The Implementation of Artificial Intelligence for Optimizing Odor Control Chemical Dose Rates

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ABSTRACT

The novel use of Artificial Intelligence (AI) techniques along with advanced dosing controllers in order to optimize odor control chemical dose rates is discussed in this paper. Through the application of AI, the practitioner was able to achieve better Hydrogen Sulfide (H_2S) compliance using industry standard measurement methods. AI techniques are effective in statistically analyzing complex equations and a large amount of historical data within a short period of time. This significantly reduces the time and effort that is required in maintaining (H_2S) compliance.

KEYWORDS

Collection Systems, Innovative Technology, Odor/Air Emissions, Artificial Intelligence, Machine Learning, Hydrogen Sulfide

INTRODUCTION

Wastewater collection systems are a complex infrastructure of gravity pipes, manholes, lift stations, and force mains that convey sewage from remote locations to wastewater treatment plants. Hydrogen sulfide gas (H_2S), which is a foul smelling, toxic, and corrosive gas, is typically generated in wastewater collection systems at points that limit the exchange of oxygen in the wastewater, thus creating septic conditions. Typically, the sewer systems operate at partial full conditions and the damp surface above the water line is home to aerobic bacteria that oxidize H_2S to sulfuric acid, impacting the pipe material. This results in corrosion of the collection system, leading to weakening of the pipes and potential collapses if left unattended. These failures result in a significant cost for the municipalities and adversely impact the community. The EPA estimated the cost of major sewer rehabilitation to be $38.8 billion (U.S. EPA, 1985) when there is a damage due to corrosion or collapse of pipelines. Hence, it is essential to understand wastewater characteristics and continuously build technology to support odor and corrosion abatement.

As per OSHA requirements the legal permissible exposure limit (PEL) for hydrogen sulfide is 20 ppm ceiling limit and 50 ppm peak limit (U.S. EPA, 1974). H_2S mitigation can be achieved by both chemical and mechanical treatment. Chemical treatment is achieved by the dosing of solutions directly into the wastewater system, upstream from the respective odor emission points. Chemical selection and dose rates are based on the respective environmental conditions, including concentration of organic matter, temperature, pH, detention time, etc. Amongst various liquid phase treatments available in the market, nitrate solutions have proven to be some of the most successful technologies at both preventing the formation of sulfide and removing existing sulfide from wastewater streams. In the prevention mechanism, nitrate acts as an additional oxygen source for the microbes, especially in anaerobic conditions. This reduces the consumption of sulphates, resulting in very minimal or no H_2S generation. When the prevention mechanism is employed, nitrate facilitates the biochemical oxidation of sulfide. Nitrate solutions are fed throughout the day at the upstream feed points during the hours of demand with advanced dosing control technologies.

The simplest method for dosing is to calculate the total amount of odor control product needed per day and then to feed the odor control product into the wastewater stream by metering the dose over a 24-hour period. More sophisticated dosing systems incorporate combinations of time-based schedules for the pump output and flow signals. In this study, a more advanced technology, the Evoqua VersaDose® automated dosing controller was used in order to provide a more accurate dose throughout the day by varying the chemical dose based on demand. H_2S concentrations can vary greatly from hour to hour with changing temperatures, wastewater flow rates, and the time of day. This feed system allows the flexibility to dose different chemical dose amounts for every single hour throughout the day, 7 days a week. This adds up to 168 independent dose rates throughout the week. The VersaDose® system has some more advanced features such as rain compensation, temperature compensation, and flow pacing based on the sewage flow rates. These advancements allow the flexibility to adapt for many different strategies while optimizing the dosing of odor control product.

However, the continuously changing dynamics of wastewater pose a whole new challenge for optimizing the dose amount and duration more accurately and frequently. This would involve a significant amount of human effort and time in generating dosing trends that would meet the changing demand of nitrate solution. Currently multiple IoT devices are available in the market that help us capture real time data and further feed the necessary amount of chemical into the wastewater system. With these devices, Artificial Intelligence (AI) can be used to facilitate the modeling and optimization of feed rates based on historical data with minimal effort.

METHODOLOGY

Wastewater collection systems can be manually optimized by evaluating changing conditions and adjusting chemical dose rates to accommodate for the demand. However, this is a time-consuming effort, that relies on the skill of the individual and is typically performed no more than twice per year during seasonal changes. The process is not repeatable across a large number of odor control sites with multiple practitioners as individual sentiments come into play when optimizing against two inversely proportional variables, for example H_2S level and budget.

With the help of AI, chemical dosing is continuously optimized based on both real-time and historical process data. This chemical dosing platform provides site dosing recommendations while ensuring compliance and contractual adherence to H_2S limits for clients. With the help of Machine learning (ML), a branch of AI technology, large and varied data sets can be statistically processed and analyzed. New black box methods of AI such as Artificial Neural network (ANN), Deep Learning Neural Network (DLNN), Support Vector Machine (SVM), etc. are being used in the process optimization of similar wastewater processes. Critical odor control indicators such as H_2S concentrations are correlated to product dose rates, wastewater flow and budget with the application of novel Machine learning algorithms. These algorithms predict, estimate, and forecast key performance indicators into the future. Core to this process are two dimensions that the process is optimized against, H_2S concentration and chemical volume. H_2S is optimized against static upper and lower control limits that act as boundaries for acceptable H_2S measurement. The second dimension of chemical volume is established based on the specific goals of the program, to either minimize the use of chemical or ensure that a certain volume of chemical is used in a specified period of time.

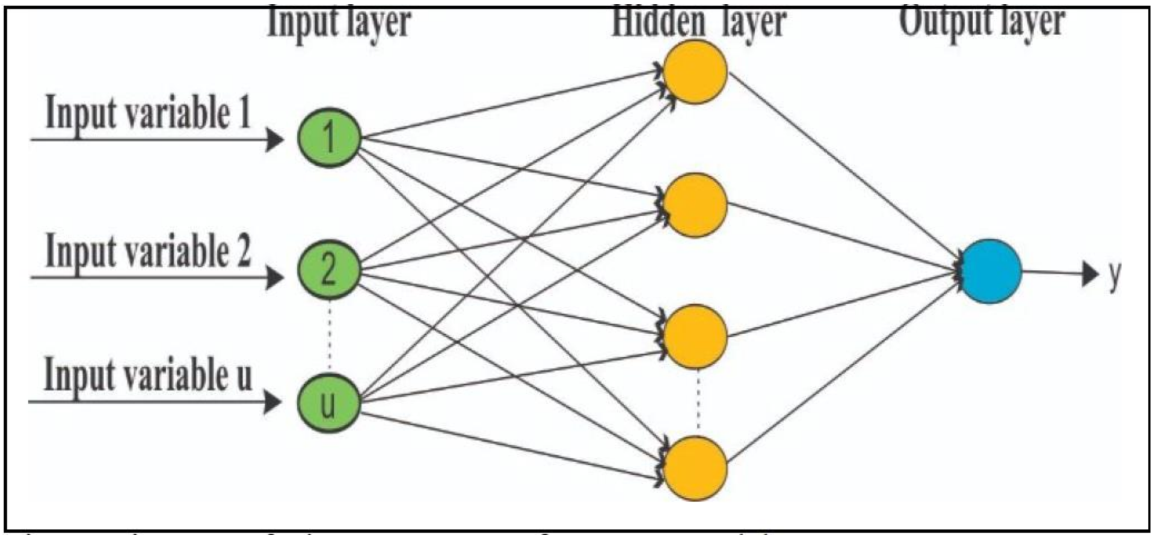

Figure 1: Layer structure of an ANN model

In this application, the AI tool is provided with all the preliminary information and a historical data set. This information, along with some contractual targets and limitations, helps the tool in learning and identifying the control pattern required at that location. It leverages new and historic data including wastewater temperature, flow rates, hydrogen sulfide levels, and past dosing history, as well as immutable characteristics of the collection system such as pipe length and diameter to make modifications to pre-existing chemical dose curve ml/min setpoints, or ppm setpoints if the chemical dose is designed to change proportionally to the wastewater flow rate. The AI model produces a week of H_2S predictions into the future. Each hour dosing setpoint is evaluated to see if the given dose will result in a predicted H_2S concentration above or below the H_2S control point. The model then tries to derive a dosing setpoint that brings the H_2S levels below the threshold up and H_2S levels above the threshold down. This process is then repeated until an optimal dosing curve is achieved for the upcoming week.

RESULTS

Chemical dose optimization using AI was implemented at two different feed sites**.** These two locations were chosen based on the following criteria:

- Presence of IoT monitoring and feed devices at both upstream and downstream locations of interest.
- Availability of force main (FM) information – sewage flow rate, FM diameter, FM length and retention time.
- Compliance targets w.r.t H_2S levels
- Budget information (annual)

In addition to the presence of IoT devices at both the feed and monitoring locations, it is essential to have continuous data transfer from the devices to the AI technology. This information helps the tool to learn trending patterns with respect to the chemical demand and resulting H_2S concentrations. The tool provides weekly dose curves that can be uploaded to the advanced dosing controller present on site to accurately dose the chemical for maximum compliance.

Case Study 1:

This sewage pump station located in Northeastern coastal region was selected as the study site for evaluating the impact of Artificial Intelligence (AI) in optimizing the dose rates. Bioxide® (calcium nitrate) solution was fed at this pump station using an advanced dosing controller in order to maintain H_2S concentrations less than 10 ppm average and 20 ppm peak.

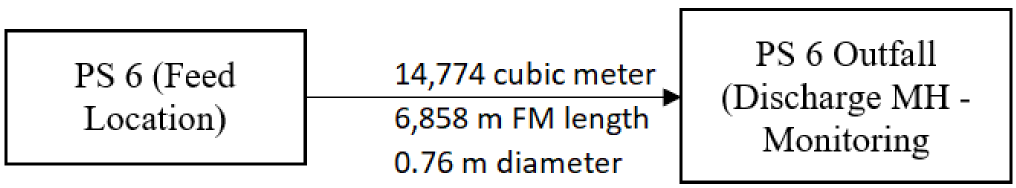

Figure 2: Case study 1 - PS 6 FM Line Diagram

Pump Station (PS) 6 collects sewage from upstream locations and pumps the collected sewage out through a force main, which then discharges at a downstream manhole. In this application we are monitoring the discharge MH (PS 6 Outfall) in order to maintain the H_2S gas level concentration as per the contractual limits. The force main information is provided in Table 1:

Location	Pump Station 6, Monroe Township, NJ
System Treated:	Force Main
Diameter of Line:	0.76 meters (30 inches)
Length of Line:	6,858 meter (22,500 feet)
Daily Flow (approx.):	14,774 cubic meter (3.25 MGD)
Type of Wastewater:	Residential
Detention Time:	6.1 hours
Control Point	Discharge Manhole
AI Start Month	January, 2021

Table 1: Case study 1 - PS Flow parameters

An advanced dosing controller (VersaDose®) is deployed at this location and was used for liquid phase odor control chemical dosing. These controllers are able to dose odor control product on a 168-point interpolated curve rather than a fixed rate, allowing a dosing profile that matches the hydrogen sulfide being generated during typical diurnal flow patterns. The downstream hydrogen sulfide is recorded using a Vaporlink® remote indicating hydrogen sulfide monitoring device.

The overall performance was determined based on the feed rates and H_2S levels before and after the introduction of AI.

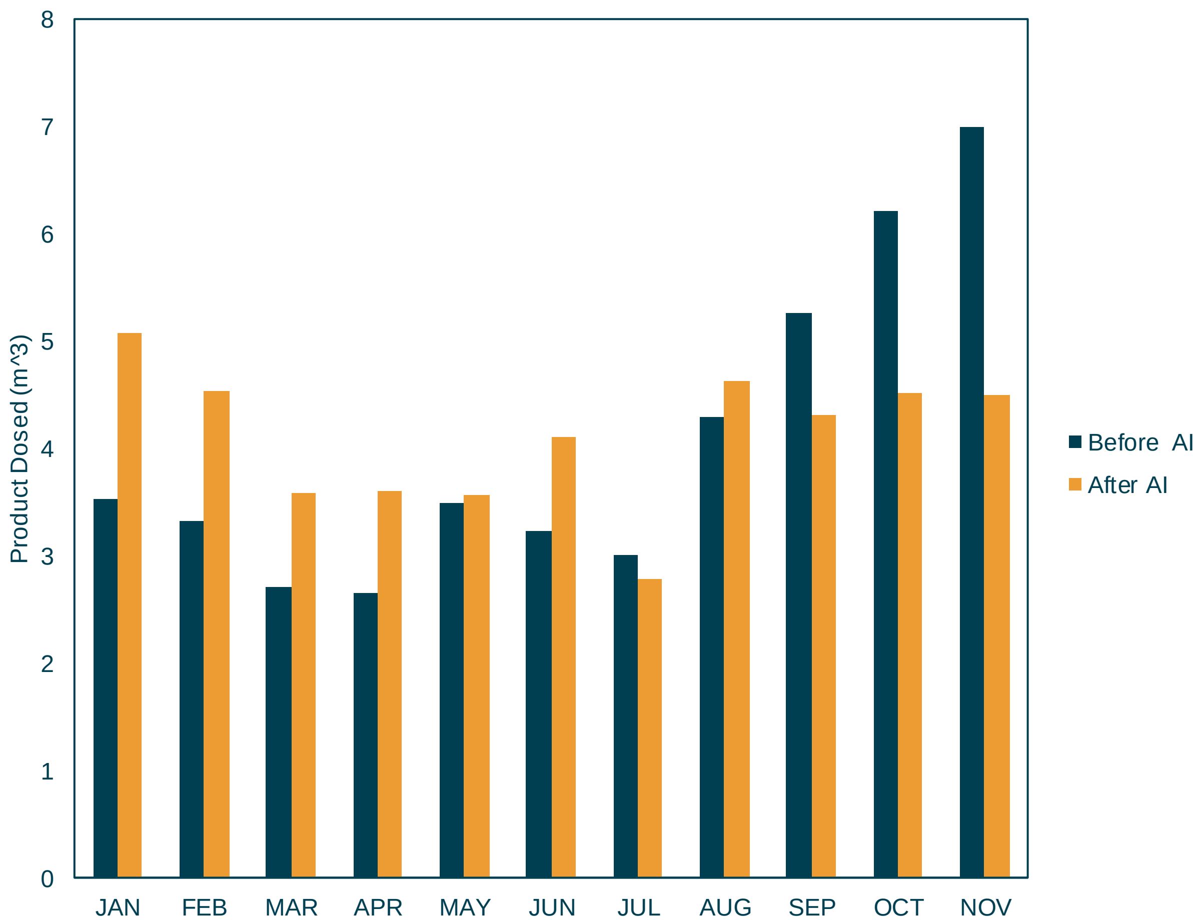

Figure 3: Case study 1 – Chemical Feed (volume) monthly comparison

Before AI (cubic meter)		After AI (cubic meter)	
January, 2020	3.53	January, 2021	5.08
February, 2020	3.32	February, 2021	4.53
March, 2020	2.71	March, 2021	3.59
April, 2020	2.65	April, 2021	3.61
May, 2020	3.50	May, 2021	3.56
June, 2020	3.24	June, 2021	4.10
July, 2020	3.00	July, 2021	2.79
August, 2020	4.30	August, 2021	4.63
September, 2020	5.26	September, 2021	4.30
October, 2020	6.20	October, 2021	4.52

November, 2020	7.00	November, 2021	4.49
December, 2020	7.33	December, 2021	5.48

Table 2: Product Feed data comparison before and after using AI at PS 6, Monroe Township

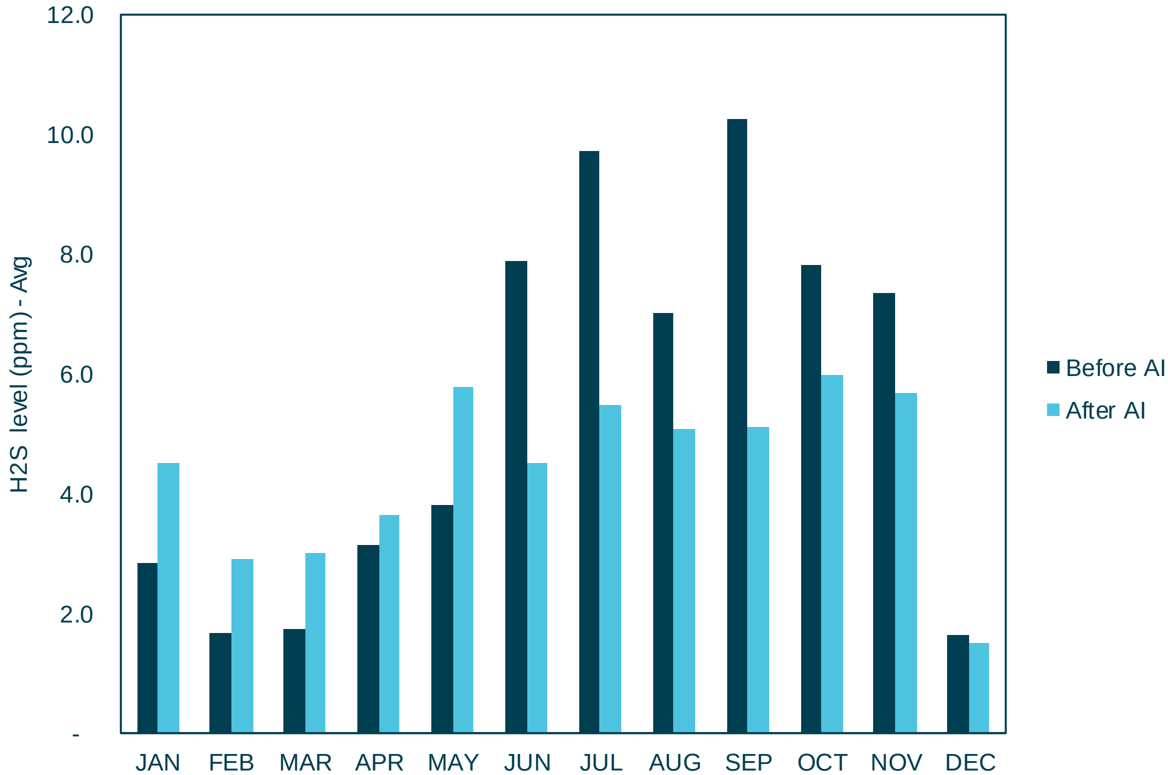

Figure 4: Case study 1 – H_2S Levels (ppm) monthly comparison

Before AI (ppm)		After AI (ppm)	
January, 2020	3	January, 2021	5
February, 2020	2	February, 2021	3
March, 2020	2	March, 2021	3
April, 2020	3	April, 2021	4
May, 2020	4	May, 2021	6
June, 2020	8	June, 2021	5
July, 2020	10	July, 2021	5
August, 2020	7	August, 2021	5
September, 2020	10	September, 2021	5
October, 2020	8	October, 2021	6
November, 2020	7	November, 2021	6
December, 2020	2	December, 2021	2

Table 3: Average H_2S level comparison before and after using AI at PS 6, Monroe Township

Chemical feed at PS 6 was optimized using AI from January 2021. Table 3 and 4 provide a monthly comparison of amount of chemical fed with respect to resulting average H_2S concentrations. This annual comparison clearly indicates that with the help of AI, H_2S concentrations were maintained within the contractual targets without having to increase the chemical feed rates. Month over month the AI tool was able to provide better optimization, which was clearly indicated by the reduction in feed rates and also maintaining the H_2S levels below 10 ppm.

Case Study 2:

For the next case study, we have considered a pump station from a Southeast coastal region. This pump station has a monitoring location downstream at an air relief valve (ARV) with a control target of 50 ppm average throughout the year. This system is slightly manifolded with flow from one other lift station joining the force main, finally reaching the monitoring location.

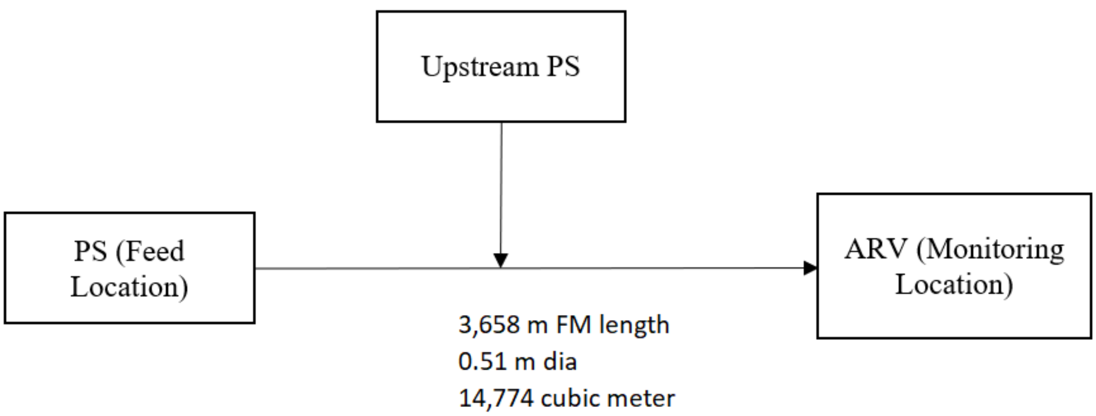

Figure 5: Case study 2 – Southeast PS FM Line Diagram

Calcium nitrate was being fed at just one pump station at a calculated feed rate in order to maintain the H_2S levels as per the customer's requirement. H_2S gas will be released at the monitoring location only when the ARVs open. This adds more variables for the AI to learn from when designing the dose curves.

System Treated:	Force Main
Diameter of Line:	0.51 meter (20 inches)
Length of Line:	3,657 meter (12,000 feet)
Daily Flow (approx.):	14,774 cubic meter (3.25 MGD)
Type of Wastewater:	Residential

Detention Time:	6.1 hours
Control Point	Air Release Valve (ARV)
AI Start Month	October, 2021

Table 4: Case study 2 - PS Flow parameters

The pump station in this case study is located in a residential area and Bioxide® (calcium nitrate) solution was fed using an advanced dosing controller in order to maintain H_2S concentrations. Based on the force main information and the safety requirements, calcium nitrate is dosed at both the locations for the removal and prevention of sulfides. The physical attributes of the site along with the historical data sets from both the monitoring and the feed locations are fed into the AI platform. This helps the tool in evaluating the necessary dose rate and the periodic dose values to improve site compliance. The AI tool also validates the calculated dose rate is within the suggested budget limit.

The overall performance evaluation was determined based on the feed rates and H_2S levels before and after the introduction of AI.

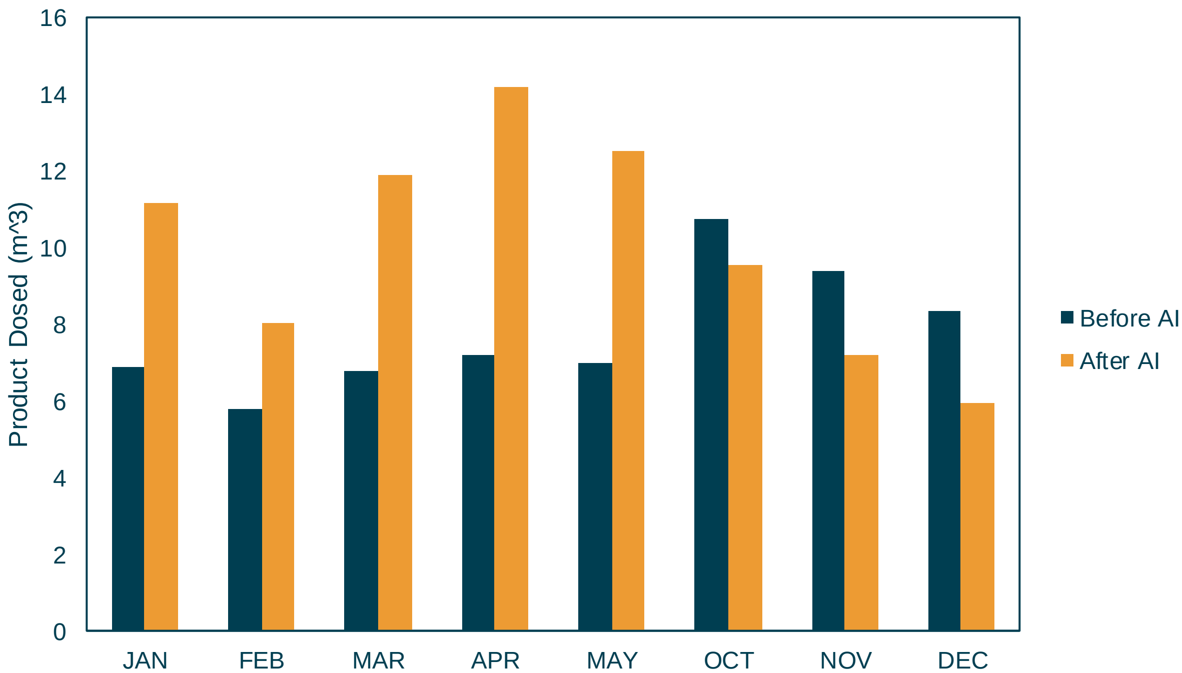

Figure 6: Case study 2 – Chemical Feed (volume) monthly comparison

Before AI (cubic meter)		After AI (cubic meter)	
January, 2021	6.86	January, 2022	11.15
February, 2021	5.81	February, 2022	8.05
March, 2021	6.79	March, 2022	11.88
April, 2021	7.21	April, 2022	14.18
May, 2021	6.96	May, 2022	12.51

October, 2020	10.77	October, 2021	9.54
November, 2020	9.38	November, 2021	7.18
December, 2020	8.34	December,2021	5.93

Table 5: Product Feed data comparison before and after using AI at a Southeast PS

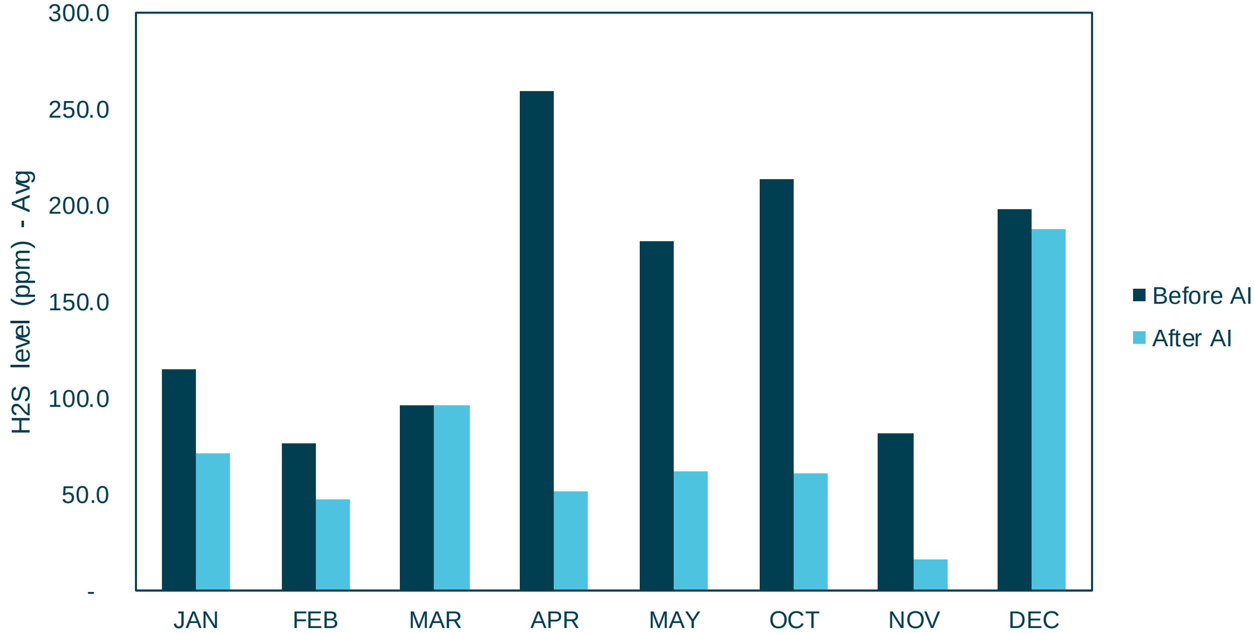

Figure 7: Case study 2 – H_2S Levels (ppm) monthly comparison

Before AI (ppm)		After AI (ppm)	
January, 2021	115	January, 2022	72
February, 2021	76	February, 2022	47
March, 2021	96	March, 2022	96
April, 2021	259	April, 2022	52
May, 2021	181	May, 2022	62
October, 2020	213	October, 2021	61
November, 2020	82	November, 2021	17
December, 2020	198	December,2021	188

Table 6: Product Feed data comparison before and after using AI at a Southeast PS

The pump station in the Southeast region was slightly complex to optimize manually due to the influence of a different stream coming from the north and the monitoring location being an ARV. Despite having these challenges, AI was able to show a reduction of H_2S concentrations by 51%. Especially during the beginning of summer (from April to May) with rising temperatures, the AI tool was able to bring the peaks down and maintain the average H_2S concentrations around 50 ppm. Before the introduction of AI, the average of peaks throughout the considered period were around 826 ppm. It was later reduced to 531 ppm which is almost a 35% reduction and is continuing to trend down. This control was achieved with a slightly higher chemical dose rate in order to meet the underdefined goals. The chemical dose rates were reduced during the winter months (of October, November, and December) by 20% by reducing the H_2S loadings by 46%.

DISCUSSION

With the help of AI, a measured odor control product was dosed in order to maintain the H_2S concentrations around the provided targets. The AI technology was able to reduce the H_2S concentrations by 20% and 51% in both the case studies. Optimal odor control without over or underfeeding of chemical was achieved by using AI. Historic H_2S concentrations were tracked and used to predict the demand for the upcoming weeks, significantly reducing the workload of the user to continuously optimize dose rates.

CONCLUSION

Artificial intelligence is one of the uprising soft computing and communication technologies widely used in various industries for process monitoring and optimization. AI tools are effective for optimal modelling and data forecasting. Municipal utilities, which are highly driven by environmental and social factors, and subject to immutable infrastructure and budget constraints, will benefit from continuous optimization using AI in their liquid phase odor control programs. With the help of AI, we are able to achieve better optimization with very little effort and time. By providing accurate upper and lower limits we will be able to operate with higher productivity and confidence. The presented case studies indicate that the AI was able to optimize odor control dose rates more effectively and consistently than optimizing manually in a very short period of time.

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