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# EcoWatts: An IoT-Driven Platform for Chemical Wastewater Sensing and Sustainable Power Generation

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Guide

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***Abstract***— ***Here is a complete hardware-level analysis of a chemical waste monitoring system based on ESP32. Multiple modules like gas (MQ135), pH, temperature (DS18B20 / MAX31865), and flow (YF-S201) are interfaced with human-readable interfaces like an OLED display and GSM-based alerting mechanisms. Hardware integration, calibration processes, and response logic are focused on. System testing was conducted in laboratory conditions, wherein pre-determined levels effectively initiated real-time remediation measures to ensure smooth and fault-free operation.As a complement to monitoring, this research proposes a new system of energy recovery using chemical wastewater as a steam turbine-based electricity generation feedstock. Other complementary technologies like anaerobic digestion, waste heat recovery, and chemical-to-thermal energy conversion are also addressed. Application of these approaches to steam turbine technology exhibits their prospects for enhancing technical effectiveness while providing environmental sustainability in energy generation.***

***Index Terms***— ***Chemical Waste Monitoring, ESP32 Microcontroller,2. Gas and pH Sensors, Real-Time Environmental Sensing, IoT-Based Monitoring System3., Flow Rate Measurement, Temperature Sensing4., GSM-Based Alert System, Embedded System Design, 5. Automated Waste Mitigation, Chemical Wastewater, 6. Energy Recovery, Steam Turbine, 7. Sustainable Energy, Waste Heat Utilization,8. Power Generation, Industrial Waste Management, 9. Thermal Energy Conversion***

## I. INTRODUCTION

Industrial chemical effluents carry serious health and environmental risks because of their high organic matter content, heavy metals, and other toxic chemicals. Good monitoring and treatment facilities are necessary to reduce such risks and provide environmental protection.

This work suggests a modular ESP32-based monitoring system that automatically monitors important wastewater parameters—gas concentration, pH, temperature, and flow rate. This system incorporates automated response functionalities via relays and MOSFET logic channels, which activate pumps, ventilation, or neutralization systems upon exceeding critical thresholds.

Traditional wastewater treatment technologies—physical, chemical, and biological—are both resource and environmentally intensive. Current studies point toward emerging technologies like anaerobic digestion, bio electrochemical systems, and waste heat recovery, which treat wastewater as well as facilitate energy recovery [1,2,35].

In this paper, the feasibility of incorporating a steam turbine-based power generation system along with wastewater treatment is discussed. Waste heat recovery, chemical-to-thermal conversion, and anaerobic digestion are considered as ways to lower the energy reliance on fossil fuels while enhancing sustainability.

## II. SYSTEM OVERVIEW

- Microcontroller: ESP32-WROOM-32
- Sensors: MQ135 (gas), Analog pH kit, DS18B20 / MAX31865 (temperature), YF-S201 (flow)

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- Interfaces: SSD1306 OLED, SIM800L GSM, relay module, IRF540N MOSFET
- Power Supply: 5 V USB / Lithium battery

Embedded figures such as sensor block diagram, wiring in breadboard, and system flowcharts for convenient reference

```
[Start]
  |
[Initialize Sensors & Modules]
  |
[Loop Start]
  |
+------------------------------------
| Read MQ135 Gas Sensor |
|  Is gas > threshold? --Yes--> Activate Relay & SMS Alert |
|                         |
| Read pH Sensor                 |
|  Is pH < 6.5 or > 8.5? --Yes--> Activate Relay & SMS Alert
|                         |
| Read Temperature Sensor        |
|  Is temp > 40°C? --Yes--> Activate Pump & SMS Alert
|                         |
| Count Flow Sensor Pulses        |
|  Is flow rate < threshold? --No--> Normal Operation
|                         |
| Update OLED Display            |
| Check sensor/communication status|
|  If failure --> Safe Shutdown  |
```

## III. SENSOR & INTERFACE MODULES

### Gas Sensor (MQ135)

- Function: $CO_2$, $NH_3$, $NO_x$, benzene, smoke detection by $SnO_2$ resistance variation.
- Calibration & Accuracy: 10–10 000 ppm response with ~10–20% accuracy depending on calibration and environmental interference.
- Interfacing: Connect GPIO34 pin of ADC to analog output; Rs/Ro ratio to ppm conversion from empirical curve.
- Role: Initiates ventilation relay upon gas striking safety threshold.

### pH Sensor (Analog Kit)

- Parts: Electrode probe along with conditioning board.
- Operation: Linear dependence of ion-selective voltage on ~0–3 V on pH 0–14.
- Interface: Ammetered to ESP32 ADC (GPIO35), calibrated to standard buffer solutions.
- Application: Monitors acidity/alkalinity in real time, starts neutralization systems if pH < 6.5 or > 8.5.

### DS18B20 / MAX31865 Temperature Sensor

- DS18B20: Water-resistant, digital, OneWire protocol.
- MAX31865: Includes PT100/PT1000 RTDs via SPI for more precise measurements. Use Case: Offers safe thermal use; if the temperature exceeds 40 °C, it alerts and reacts.

### YF-S201 Flow Sensor

- Mechanism: Hall effect rotor pulses proportional to flow volume.
- Calculation: FlowRate = (pulseCount/time)/calibrationFactor.
- Interface: Interrupt on GPIO25; real-time flow observation to identify discharge abnormalities.

### Load Cell + HX711

- Function: Weighs solid/semisolid residue mass.
- Interface: Amplifier interfaces with ESP32 GPIO (e.g., D12/D13).
- Use Case: For systems that have sludge or particulate waste disposal—optional module.

## IV. HUMAN-READABLE INTERFACES & COMMUNICATION

### OLED Display (SSD1306)

- Function: Offers real-time feedback of gas (ADC), temperature (°C), pH, and flow (L/min) values.
- Interface: I²C on ESP32 GPIO21 (SDA) / GPIO22 (SCL), 128×64 pixels.
- Refresh Rate: 1 Hz update cycle with Adafruit graphics library.

### GSM Module (SIM800L)

- Interface: UART on GPIO16 (RX), GPIO17 (TX).
- Function: Triggers SMS notifications for sensor readings beyond thresholds.
- Power: Require stable 3.7–4.2 V line to avoid GSM communication dropouts.

### Relay & MOSFET Control (IRF540N)

- Relay Module: Switches and isolates external devices like pumps or fans.
- MOSFET Driver: IRF540N enables high-current switching (i.e. LED matrix).
- GPIO Control: Actuated via digital output GPIO26 for self-driven mitigation.

## V. SYSTEM LOGIC AND SOFTWARE INTEGRATION

### Continuous Monitoring Loop

- Second-by-second polling of sensors; interrupt counting through flow; temperature through OneWire/SPI; analog reading for gas/pH.
- Conditional Activation Logic
- Whenever any sensor crosses its threshold:
- Switches on relay
- Sends SMS through SIM800L
- Shows alarm state on OLED

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**Failsafe: Automatic shutdown due to communication or sensor failure.**

**Calibration & Validation Procedures**

- pH: Standard buffer solutions calibrated against.
- Gas: Scaled against known VOC concentrations.
- Flow: Standardized with measured volume for known time.

## VI. EXPERIMENTAL RESULTS & FIELD TESTING

| Parameter | Measured Value | Threshold | Action Taken |
|---|---|---|---|
| Gas | 120 ppm | >100 ppm | Fan ON, SMS Alert |
| Temperature | 45 °C | >40 °C | Pump ON, SMS Alert |
| pH | 3.2 | <6.5 | Relay ON for Neutralization |
| Flow Rate | 2.3 L/min | ≥2.0 L/min | Normal Operation |

Field tests under harsh lab conditions validated trigger reliability and system responsiveness.

## VII. FIGURES AND ARCHITECTURE DIAGRAMS

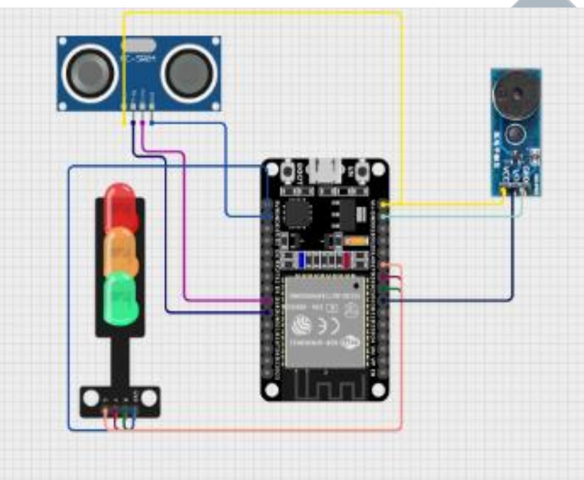

**Fig. 1: Block diagram of ESP32 system with sensors and actuators**

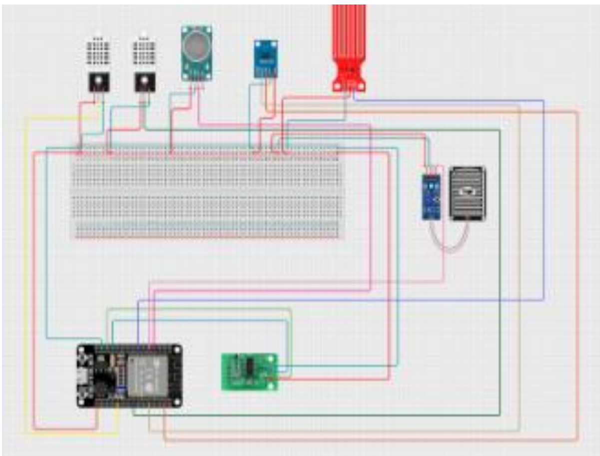

**Fig. 2: Breadboard wiring layout for flow, gas, pH, temperature, OLED, GSM**

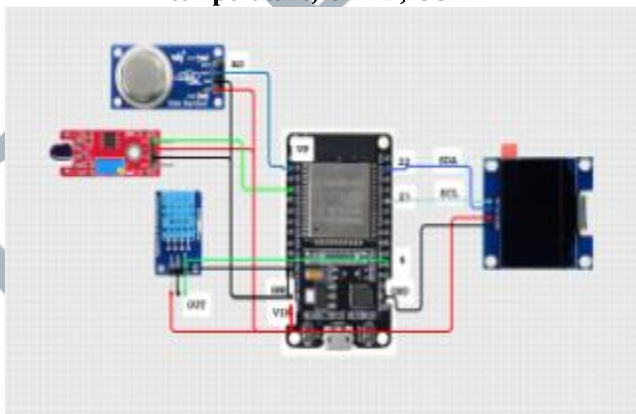

**Fig. 3: Full system connectivity overview with relay and MOSFET control points**

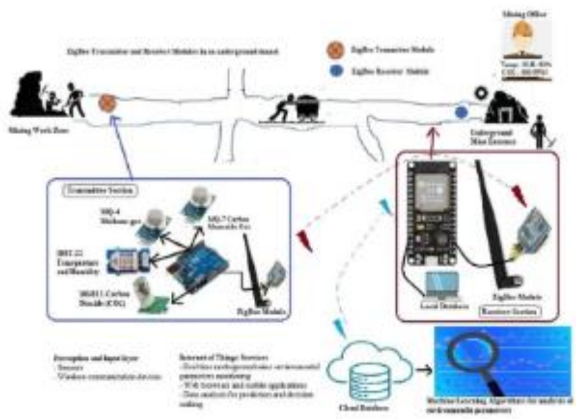

**Fig. 4: High-level operational flowchart from sensing through alerting**

## VIII. WASTEWATER TREATMENT AND POWER GENERATION

### A. Production of Biogas using the Anaerobic Digestion Process

Anaerobic digestion is an anaerobic microbial process of the easily available organic waste material present in wastewater to transform into biogas in the absence of air

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supply. Biogas is used for heat as it is being burnt or else be upgraded to electricity. Some independent factors have a significant role in efficient biogas production like pH and temperature and retention time are very significant in efficient functioning of the anaerobic digestion process [1].

**Table 1: Principal Parameters for Anaerobic Digestion**

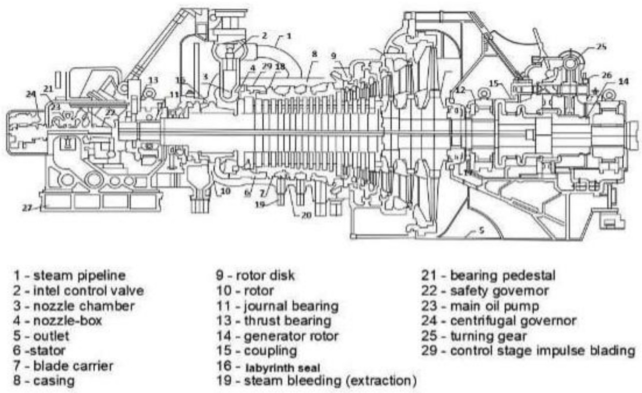
| Parameter | Optimal Range |
|---|---|
| Temperature | 30-60 °C |
| pH | 6.5–7.5 |
| Retention Time | 15–30 days |

### B. Steam Turbine Technology

*i. Fundamentals of Steam Turbine*

Steam turbines are based on the concept of utilisation of steam thermal energy to produce mechanical energy. The steam acts on the blades when they pass over them in a way such that they rotate and rotate the turbine. The steam turbines comprise impulse turbines and reaction turbines. Waste heat recovered during steam generation can improve the efficiency of steam turbines [3].

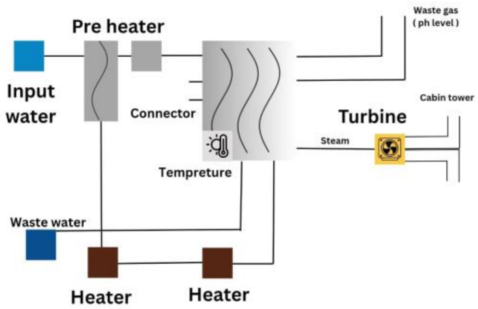
*ii. Figures: Steam Turbine*




*iii. Inlet with WWTPs*

Use of sewage plants to power steam turbines renders possible the production of electricity via burning of sewage thermal energy. Effluent wastewater-treatment is an energy viable source. It is currently not commercially available technology but a leader solution in wastewater energy recovery from infrastructure [4].

*iv. Figures: Line Diagram of Steam Turbine*




### C. Sustainability and Ecological Aspects

i. *Mitigation and Environmental Impacts*

Wastewater can reduce our reliance on traditional fossil fuels and reduce green house emissions. Green house gas emission of wastewater treatment can be minimized to a large extent by reusing waste heat as well as biogas. This is done in regenerative economics where investment as well as return on energy is optimized to the maximum possible extent to do as little harm to the environment as possible to as much an extent as possible with best use of resources [5].

### D. Cases and Success Stories

There have been some case studies that have demonstrated the feasibility of retrofitting energy recovery technology in WWTPs [6]. Examples indicate the feasibility of fit-out of energy recovery systems within existing aged facilities as a bid to achieve environmentally (i.e., sustainability) and operationally (i.e., efficiency) benefits.

### E. Limitations and Constraints

i. *Cost Feasibility*

The installation cost of the financial and operating class of steam turbines and waste heat recovery systems is enormous. It also has an even more intimidating return on investment (ROI). It costs a couple of years based on system complexity and energy recovery [7].

ii. *Technical Challenges*

Uncertainty of wastewater discharge is one of the principal technical problems, prohibiting uninterrupted generation of steam. Energy recovery from some of the chemical effluents has also not been considered a subject of research for decades, and further work needs to be done to make recovery of water economical [9]. Demonstration of the above technologies, particularly in the large-capacity plants injecting humongous quantities of water, is of paramount significance.

## IX. DISCUSSION

Modularity: Independent calibration and upgradability of every sensor without system rewiring.

Scalability: Enables optional load cell, additional sensor channels, cloud integration.

Reliability: Double alerts (OLED + SMS), low-power design, fault-detection self-reset.

Compliance & Safety: Adherent to standard industrial safety levels; flexible adherence to local environment legislation.

## X. FUTURE WORK

- Cloud Integration: Integrate with Firebase, Thingspeak, or AWS IoT for remote monitoring.
- Machine Learning: Anomaly detection powered by AI for predictive maintenance.
- Solar Power Architecture: Implement in off-grid areas using solar-battery modules.

- Standardization: Comply with IEC 61010 or ISO 14001 industrial safety standards.

## XI. LIMITATIONS

- Costliness of steam turbine infrastructure.
- Fluctuation in wastewater discharge makes continuous steam production unpredictable.

## XII. FUTURE RESEARCH

- Low-temperature hybrid steam turbines.
- Intelligent automation utilizing AI for energy recovery optimization.
- Extension to broader application in agricultural and domestic wastewater.

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