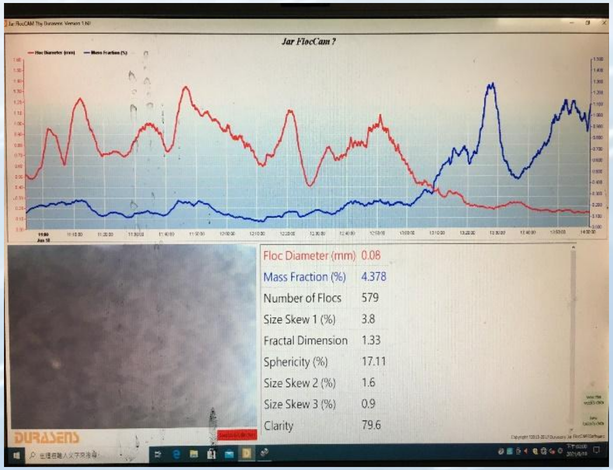
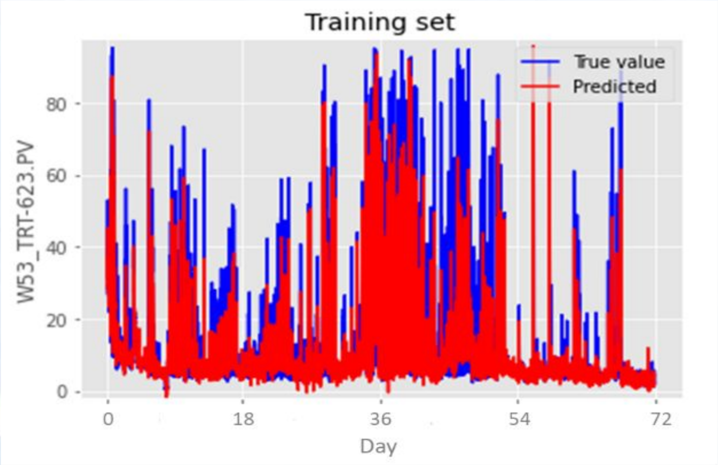


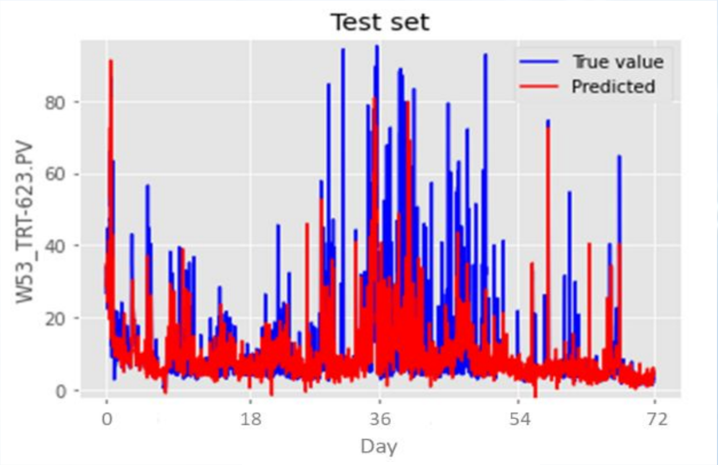
Image converts to quantitative data

3.5 Data selection and modelling

1) **Data source: 20 variables from floccam and other 10 variables, including chemical dosing concentration, pH, and water volume flow rate of influent.**
2) **Target: S.S. of effluent < 30 mg/L**
3) **Data gathering frequency is every 5 mins and the HRT is taken into account that the model is set to predict the result in 25 minutes later.**
4) **Testing algorism: random forest, XGBoosting, and deep learning**



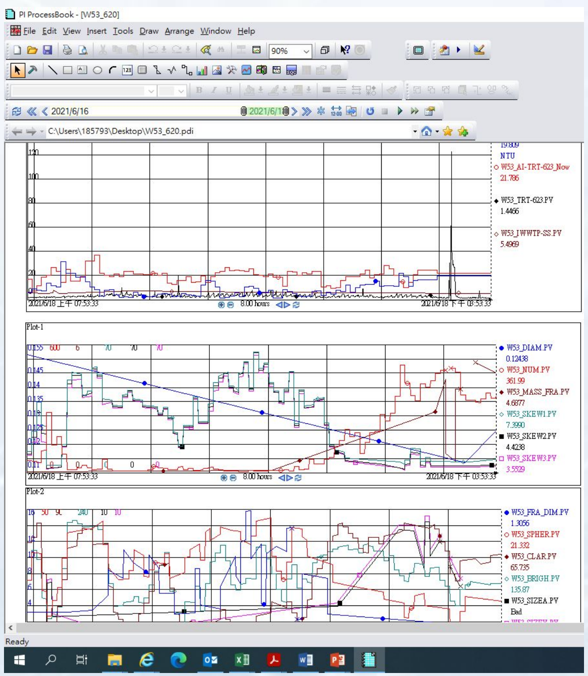
Training

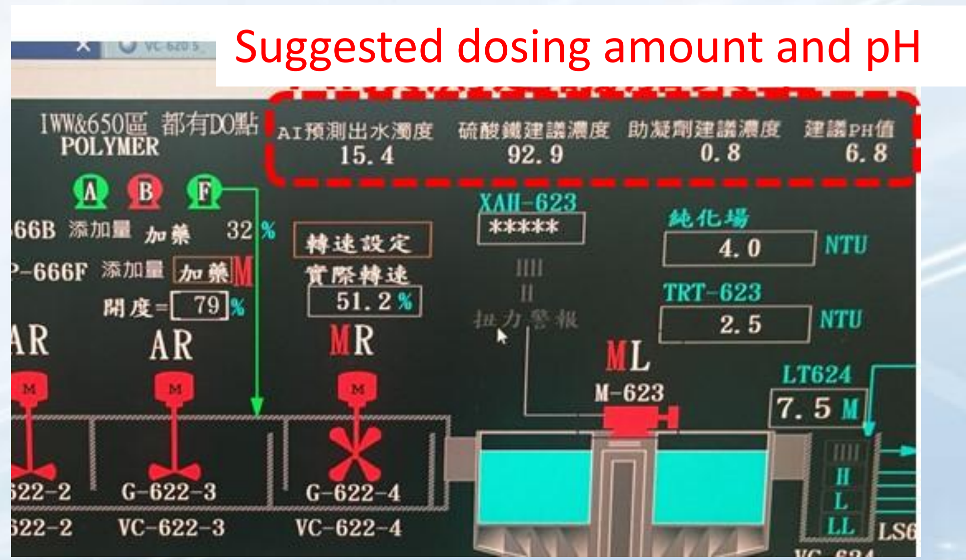


Testing

3.6 Result shown on DCS

1) **SHapley Additive exPlanations** is used to analyze the importance of each variables
2) The suggested **chemical dosing concentration** and **pH** were calculated, exported from PI system, and shown on **DCS**





3.7 Benefit assessment

1. **Better quality of Effluent:** The average S.S concentration is 5.35 and the maximum is 13, which is lower than the 30 mg/L effluent standard.
2. **Save dosing fee:** 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.。

	coagulant		flocculant		Total dosing fee		Water quality	
	dosage	Difference %	dosage	Difference %	dosage	Difference %	S.S. average	S.S Max
Before	0.161		0.000399		0.675		16.9	24
After	0.154	-4.1	0.000309	-22.4	0.643	-4.8	5.35	13

4.1 Summary

Expert system in Biological WWTP

- **Model**: Lab data and XGBoost were used
- **Predict and warning**: predict NH_3-N value in effluent
- **Optimal operation**: pick up the key factors that affect the NH_3-N in the effluent and give suggested value of the key factors.

□The number of days that the NH_3-N exceeding the internal control has dropped significantly to 1.3%

Expert system in Industrial WWTP

- **Model**: 20 Floccam data, 10 online data, and Xgboost were used
- **Predict and warning**: predict S.S. value in effluent 25 minutes later
- **Optimal Operation**: give suggested chemical dosing concentration and pH

□The total chemical dosing fee was decreased by 4.8% which is meeting the initial 3% target.

4.2 Future Plan

1. The data of both WWTP will be continuously collected, accumulated and stored in the AVEVA PI System.

2. The expert systems of both WWTP would be fixed and modified every 6 months.

3. The research team and operators would have regular communication and discussion to improve both systems.

Thank You