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Instrumentation and Automation in Effluent Treatment Plants (ETP): A Technical Review and System Design Approach

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Abstract: *Effluent Treatment Plants (ETPs) are essential systems for minimizing industrial environmental impact by treating wastewater prior to its discharge or reuse. [1], [2]. With increasing regulatory requirements and operational complexity, contemporary ETPs depend extensively on instrumentation and automated control technologies to enhance process efficiency, ensure compliance, lower human dependency, and optimize the consumption of chemicals and energy. [3], [4]. This paper provides an in-depth review of key measurement instruments employed in ETP operations, such as sensors for flow, level, pH, dissolved oxygen, turbidity, oxidation–reduction potential, and pressure. An integrated automation framework incorporating PLCs, SCADA systems, control valves, closed-loop control strategies, and safety interlocks is presented. The study further analyses improvements in operational performance achieved through automation across major treatment stages, including equalization, aeration, clarification, filtration, and sludge handling. Emerging developments such as IoT-enabled water quality sensing, softsensor modelling, and AI-driven predictive treatment optimization are also explored.*

Keywords*:* Effluent Treatment Plant (ETP), Automation, Instrumentation, pH Control, SCADA, PLC, Dissolved Oxygen Sensor, Wastewater Treatment

I. INTRODUCTION

Industrial effluents typically contain hazardous chemicals, suspended particulates, high organic content, and dissolved contaminants. If such wastewater is discharged without adequate treatment, it can cause severe environmental degradation and pose significant risks to public health. To prevent these impacts, environmental authorities require industries to implement and operate effective Effluent Treatment Plants (ETPs). The operational efficiency of an ETP is strongly influenced by its instrumentation system, which enables continuous monitoring, precise measurement, and automated regulation of key process variables.

Earlier generations of ETPs depended largely on manual sampling methods and operator experience, often leading to process variability and suboptimal treatment efficiency. [1]. However, the integration of modern automation technologies—such as programmable logic controllers (PLCs), supervisory control and data acquisition (SCADA) systems, intelligent sensors, and automated control valves—has transformed ETP operations. These advancements support consistent plant performance, minimize human intervention, enable precise chemical dosing, reduce operational downtime, and enhance aeration efficiency. [3], [4].

This paper presents an in-depth technical analysis of an Effluent Treatment Plant from an instrumentation and automation standpoint. It further proposes a comprehensive automated control architecture designed to meet the performance, reliability, and compliance requirements of industrial-scale wastewater treatment facilities.

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II. PROCESS DESCRIPTION OF A TYPICAL ETP

A. High COD / TDS Treatment Scheme

A typical high COD/TDS treatment scheme consists of the following major units:

1) Oil & Grease Trap: Removes oils and floating contaminants before chemical treatment.
2) Collection Tank: Collects high-COD effluent and equalizes flow for stable treatment.
3) Neutralization Tank I & II: Adjusts pH of highly acidic or alkaline wastewater for optimal coagulation.
4) Flash Mixer: Rapidly mixes coagulants (alum) with wastewater to destabilize suspended particles.
5) Flocculator: Promotes formation of large flocs suitable for settling.
6) Primary Settling Tank: Allows heavy flocs to settle out, reducing suspended solids.
7) MEE Feed Tank: Feeds partially clarified effluent to the MEE unit for concentration.
8) Stripper: Removes volatile organic compounds and solvents from wastewater via steam stripping.
9) MEE (Multiple Effect Evaporator): Evaporates and concentrates high-TDS wastewater to separate salts from clean condensate.
10) MEE Condensate Tank: Collects clean condensate from MEE for further treatment in ETP.
11) RO Reject Tank: Stores rejected high-TDS brine water generated from RO systems.

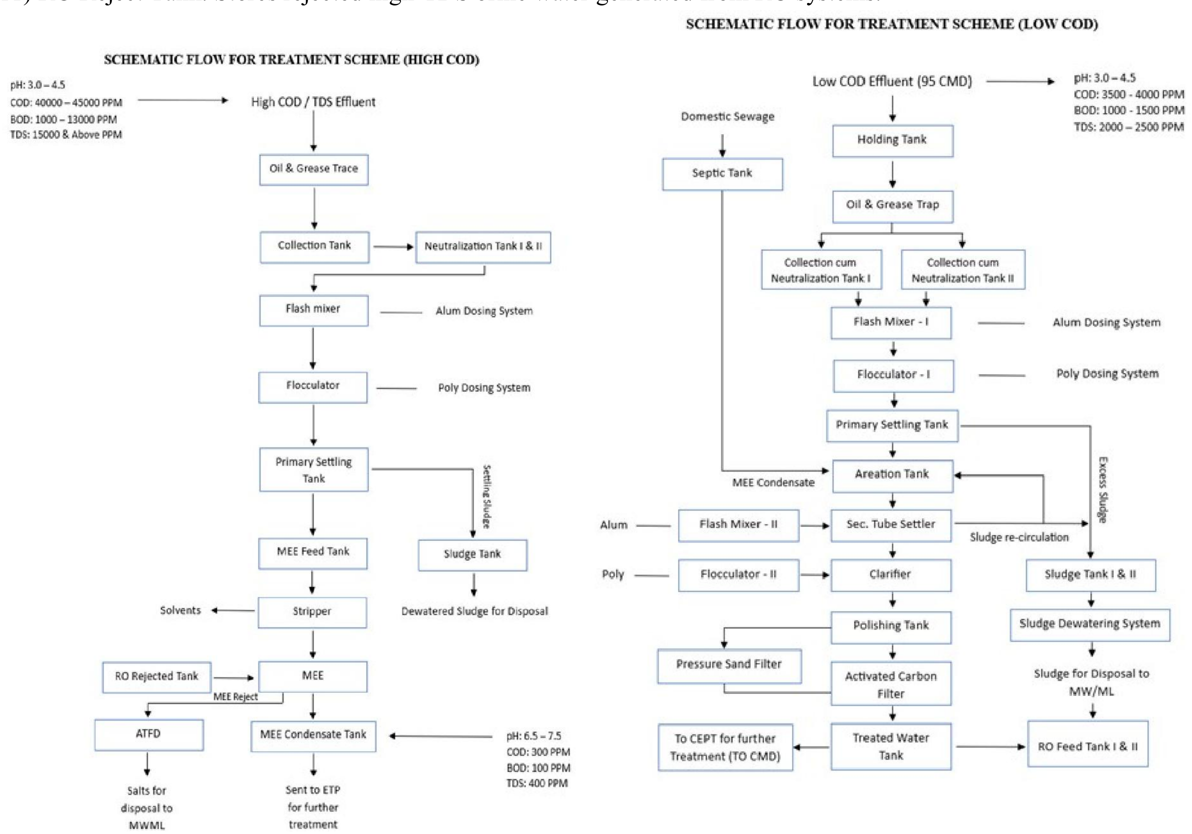

Fig. 1. Schematic Flow for treatment scheme (High COD)

12) ATFD (Agitated Thin Film Dryer): Dries MEE/RO reject salts into solid form for disposal.
13) Sludge Tank: Receives settled sludge from primary settling for further processing.
14) Dewatered Sludge Disposal: Sends dried sludge to authorized waste disposal facilities (MWML).

B. Low COD Treatment Scheme

The low COD treatment scheme includes:

1) Septic Tank: Treats domestic sewage through anaerobic digestion to reduce solids and pathogens.

2) Holding Tank: Collects incoming low-COD effluent and maintains steady flow to downstream units.
3) Oil & Grease Trap: Removes floating oils and fats to prevent interference with chemical treatment.
4) Collection cum Neutralization Tank I & II: Balances wastewater acidity/alkalinity by dosing acid or alkali for pH correction.
5) Flash Mixer – I: Rapidly mixes alum with wastewater to initiate coagulation.
6) Flocculator – I: Gently stirs wastewater allowing microflocs to grow into larger settleable flocs.
7) Primary Settling Tank: Allows heavy flocs to settle by gravity, separating sludge from clarified water.
8) Aeration Tank: Supplies oxygen to microorganisms for biological degradation of dissolved organics.
Fig. 2. Schematic Flow for treatment scheme (Low COD)
9) Secondary Tube Settler: Settles biologically treated suspended solids to further clarify water.
10) Flash Mixer – II: Performs additional chemical mixing (alum) for polishing before final clarification.
11) Flocculator – II: Facilitates the development of stronger and more stable flocs, improving the efficiency of final sedimentation.
12) Clarifier: Allows the separation of residual suspended matter, resulting in a clearer treated effluent.
13) Polishing Tank: Ensures adequate retention time to further refine effluent quality before it undergoes filtration.
14) Pressure Sand Filter (PSF): Eliminates fine suspended particles by passing the water through a graded sand filtration media.
15) Activated Carbon Filter (ACF): Removes colour, odor, and dissolved organic contaminants through adsorption, providing final water polishing.
16) Treated Water Tank: Stores fully treated water for reuse or final discharge.
17) RO Feed Tank I & II: Collects treated water as feed for Reverse Osmosis purification if required.
18) Sludge Tank I & II: Stores settled sludge collected from settler units.
19) Sludge Dewatering System: Reduces moisture content in sludge for efficient disposal.
20) Sludge Disposal to MWML/ML: Final disposal of dried sludge through authorized waste management facilities.
21) MEE Condensate Return: Returns condensed clean water from MEE back to the ETP for further treatment.

C. Major Treatment Units

A typical industrial ETP consists of the following major treatment units:
1) Collection and Screening Unit: Raw effluent enters the ETP and passes through bar screens and grit chambers to remove large solids.
2) Equalization Tank: Maintains uniform effluent characteristics and regulates flow. Mechanical agitators prevent settling.
3) pH Correction / Neutralization: Acids or alkalis are dosed automatically to maintain optimum pH for downstream treatment.
4) Aeration Tank (Biological Treatment): Microbial degradation of organic pollutants occurs here. Aeration blowers supply oxygen.
5) Clarifier / Settling Tank: Suspended solids and biomass settle at the bottom as sludge. Clear supernatant moves forward.
6) Filtration Systems: Used for polishing of treated water:
• Pressure sand filter (PSF)
• Activated carbon filter (ACF)
7) Sludge Handling: Sludge drying beds, filter presses, or decanters are used.
Each stage requires precise instrumentation to maintain process quality.

III. INSTRUMENTATION IN ETP

Instrumentation ensures that every process variable—flow, level, pH, DO, ORP, turbidity—is continuously monitored and controlled [1], [3].

A. Flow Measurement

1) Electromagnetic Flow Meter
- Ideal for conductive liquids
- No moving parts
- Used at inlet & outlet streams

2) Ultrasonic Flow Meter
- Non-contact
- Suitable for corrosive waste

3) Orifice Flow Meter (Differential Pressure)
- Low-cost option for constant process lines

B. Level Measurement

1) Ultrasonic Level Transmitter — non-contact; used in EQ tank, aeration tank.
2) Hydrostatic (DP) Level Transmitter — used in clarifiers and sludge tanks.
3) Float Level Switches — for pump control and interlocks.

C. pH Measurement pH plays a crucial role in neutralization and biological treatment [1].

- Glass-electrode based pH sensor
- Installed in collection tank, neutralization tank & final treated water
- Controlled through chemical dosing pumps

D. Dissolved Oxygen (DO) Measurement

DO concentration is vital for microbial activity [1], [5].
- Optical DO sensors (luminescent)
- Installed in aeration tank

E. Oxidation-Reduction Potential (ORP)

Used in chemical oxidation or reduction processes.

F. Turbidity & TSS Sensor

Installed after clarifier or filtration to check water clarity.

G. Pressure Measurement

Used in filters, pumps, and pipelines.

H. Control Valves & Dosing Systems

Automated dosing based on feedback from analysers:
- Acid/alkali dosing valve
- Coagulant dosing pump
- Polymer dosing for sludge thickening

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IV. AUTOMATION ARCHITECTURE OF ETP

Fig. 3. Typical stages of an industrial effluent treatment plant (ETP)

A. PLC-Based Control System

Key functions:

- Control of pumps, blowers, agitators
- Valve actuation
- PID loops for pH control and DO control
- Alarm and trip logic

Common PLC Modules:

- Analog Input (AI) for sensors
- Analog Output (AO) for control valves
- DI/DO modules for pumps & motors
- Communication: Modbus, Profibus, Ethernet/IP

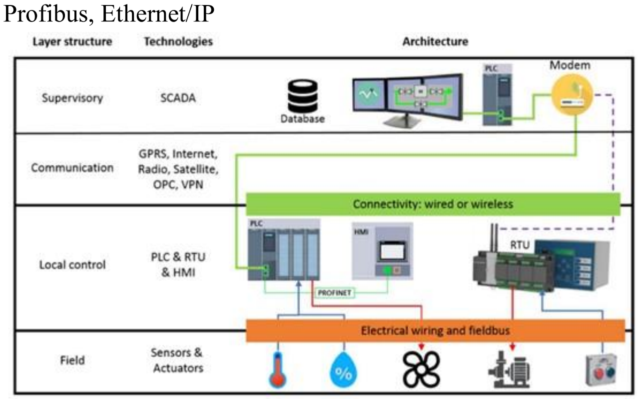

Fig. 4. Layered architecture of an industrial automation and SCADA system

B. SCADA System

SCADA provides real-time visualization [3]:

- Tank levels & trends
- pH & DO trends • Flow rate
- Turbidity & TSS
- Alarm history
- Automatic report generation

C. Control Loops

1) pH Control Loop:

• pH transmitter → PLC → Dosing pump control valve

• PID or ON/OFF control depending on accuracy requirements

2) DO Control Loop:

• DO sensor → PLC → Blower VFD → Aeration rate control

3) Level Control Loop:

• Level transmitter → Pump ON/OFF or modulating valve 4) Flow Control Loop:

• Flow transmitter → Control valve → Maintain constant flow

D. Interlocks & Safety Logic

• High-level → Pump OFF

• Low-level → Agitator OFF

• High pressure → Filter backwash starts

• Motor overload → Auto-tripping

V. INSTRUMENTATION DESIGN RECOMMENDATIONS

A. Sensor Placement Guidelines

• Ensure laminar flow conditions for flow sensors

• Avoid air bubbles near pH & DO sensors [1], [3]

• Install strainers to prevent fouling

B. Calibration & Maintenance

• pH: Weekly calibration

• DO: Monthly membrane check [1]

• Flow: Annual verification

• SCADA: Backup every week

VI. RESULTS & DISCUSSION

Automation brings multiple advantages [4], [5]:

TABLE I: COMPARISON OF MANUAL AND AUTOMATED OPERATION

Parameter	Manual	Automated
pH Stability	±1.0 deviation	±0.1 deviation
DO Control	Unpredictable	Stable ±0.2 mg/L
Chemical Usage	High	Reduced 20–30%
Energy Usage	Unoptimized	Saves 15–25%
Operator Need	Very high	Minimal
Alarm Safety	Poor	Real-time logging

VII. FUTURE SCOPE

A. IoT-based Smart ETP

Cloud-based dashboards provide remote monitoring of [5]:

• pH, DO, ORP, TSS

• Chemical usage

• Equipment health

B. Soft Sensors

AI models predict COD/BOD using online sensors like turbidity, ORP, and pH.

C. Machine Learning-Based Predictive Maintenance

• Predict pump failures using vibration data
• Forecast blower performance degradation

D. AI-driven Optimal Dosing

Adjust coagulant dose automatically based on influent quality [4].

VIII. CONCLUSION

Instrumentation and automation significantly enhance the performance, reliability, and regulatory compliance of Effluent Treatment Plants. Proper selection and placement of sensors, integration with PLC–SCADA systems, and implementation of advanced control strategies result in improved water quality and reduced operational costs. With the adoption of Industry 4.0, IoT, and AI-based technologies, future ETPs will become fully autonomous, predictive, and self-optimizing, contributing significantly to sustainable industrial operations.

REFERENCES

[1] M. J. H. Mridha, M. M. Hossain, S. M. Imran, S. A. Al Wahid, A. Tahsin, M. G. R. Alam, A. Talukder, and A. W. Reza, "A real-time ETP outlet monitoring framework leveraging environmental IoT, colorimetry, and learning theory" IEEE Access, vol. 13, pp. 98729–98746, 2025, DOI: 10.1109/ACCESS.2025.3576826.
[2] R. M. M. Salem, M. S. Saraya, and A. M. T. Ali-Eldin, "An industrial cloud-based IoT system for real-time monitoring and controlling of wastewater" IEEE Access, vol. 10, pp. 6528–6540, 2022, DOI: 10.1109/ACCESS.2022.3141977.
[3] A. Alshami, E. Ali, M. Elsayed, A. E. E. Eltoukhy, and T. Zayed, "IoT innovations in sustainable water and wastewater management and water quality monitoring: A comprehensive review of advancements, implications, and future directions" IEEE Access, vol. 12, pp. 58427–58455, 2024, DOI: 10.1109/ACCESS.2024.3392573.
[4] K. K. Kesari, R. Soni, Q. M. S. Jamal, P. Tripathi, J. A. Lal, N. K. Jha, M. H. Siddiqui, P. Kumar, V. Tripathi, and J. Ruokolainen, "Wastewater treatment and reuse: A review of its applications and health implications" Water, Air, & Soil Pollution, vol. 232, no. 208, pp. 1–28, 2021, DOI: 10.1007/s11270-021-05154-8.
[5] K. Sathya, K. Nagarajan, G. C. G. Malar, S. Rajalakshmi, and P. R. Lakshmi, "A comprehensive review on comparison among effluent treatment methods and modern methods of treatment of industrial wastewater effluent from different sources," Applied Water Science, vol. 12, no. 70, pp. 1–27, 2022, DOI: 10.1007/s13201-022-01594-7.