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Odour Control System utilizing Activated Carbon Filtration and Remote Sensing Technologies

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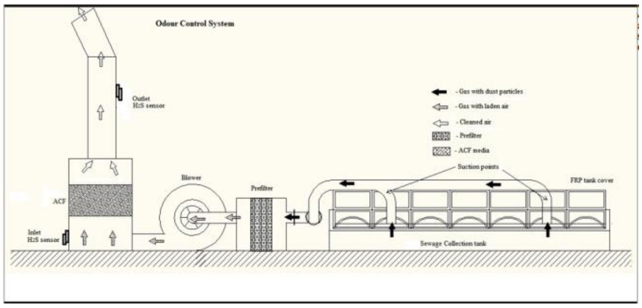
Graphical abstract



Abstract

Breathing clean air is essential for human well-being, yet odour nuisance remains a persistent issue in wastewater treatment facilities. These facilities emit hazardous gases such as methane, ammonia, and hydrogen sulphide (H_2S), which pose severe health risks, including suffocation, loss of consciousness, and even death at high concentrations. Furthermore, odourous outflows can lead to legitimate and regulatory challenges when wastewater treatment plants are found in close proximity to residential zones. To address these concerns, this study is proposed to investigate the effectiveness of Activated Carbon Filtered (ACF) Odour Control System (OCS) in reducing H_2S concentrations employing a coal-based activated carbon media filter. H_2S values measured over three months showed up to 20 ppm, daily midpoints of 6–10 ppm, and weekly midpoints of 5–8 ppm. IoT-based remote sensing processes were used to assess real-time concentrations of hazardous gases. The utilization of the ACF - OCS viably diminished H_2S radiations to approximately zero ppm, outlining its reasonability. Scanning Electron Microscopy (SEM) examination asserted the adsorption of H_2S by enlightening structural changes in the activated carbon, though X-ray Diffraction (XRD) examination appeared minor changes to its indistinct structure due to interactions with adsorbed compounds. The results validate the efficiency of the ACF system in directing odour emissions, improving air quality, and diminishing corrosion risks in wastewater treatment environments.

Keywords: Toxic gases, odour control system, wastewater treatment plants, activated carbon filter, IoT.

1. Introduction

Odour is described as the sense of fragrance or, in academic words, as an experience produced by the nasal sensing method's receipt of input. Smell, either good or bad is caused by breathing aromatic substances or substances in the ambient environment. The stench problem has grown out of control as the world's populace, industry, and cities have increased. The lack of sufficient sanitary infrastructure in areas is a key source of the smell problem. Through unpleasant commercial procedures, increasing urbanization has exacerbated the situation. Unwanted smell leads to environmental pollution problems and affects people's lives. Odour is without a doubt the greatest challenging environmental issue.

People are influenced by odour in a variety of manners. Potent, unfavourable, or irritating odours may impair an individual's pleasure of existence, particularly if they are recurrent and/or chronic. The impact, length of smell contact, rate of odour recurrence, acceptance, as well as receiver anticipation are all important elements in perceived olfactory irritation. Though bad odour might not directly harm well-being, hazardous smell enhancers can induce disease or breathing issues. Individuals may experience vomiting, sleeplessness, or soreness as an adverse consequence. Persistent smells may cause nostril awkwardness and provoke indications in those who have respiratory issues or bronchitis. On the financial level, asset valuation decreases around smell-inducing companies and unpleasant environment is a result of objectionable smell (Guidelines on Odour Pollution & its Control 2008).

Hazardous substances may be found at almost every level of effluent regulation, from the drainage system to the modern effluent facility to sediment treatment. Even while the effluent is still in drains, H_2S production is an important problem because adverse circumstances in the circuit enhance effluent decay and lead to harmful discharges (Kamil Pochwat *et al.* 2019). Joseph Jjagwe et.al. conducted a thorough examination of recent advances in the synthesis of granular utilizing biomass refuse for water purification and discussion on production factors, including granular circumstances, adhesive usage, carbonation, stimulation processes, and their effect on morphological attributes (Joseph Jjagwe *et al.* 2021). Design of filtration system was discussed for aerated sewage water and the biological activated carbon treatment process was explored for advanced water and wastewater treatment. Bio-filters and bio-trickling filtration are the most often used techniques for reducing odours in facilities. These methods are preferred because they are affordable and have significant levels of odour elimination. A report is provided that analyses the smells released by various sewage processing units, to identify the primary causes of these smells [Pal Nirosha *et al.* 2023; Jin *et al.* 2013; Vincenzo Senatore *et al.* 2021]. Gonzalez *et al.* investigated the procedure of identifying odours, the method for detecting fragrances, and the primary sources of harmful chemical pollution and concluded that effectively controlling odour is the prime hindrance to the profitable operation of contemporary sewage disposal facilities [Gonzalez *et al.* 2022].

Oxidized nitrogen recycling and activated sludge recycling are the methods, which have significant financial and environmental advantages, can be easily incorporated into the amenities identified a significant drop in odour emissions [Toledo & Munoz 2023]. The detection of odour discharges in a sewage processing facility was explored by employing a drone based molecular detector platform (Burgues *et al.* 2022). The two-level bio-trickling filtration technique proved robust against the fluctuating natural sulphur components and high H_2S levels. H_2S resistance was successfully reduced, and volatile organic sulphur compounds breakdown was promoted. [Sun *et al.* 2019; Rai Nitish Kumar 2018).

Chemical scrubbing technology, biodegradation technology, activated carbon adsorption filtration systems and the combined systems are the most commonly used technologies for odour control systems. They are discussed based on their operational parameters, environmental performance, operating cost and investment. Higher environmental impacts were observed from physical adsorption technologies compared with the chemical and biological techniques (Hongxia Du *et al.* 2024; Ouradou *et al.* 2023; Joanna Czarnota *et al.* 2023; Baisali Rajbansi *et al.* 2014.; Estrada, Jose *et al.* 2011).

Unregulated outflows of NH_3 and H_2S can lead to natural contamination and posture wellbeing dangers. In this way, ceaseless checking makes a difference in keeping up secure levels of these gasses, advancing a solid work environment and diminishing natural harm. Numerous studies explore the impact of policy ambiguity in carbon emissions, green energy, and high-tech sectors on the financial market, using panel data from various industrial sectors. It evaluates the impact of varying environmental guidelines under the 12th, 13th, and 14th Five-Year Plans on industrial pollution control (Xilin Zhang *et al.* 2025; Zhang, Xilin *et al.* 2025; Zhiqiang Tong *et al.* 2025; Zou, Fei *et al.* 2024; Wu, Q *et al.* 2024).

With increasing urbanization there is increased stress on sewage systems so there is a need for smart and efficient sewage systems. Implementing monitoring and proactive management measures will optimize the ability of the sewage framework, facilitate the passage of effluents throughout disposal pathways, and prevent the network from overloading throughout seasons of high rainfall (Vivek Chauhan 2020) . In the context of the Internet of Things, researchers developed a combined surveillance network which utilizes data from enhanced sensory devices to control and reduce odours in farms or drainage systems. A concrete method for monitoring the wastewater network has been created to handle the problem of tracking the hazard of vapours in wastewater. The detection of hazardous substances is crucial to prevent potential harm to individuals (Kim, HY 2019; Perez Padillo *et al.* 2022; Revanth M S *et al.* 2021; Lizzy NesaBagyam *et al.* 2020). Internet of Things system that can also be used to identify and measure moisture, temperature stages, and gaseous composition. This technology is capable of detecting different types of gases and monitoring their levels, while also tracking immediate variations in these aspects. If the values above the predefined restriction it will send a notification to the designated individuals who are temporarily situated at the workspace on their linked mobile devices (Anushka *et al.* 2020; Anitha and Kumar 2023).

Olfactory contamination may be quantified using many parameters such as limit, detectability, level, strength, retention, nature, and irritation. The smell assessment may be conducted using several approaches, including instrumental techniques, chemical analysis, electronic methods, and sensory test methods, such as olfactometry. Based on the level of odour intensity and toxicity, the sewage pipes, drainages, pipe couplings etc. are heavily eroded and corroded which is shown in **Figure 1.**

To protect people’s health, surrounding biological life and mother nature, and to comply with emission norms & standards set by the pollution control board and to eliminate corrosion and erosion, our investment in the plant equipment, thus raises the need for an odour control system. The Odour Control System is not only used to de-odourise the plant but also eliminate harmful gases generated from the source before they get released into the atmosphere, thereby protecting society and preventing equipment from any kind of corrosion or erosion. Coal-based activated carbon filtering media filters effectively control odours due to their high adsorption capacity, primarily driven by their large surface area and porous structure, which trap odour-causing molecules. Through physical adsorption, Vander Waals forces attract and retain volatile organic compounds (VOCs) and other pollutants. Their arrangement of micropores, mesopores, and macropores empowers them to capture a wide run of particle sizes specifically. Moreover, actuated carbon can be recovered for reuse in a few applications, making it a flexible arrangement for smell control in sewage water treatment.

In this way, the coal-based activated carbon filtering media could be a novel progression in odour control, offering upgraded adsorption effectiveness, progressed toughness, and better resistance to moisture and chemical debasement. Its functionalized sulphone groups specifically adsorb sulphur-based compounds like H_2S, guaranteeing higher removal effectiveness and longer channel life. Furthermore, it coordinating well with IoT-based observing for real-time odour evaluation, making it a cost-effective and economical arrangement for wastewater treatment and mechanical applications.

Figure 1. Corroded and eroded sewage pipes, drains and couplings due to toxic gases

2. Methods and systems

The predominant techniques employed in odour management include molecular cleaners and bio-trickling filtration systems. The choice of the appropriate equipment is contingent upon other criteria. This study describes the design and development of an activated carbon-filtered odour control system for sewage pumping stations and monitors the odour intensity levels by using IoT. Purified carbon may be derived from various carbon-based resources and treated to improve its characteristics. Stimulated carbon may be produced from an assortment of assets. Due to their excellent adsorptive activity and capability for a wide range of chemicals, activated carbon is the most widely used adsorbent in many industrial sectors including sewer odour control applications (Junaid Saleem *et al.* 2019).

2.1. Activated Carbon Filter System

The Activated Carbon Filter works on the basic principle of physical adsorption of pollutant particles from contaminated air or sewer gas. The sewer gas is usually captured from the source tank of any sewage treatment plant (STP). In general, the source tank can be the collection tank, equalization tank, balancing tank, screen chambers and sludge treatment areas. The sewer or waste gas is generated in the freeboard volume above the wastewater surface. These gases are sucked in via a radial fan and sent to the OCS for treatment. The sewer gas passes through the pre-filter initially. It is an essential part of the OCS which acts like a safety device which separates and traps any kind of moisture, oil, grease and other impurities which can damage the operation of the OCS. Only the polluted gas is allowed to pass further through the non-return damper which prevents any backpressure on the plant equipment. The radial fan drives the waste gas into the filter vessel through the volume control damper which is provided for maintenance purposes. The gases reach the space at the bottom of the ACF vessel, go up and react with the coal-based catalytical type water re-generable activated carbon media. During the reaction, the pollutant constituent which is the elemental sulphur 'S' gets adsorbed on the fine porous surface of the activated carbon pellet and only the treated air leaves through the outlet stack. This air is harmless and free from any objectionable odour. The efficiency of the system is validated through the inlet and outlet H_2S monitors. The schematic of the process flow of the activated carbon filter odour control system is shown in **Figure 2** and the assembly of the tank cover and ACF standalone unit design is depicted in **Figure 3**. All the dimensions are specified in mm.

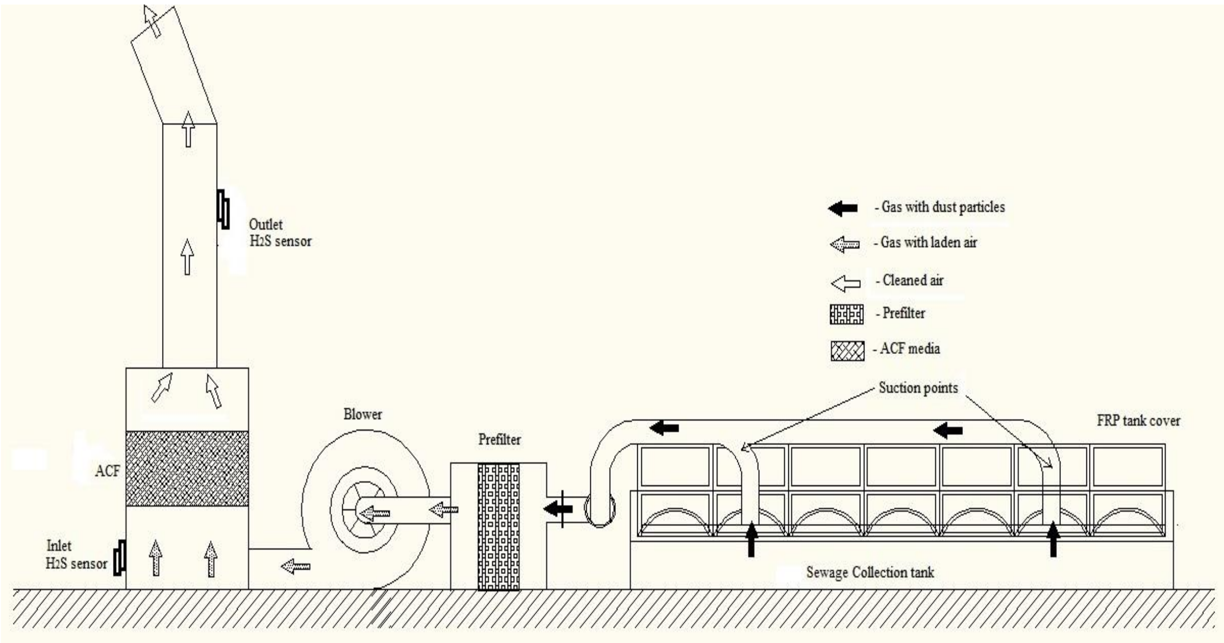


Figure 2. Process flow of activated carbon filter odour control system

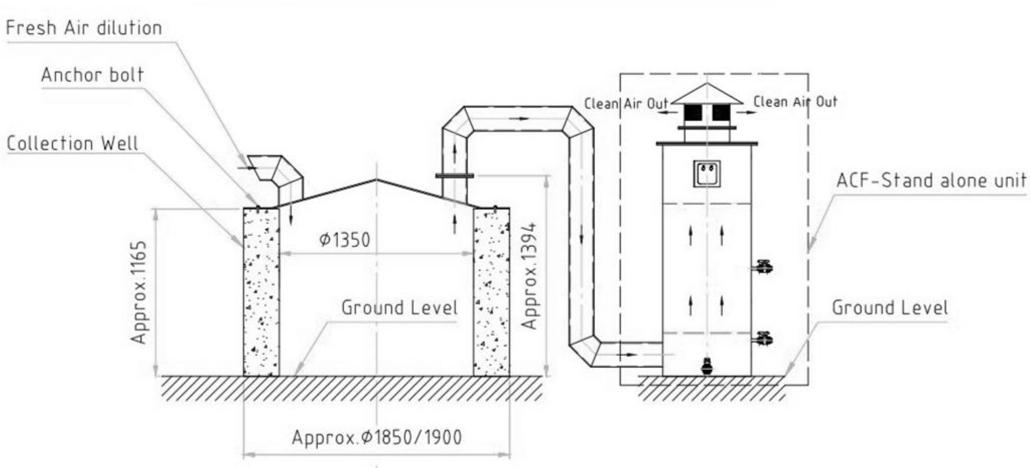


Figure 3. Assembly of tank cover and ACF standalone unit design

The unit of an odour control system and the activated carbon media are depicted in **Figures 4 and 5**. Activated carbon-based methods use the concept of absorbing to capture unpleasant gaseous particles onto the exterior of the substance. The collected gaseous components are then oxidized, resulting in the release of undetectable substances into the environment. Filtering material with the ability to remove H_2S, and VOCs, is employed to remove smells in sewage. It is advisable to use a modified carbon material that is capable of effectively managing these malodourous pollutants. Essentially impregnated triggered carbon medium and particularly processed virgin activation carbon material are used to address sewerage issues. The amount of air that the odour control systems will treat in an hour ranging from 50 m^3/hr to 1,000 m^3/hr, which appears to be rather large is the capacity of the OCS. The capacity of OCS is defined by the system dimension, adsorbent, adsorption ability and process parameters like temperature, chemical components, and moisture.Activated carbon adsorption efficiency depends on molecular properties, temperature and humidity. It has a highly efficient adsorption for hydrogen sulphide and low efficiency for methane and carbon-di-oxide, which are produced very low in percentage.

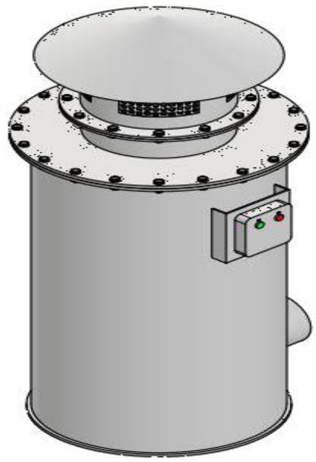


Figure 4. Unit of odour control system

The described system is a field-tested application (Venus nagar OCS, Chennai, Tamilnadu, India). The specified OCS is a dry scrubber system which is designed for efficient H_2S odour removal for large odour removal operations at sewage collection well at a site, Venus Nagar, Chennai, Tamilnadu, India. The collection or pumping well of 4 meters diameter, 8 meters depth with the volume of $100m^3$ is designed to take up a flowrate of 100 CMH (cubic meter per hour), with the static pressure of 40 mm WC (water column). 380 kg of activated carbon media is kept for high adsorption of H_2S, which is a target pollutant. The adsorption efficiency of the system is greater than 95%, suited for processing 600 to 1000 CMH.

Figure 5. Activated carbon media

Once the activated carbon media is loaded completely, the lifetime of the carbon is further extended through a simple process of regeneration. The media inside the carbon filter vessel is washed with water through an in-built sprinkler system or spray nozzles. The water coming in contact with the elemental Sulphur reacts and forms a very dilute form of Sulphuric Acid which is drained and sent to the sewage treatment plant. This regeneration process can be done up to 5-10 times, providing a very long lifetime for the Carbon media. So the filtration system may last up to 5 to 6 years based on the airflow rate and system usage, temperature and humidity.

The data is collected daily-hourly basis, from morning 7.00 till evening 7.00 by dynamic olfactometry technique with ASTM E679 standard in ppm by the Odour Detection Threshold (ODT) which is the minimum concentration of an odourant detectable by the human sense of smell. The process involves preparing high-purity odourant samples in clean air, selecting and training a panel of assessors, and using an olfactometer for controlled odour presentation. Panellists identify odours in ascending concentration series, and individual thresholds are recorded. The geometric mean of these thresholds is calculated to determine the group ODT, expressed in ppm. Quality control measures, including repeat testing, statistical validation, and instrument calibration, ensure accuracy and reliability.

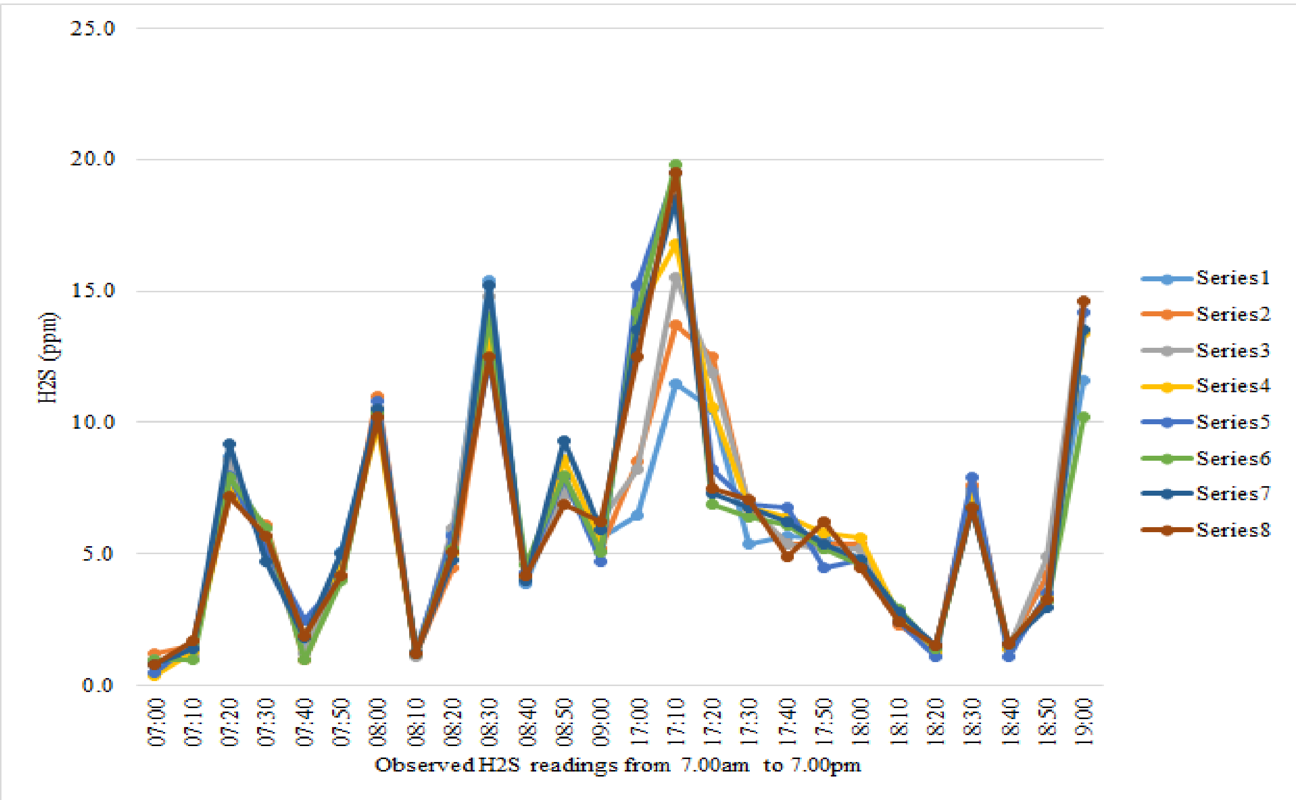


Figure 6. Variation of H_2S levels at various depths in sewage collection well during operation

Table 1. Variation of H_2S levels (ppm) at the inlet of collection well during a week day

Time	Depth 1	Depth2	Depth3	Depth4	Depth5	Depth6	Depth7	Depth8
07:00	0.9	1.2	1.0	0.4	0.5	1.0	0.8	0.8
07:10	1.2	1.5	1.1	1.3	1.6	1.0	1.4	1.7
07:20	8.7	7.3	8.6	7.4	8.0	7.9	9.2	7.2
07:30	5.4	6.1	5.3	5.6	5.2	6.0	4.7	5.7
07:40	1.5	1.0	1.2	1.8	2.5	1.0	1.8	1.9
07:50	5.1	4.2	4.5	4.6	4.1	4.0	5.0	4.2
08:00	10.3	11.0	10.6	9.9	10.8	10.4	10.5	10.2
08:10	1.2	1.2	1.1	1.3	1.3	1.2	1.2	1.2
08:20	5.8	4.5	6.0	5.0	5.7	5.2	4.8	5.1
08:30	15.4	12.7	14.8	13.5	12.3	14.0	15.2	12.5
08:40	3.9	4.1	4.1	4.2	4.3	4.6	4.0	4.2
08:50	7.6	7.9	7.3	8.6	7.9	8.0	9.3	6.9
09:00	5.6	5.2	6.3	5.5	4.7	5.1	5.9	6.2
17:00	6.5	8.5	8.2	14.2	15.2	14.2	13.5	12.5
17:10	11.5	13.7	15.5	16.8	19.5	19.8	18.5	19.5
17:20	10.5	12.5	11.9	10.6	8.2	6.9	7.3	7.5
17:30	5.4	6.8	6.9	6.8	6.9	6.4	6.8	7.1
17:40	5.7	5.4	5.4	6.4	6.8	6.1	6.2	4.9
17:50	5.6	5.4	5.2	5.8	4.5	5.2	5.4	6.2
18:00	4.8	5.4	5.2	5.6	4.8	4.6	4.8	4.5
18:10	2.4	2.3	2.7	2.6	2.4	2.9	2.8	2.4
18:20	1.4	1.4	1.3	1.3	1.1	1.4	1.5	1.5
18:30	7.5	7.6	7.4	7.2	7.9	6.8	6.7	6.8
18:40	1.5	1.6	1.4	1.4	1.1	1.6	1.6	1.6
18:50	4.2	4.2	4.9	3.4	3.5	3.2	3.0	3.3
19:00	11.6	13.4	14.6	13.4	14.2	10.2	13.5	14.6

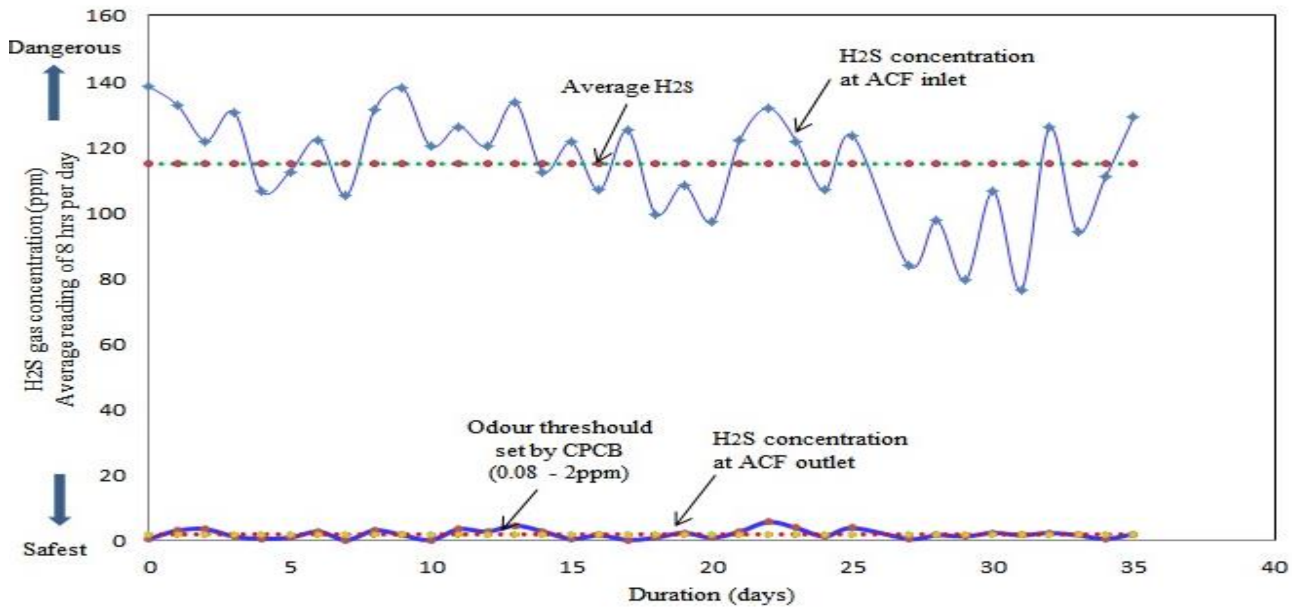


Figure 7. Comparison of Odour Levels at the Inlet and Outlet of an Odour Control System over a Five-Week Period.

The measured H_2S levels in a sewage well at 8 various depths specified as series, during a week day, as shown in the **Figure 6**, and at **Table 1**, reveal that odour concentrations are peak during the morning (7.00am to 9.00am) and evening (5.00pm to 7.00pm) hours, likely due to increased wastewater flow and microbial activity. During these times, the decomposition of organic matter accelerates, releasing higher amounts of hydrogen sulphide gas (H_2S), which results in stronger odours at various depths within the sewage well. Similarly, the readings are observed for the prediction of H_2S levels. **Figure 7** shows the comparison of odour levels at the inlet and outlet of an OCS over a five-week period. The information appears an average of 118 ppm of H_2S at the inlet, with levels decreased to between 0 and 2 ppm at the outlet, which ensures that the system provides more than 95% efficiency. Activated carbon filtered dry scrubber odour control system uses activated carbon to adsorb H2S is a compact, passive and highly effective odour control system. In comparison with bio-trickling or biofilter system, activated carbon filtered OCS provides more than 95% efficiency, which is depicted in **Figure 7** at out let with 0 t0 2 ppm of H_2S. Bio-trickling filtered system provides 80 to 85% of odour control efficiency, with high water usage and moderate energy usage, needs a bio-bed and misting system. The maintenance of activated carbon filtered OCS requires a moderate maintenance comparing with the bio-trickling system which requires high maintenance (Estrada, Jose *et al.* 2011). This noteworthy diminishment highlights the viability of the odour control system. The trend illustrates the energetic nature of odour emanations in sewage frameworks, emphasizing the need for focus on odour control procedures, particularly amid top hours when the discharge of H_2S is most noticeable.

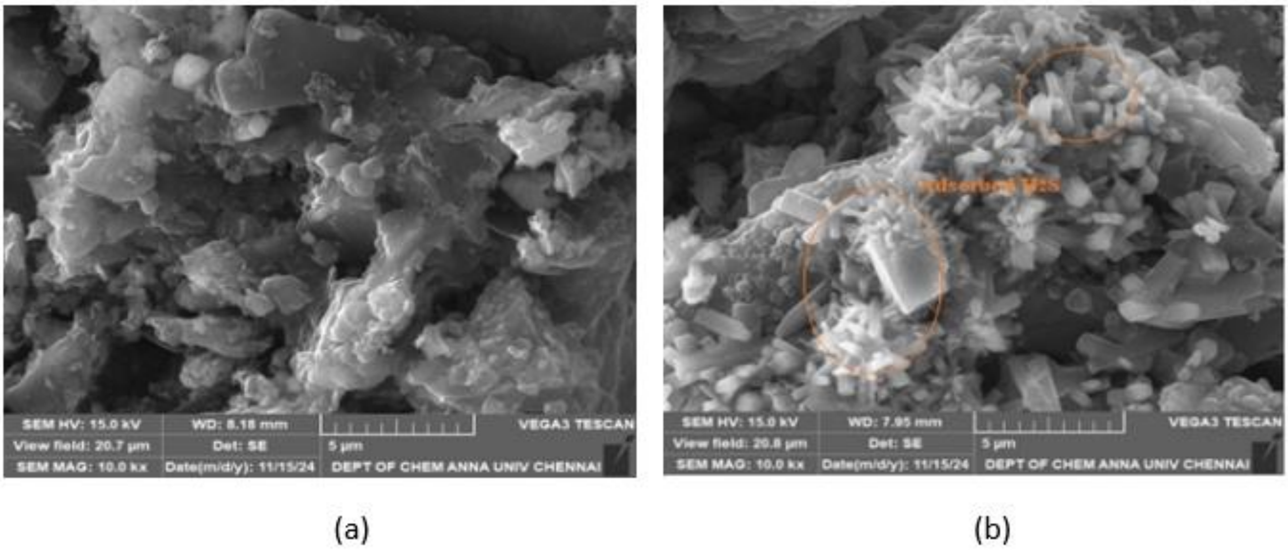


Figure 8. SEM images of activated carbon filtering medium before and after adsorption

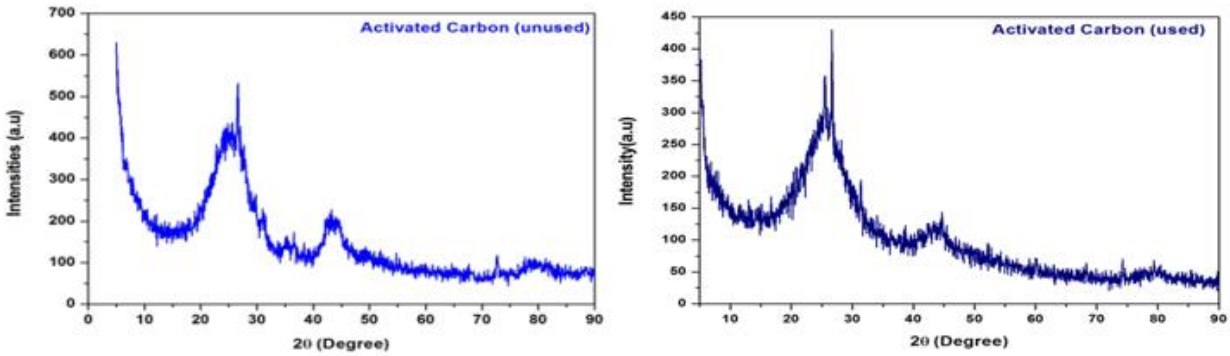


Figure 9. XRD pattern of activated carbon filtering medium before and after adsorption

Structural analyses using Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD) provided clear evidence of H_2S adsorption in the activated carbon filtering medium. SEM images taken before adsorption displayed a porous and well-defined surface structure, while images after adsorption showed noticeable changes, with the presence of H_2S adsorption visibly indicated in **Figure 8**. These modifications confirm the systems efficiency in trapping H_2S odourous compounds. Additionally, XRD patterns revealed minor structural changes in the activated carbon, suggesting interactions between the carbon matrix and the adsorbed H_2S as shown in **Figure 9**. These findings validate the effectiveness of the coal-based activated carbon media filter in mitigating odour emissions and improving air quality in sewage collection well, suction well and wastewater treatment facilities.

2.2. IoT based odour monitoring system

The IoT-based checking framework offers an effective and cost-effective arrangement for small-scale odour emanation sources by empowering real-time following, remote access, and automated alarms. Prepared with sensors, the framework ceaselessly recognizes odour-causing gasses such as alkali, hydrogen sulphide, and VOCs, transmitting information to a cloud-based stage available by means of a web entrance or smartphone application. This permits trade proprietors and regulatory bodies to screen emanations remotely, decreasing the necessitate for physical assessments. Remote sensing

(IoT) provides real time monitoring of odour levels, which are hazardous to measure directly, plays a major role in odour control system. Mechanized alarms inform clients when outflow levels surpass allowable limits, empowering speedy remedial activities to anticipate administrative infringement and community complaints. Gas sensors or ground based IoT sensors with Ultrasonic Level Transmitter is used for determining sewage water level. Flow levels and OCS's H_2S sensor readings are monitored by electromagnetic flow meter and the cumulative values are displayed on the status screen. The power consumption of the motor, well sewage levels, voltage current readings are recorded in the cloud and can be exported to MS Excel through V-Net application for reference. The H_2S gas sensor works in a range of 0-200ppm with a accuracy of ±2% and a resolution of 1ppm. It has a response time around 10 to 15 seconds with the repeatability of 1-2ppm of full scale at an operating temperature of -10 to 50'C. It needs an external DC power supply of 25V with the power consumption of 1 to 22 watts. With prescient maintenance capabilities, the system can expect potential issues, allowing proactive interventions to minimize odour emissions. On the whole, the IoT-based inspecting system gives a sensible, flexible, and successful approach for small-scale industries to enhance environmental compliance and operational capability though directing odour-related impacts.

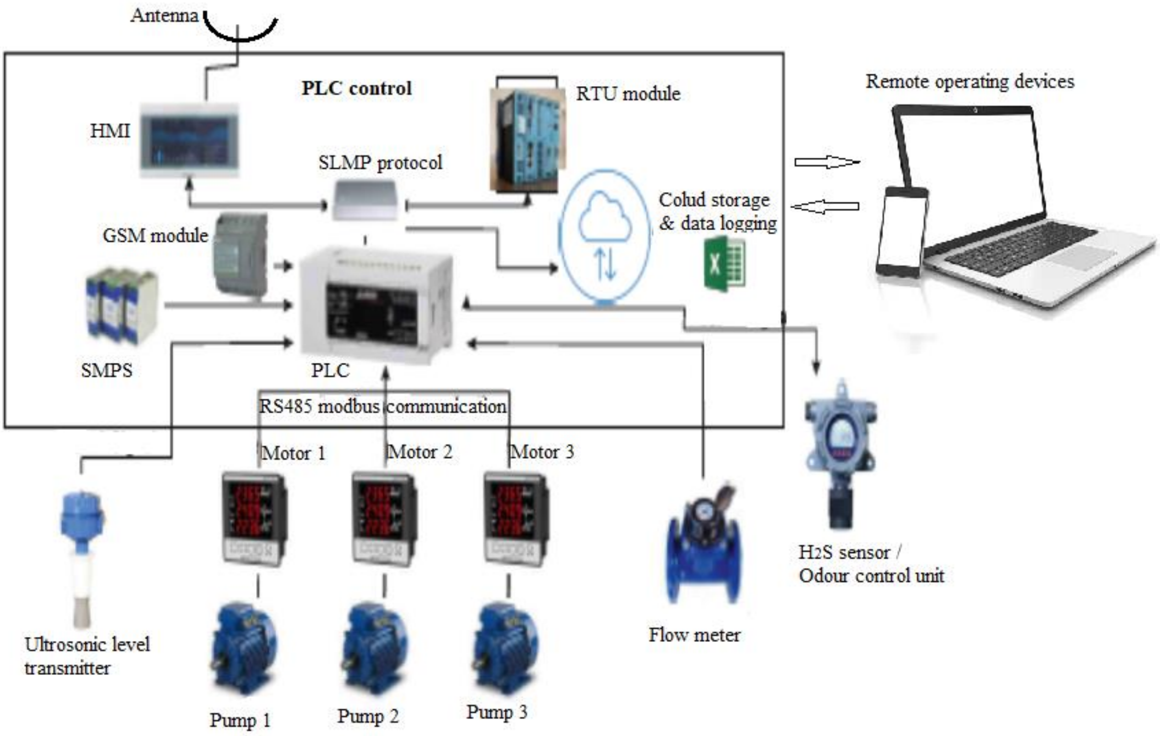


Figure 10. Schematic of IoT based sewer toxic gas monitoring system

3. Conclusion

The Activated Carbon Filtered (ACF) Odour Control System (OCS) has proven to be effective in reducing odour emissions in wastewater treatment facilities. By successfully lowering hydrogen sulphide (H_2S) levels to nearly zero ppm, it addresses critical environmental and occupational health concerns by providing an efficiency of the system greater than 95%. Real-time gas detection is improved by the integration of IoT-based monitoring, allowing for proactive management and increased operational effectiveness. Significant H_2S adsorption was confirmed by structural investigations using Scanning Electron Microscopy (SEM), while X-ray diffraction (XRD) showed slight structural alterations in the activated carbon. In applications involving the management of odours, the coal-based activated carbon media filter shown exceptional efficacy. Furthermore, by removing exposure to harmful gases, the ACF OCS reduces the likelihood of corrosion and prolongs the life of wastewater treatment facilities. Its application guarantees adherence to environmental laws, especially for establishments close to residential areas. The system is a sustainable solution because to its affordability, ease of expansion, and remote monitoring capabilities. The ACF OCS makes wastewater treatment safer and more effective by improving air quality and lowering maintenance expenses. Future studies might evaluate the adsorption processes long-term performance and investigate optimization techniques for choosing carbon media.

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