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Original Article

Process Control in Wastewater Treatment Under Overflow Events in Saudi Arabia

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Abstract - *Wastewater treatment systems are vital to preserving human health and environmental purity. However, during overflow events caused by extreme weather, infrastructure failure, or operational abnormalities, typical treatment systems may get overwhelmed, resulting in reduced efficiency and the discharge of untreated or partially treated effluent.*

Keywords - *Wastewater treatment, Overflow events, Effluent quality.*

1. Introduction

Chemical contamination in water is a big worry for society, governmental agencies, and the industrial world (Sonune and Ghate 2004; Crini 2005; Cox et al. 2007; Sharma 2015; Rathoure and Dhatwalia 2016). What is water pollution? Water pollution can be characterized in several ways. Water pollution happens when one or more compounds that negatively alter the water are dumped into it. These compounds can have negative consequences for humans, animals, their natural surroundings, and the environment. Water contamination is classified into numerous categories (Morin-Crini and Crini 2017). There are two basic sources: point and non-point. The first group includes pollutants from a single source, like industrial emissions into water, whereas the second category includes pollutants from many sources. Water pollution is caused by a variety of factors, including industrial waste, mining operations, sewage and wastewater, insecticides and chemical fertilizers, consumption of energy, hazardous waste, and urbanization. Water pollution is inevitable when used for any purpose, including domestic, agricultural, and industrial, which generates wastewater containing undesired pollutants that can be harmful. In this environment, a continuous effort is made to protect the water. (Khalaf 2016; Rathoure). Liquid industrial effluent is subject to tougher legislation, particularly in developed countries, which requires treatment before release into the environment. Directives in Europe have gotten progressively severe since the end of the 1970s, with 0% rejection sought by 2020. The Water Framework Directive (WFD) of 2000 currently governs European water policy, including criteria for the protection of surface water, subsurface water, and coastal water (Morin-Crini and Crini 2017). The WFD divided chemicals into two categories of priority substances. The “Black List” includes Dangerous Priority Substances (DPS) that are persistent, highly toxic, or cause bioaccumulation. The “Grey List” includes priority compounds that pose a significant concern to the environment. These compounds can be chosen based on specific substances, substance families, or the industrial sector (for example, agro-food, chemicals, and metal finishing). Europe is currently requesting that industries innovate to limit and/or eliminate the emission of DPS and PS chemicals into their wastewaters.

Furthermore, recycling wastewater is beginning to get serious attention from industry in the framework of sustainable development. (e.g., environmental protection, development of “environmentally friendly chemistry,” the use of renewable resources), improved water usage (wastewater recycling), and health problems (Kentish and Stevens 2001; Cox et al. 2007; Sharma and Sanghi 2012; Khalaf 2016; Rathoure and Dhatwalia 2016; Morin-Crini and Crini 2017). Effluent treatment has become a top priority in the industrial world.

Over the last 30 years, various physical, chemical, and biological technologies have been reported, including Processes used such as flotation, precipitation, oxidation, solvent extraction, evaporation, carbon adsorption, ion exchange, and membrane filtering, electrochemistry, biodegradation, and phytoremediation (Berefield et al. 1982). What is the best method? Each treatment has advantages and limits, including cost, efficiency, feasibility, and environmental impact, making it impossible to provide a precise response. In general, contaminants are eliminated through physical, chemical, and biological processes. Due to the complexity of industrial effluents, there is currently no one approach that can effectively treat them. In practice, a variety of technologies are frequently utilized to attain the most cost-effective target water quality. This chapter introduces the main contaminants/pollutants and types of effluents before presenting a generic wastewater treatment strategy and comparing the benefits and drawbacks of various treatments. In wastewater treatment facilities, operators and designers must manage a variety of unpredictable occurrences, including events involving increasing effluent volumes. From a process control standpoint, decisions should be made initially about the flow rates at which potential problems could arise. These are known as overflow events and can have a considerable, if not drastic, impact on the treatment process's performance (Imam and Elnakar, 2014).

Process controls play an important part in how the wastewater treatment plant manages process hazards and how emergency measures are carried out. A lack of trustworthy and effective process controls could lead to an unforeseen process incident that cannot be eliminated, controlled, or monitored. Process controls range from manual basic actions to computer-based controllers that are insulated from the fundamental action point and have extra composition feedback mechanisms. These systems must be designed to minimize the need to activate minor safety mechanisms. Process reliability, allowable margins, principles, and process control are fundamental safety measures that influence the level of overflow at the wastewater treatment plant (Nolan, 2014). In Saudi Arabia, the number and capacity of wastewater treatment plants are expanding, as is the reliance on those facilities. Furthermore, flow rates at these plants are changing as a result of rising population, increased supply, and environmental changes (Ouda, 2016). As a result, this study uses a combination of life cycle assessment and simulation analysis to investigate the effectiveness of process control measures used at the wastewater treatment plant at Al-Jouf in Saudi Arabia.

Overflowing also has major direct and indirect costs, such as rescue operations, infrastructural repairs, and potential environmental consequences. Untreated discharges affect water reuse plans, causing problems in the agricultural and industrial sectors, which are critical to the Kingdom's economic diversification. Communities near treatment plants or flood-prone locations confront considerable concerns. Untreated wastewater affects public health by causing waterborne infections, while odors, pollution, and property damage degrade living conditions and weaken community trust in infrastructure services. Vulnerable populations are significantly impacted. The January 2011 floods in Jeddah caused an estimated 6 billion Saudi riyals in damage, wreaking havoc on companies and infrastructure and undermining trust in public services. Arnold, T (2011).

2. Research Gap

According to Rice et al. (2012), underutilization and operational inefficiencies are the primary causes of failure in WasteWater Teatment Plants. WWTPs with outdated or insufficient treatment technologies may struggle to effectively treat wastewater (Karaolia, 2019). This can lead to poorer treatment efficiency, greater operational costs, and more frequent equipment malfunctions (Stamatelatou & Tsagarakis, 2015). WWTPs require educated and knowledgeable personnel to operate properly. Inadequate human training or resources might lead to reduced treatment efficiency, greater operational costs, and more frequent equipment breakdowns (Skoulikaris and Ganoulis, 2012). To be effective, WWTPs should continue to invest in infrastructure, equipment, and technology (Tlili et al., 2020). Limited financial resources may result in underinvestment in critical areas, reducing treatment efficiency and increasing the risk of equipment failure. WWTPs must be continuously monitored and assessed to ensure that treatment processes are effective and treatment objectives are met (Magro et al., 2020). Inadequate monitoring and assessment can lead to operational inefficiencies and reduced treatment efficiency (Petcharat et al., 2020).

2.1. Problem Statement

Overflow occurrences in wastewater treatment plants are a significant source of pollution in receiving water basins, and their effects on aquatic ecosystems are well understood. Many studies have stressed the importance of overflows as a pathway for various contaminants (Phillips et al., 2012; Viviano et al., 2017; Weyrauch et al., 2010). Overflow concerns are more important in Saudi Arabia, particularly in Skaka and Al-Jouf, due to the abundance of underground water and the increased likelihood of rainfalls caused by climate change. Those types of risks should be controlled and managed at the appropriate moment; so, process control is an urgent call that should be properly prepared to control the processes assigned to eliminate these risks.

2.2. Theoretical Framework

2.2.1. Upstream of Centralized Wastewater Treatment Facilities, Wetlands were Constructed to Treat Combined Sewer Overflow

Combined Sewers (CSs) are designed to carry residential and/or industrial wastewater to pipes alongside urban storm water runoff (Botturi et al., 2021). In recent years, these systems have been replaced with separate sewers, which transport household waste and stormwater through separate pipelines. Nonetheless, many CS instances can be found in several European countries, including Italy, Germany, France, Belgium, Greece, and Poland (Pistocchi et al., 2019). To achieve a reasonable level of pollutant removal, WWTPs should be able to receive a discharge of 4-6 times the average Dry Weather Flow (DWF), which comprises domestic sewage, industrial discharges, and groundwater seepage (Giakoumis and Voulvoulis, 2023). Even though this condition is frequently not met to ensure the optimal operation of WWTPs are normally designed to handle a maximum of 2-3 times the DWF. However, during exceptionally powerful storm events, the sewage network's discharge could go above its conveyance capability. When a Combined Sewer Overflow

(CSO) happens, surplus wastewater is released directly into neighboring streams, rivers, or other bodies of water via a sequence of overflow structures that govern CS systems (Rizzo et al., 2020; Yu et al., 2022). Because the water spilt by CSOs is untreated, environmental contamination is the most important issue, aside from hydraulic shock. Although discharge episodes are brief and occur only a few hundred times per year, the release of huge volumes of untreated water during CSOs causes high levels of conventional pollutants, micro pollutants, pathogens, and heavy metals to enter recipient water bodies.

On a European scale, CSO-related pollution is not directly regulated, despite the most recent evaluation of the EU Urban Waste Water Treatment Directive (UWWTD) (271/91/EC) emphasizing the importance of controlling CSO pollution, which is recognized as being responsible for the discharge of BOD, N, P, and coliform loads greater than 5 million Population Equivalents (PE) (Botturi et al., 2021; Crocetti et al., 2021). According to the Water Framework Directive (2006/7/EC), it is now one of the most significant untreated sources of contamination. The most concerning consequences of CSOs include a significant contribution to the inability of European water bodies to achieve excellent status (European Commission, 2019), as well as the loss of bathing water status established by the applicable EU Directive (2006/7/EC) (Al Aukidy and Verlicchi, 2017). Furthermore, the criticality of CSOs could deteriorate in the future due to increased soil sealing caused by rising urbanization (Fu et al., 2019) and the predicted increase in the frequency of severe storm events. CSOs have both environmental and economic/social impacts. Sewage discharges during overflows also severely limit the recreational usage of urban inland and coastal waters, which is intolerable to inhabitants.

As combined sewer overflows have become a major problem for city and watershed management, a number of solutions have been suggested: (i) urban greening to limit runoff volumes; (ii) increasing the storage capacity of buffer tanks in sewers to reduce overflows; (iii) lowering pollutant load through specific treatment processes before the CSO is discharged into receiving water bodies; and (iiii) real-time monitoring of the sewer network (Garofalo et al., 2017; Pistocchi et al., 2019). Although there is no single successful remedy, a cost-benefit analysis should be conducted by examining each instance (Casal-Campos et al., 2015).

Nature-Based Solutions (NBS) are one of the most promising ways for reducing CSO environmental pressures (Rizzo et al., 2020; Petrie, 2021). Indeed, NBS systems have various advantages over traditional techniques (first flush tanks), including continuous CSO treatment (including second flushes) and extra functions like flood prevention, biodiversity enhancement, and recreational activities (Liquete et al., 2016). Among the several 'green' alternatives, built wetlands (CWs) have demonstrated powerful and well-documented removal performance for various classes of contaminants. CWs and Wetlands are classified into two types based on the kind of flow: surface flow wetlands (also known as Free Water Surface systems or FWS) and subsurface flow wetlands. In the first case, the water is frequently shallow, and macrophytes emerge or float freely, with treatment capacity comparable to natural wetlands like lakes or ponds. In the second case, however, a porous medium (such as sand or gravel) and a well-developed macrophyte root zone exist, allowing for greater interaction between the roots, biofilms, and the water being treated.

2.3. Wastewater Treatment

2.3.1. General Plan for Wastewater Treatment

When water is polluted and needs to be decontaminated, use the most effective purification method to meet legal standards. Purification typically involves five processes, as shown in Figure 1. The treatment process includes physical and mechanical pre-treatment, physicochemical and chemical primary treatment, chemical and biological secondary purification, physical and chemical tertiary treatment, and sludge disposal (supervised tipping, recycling, or incineration). Depending on the situation, Anjaneyulu et al. (2005) classify the first two steps as pre-treatment or preparatory. Pre-treatment removes floating solid particles and suspended contaminants from the effluent. Pre-treatment, whether mechanical or physical, is necessary before secondary treatment to prevent particle pollution (e.g., SS, colloids, lipids) from hindering or damaging the cleaning equipment.

Primary chemical treatments include oxidation for cyanide destruction and Cr (VI) reduction, pH correction, and re-reduction of a high organic load, which may also be necessary. Paper mill effluent has high concentrations of SS, including fibers, fillers, and particles (Anjaneyulu et al. 2005; Sharma 2015). Textile mill effluents vary in pH, but are typically alkaline and heavy in organic content. Pre-treating these effluents is crucial before contemplating further treatment options. However, these therapies are often insufficient to meet the legislation's standards. To remove chemical contamination before it may be released or reused, pre-treated effluent must go through secondary purification using appropriate biological, physical, or chemical procedures.

A final or tertiary treatment (step 4 in Figure 1) may be necessary to remove residual contaminants or molecules created during secondary purification, such as salts from organic matter mineralization. However, the use of tertiary treatment in Europe is restricted, but it may become required in the future if new restrictions are imposed. Activated Carbons (AC), ion-exchange, membrane filtration (ultrafiltration, reverse osmosis), advanced oxidation, and Constructed Wetlands (CW) are the most common types of tertiary treatments used at industrial sites today. Most of the

CW in Europe is used to treat sewage from homes and cities. Because CW configurations can be used in many different ways, they are good for treating industrial waste, such as wastewater from tanneries and pulp and paper post-treatment effluents.

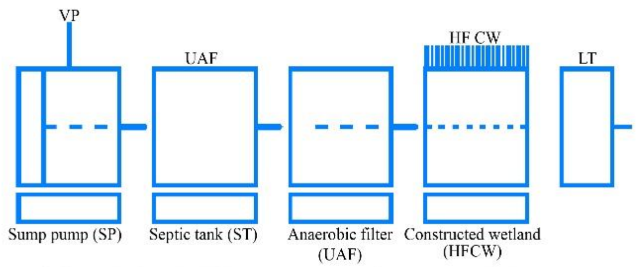

Fig. 1 Important parts of the wastewater treatment process [9]

3. Literature Review

This section summarizes key studies on the investigated topic. Feudo et al. conducted an assessment of energy at the water pump plant. Using multivariate analysis, the water pump plant assessed energy consumption in the water treatment system using permitted metrics. They projected a 55% rise in world water use by 2050. The decrease in groundwater supplies is mitigated by high energy prices, which account for 5% to 30% of overall operating expenses for water and wastewater treatment. In poor nations like India and Bangladesh, the ratio might reach 40% of overall operating expenditures. To address this challenge, high-quality service standards must be enforced. Castellet and Molinos-Senante evaluated the efficiency of wastewater treatment plants by analyzing technical, economic, and environmental data. They emphasized the importance of assessing the efficacy of water plants, particularly for wastewater.

Treatment plants, distribution networks, sensors, and actuators are among the many interconnected components that make up urban wastewater management. These components comprise a complicated multi-agent system in which each agent makes independent decisions to achieve its goals (Zulkifli et al., 2018). Deep learning applications require the correct modeling of interactions, dependencies, and feedback loops. Designing deep learning models that can successfully capture the dynamics of multi-agent systems while also facilitating collaboration among multiple agents presents challenges. The intricacy of these systems may provide obstacles such as training data shortages, scalability issues, and model output interpretability (Shen, 2018).

A successful application requires balancing individual agent goals with broader system objectives and devising algorithms for decentralized decision-making. Elaborating on these problems highlights the complexities of incorporating deep learning techniques for urban wastewater management. While deep learning has the potential to transform this industry, addressing these challenges is crucial to developing effective, ethical, and long-term solutions. The growing industrial wastewater problem has major implications for the environment and human health. Untreated wastewater can contaminate drinking water, harm aquatic life, and endanger public health (Ortúzar et al., 2022). Industrial wastewater management is vital to the environment, public health, and business operations (Rahman et al., 2023). A variety of variables contribute to the demand for good industrial wastewater management. Many regions have legislation requiring enterprises to manage wastewater appropriately and sustainably. Compliance with these standards is necessary to prevent penalties, legal action, and reputational damage. (Zan et al. 2022). Industrial wastewater must be properly managed to conserve water resources, prevent soil and groundwater contamination, and preserve biodiversity (Xi et al., 2022). Untreated industrial effluent may include hazardous contaminants that endanger human health if they infiltrate the food chain or water supply (Al-Tohamy et al., 2022). Industrial wastewater management is crucial for ensuring business sustainability and meeting the expectations of stakeholders and customers who value environmental responsibility.

Effective industrial wastewater management encompasses a wide range of activities, including wastewater treatment, reuse, and recycling, as well as water resource efficiency and pollution control. According to Atangana et al. (2021), industries clean and manage wastewater utilizing a wide range of existing techniques and practices. This involves the use of microorganisms to break down and remove pollutants from wastewater. The most common biological treatment methods are activated sludge, trickling filters, and anaerobic digestion (Verstraete et al., 2022). This includes the use of chemicals such as coagulants, flocculants, and oxidants to remove pollutants from wastewater. Precipitation, oxidation, and adsorption are three chemical treatment strategies (Zou et al., 2021). Pollutants are removed from wastewater by physical processes such as sedimentation, filtration, and membrane separation (Dwivedi et al., 2022).

This comprises the removal of specific pollutants from wastewater, which are removed utilizing current technologies such as reverse osmosis, ultrafiltration, and ion exchange (Burge et al., 2020). De Sousa et al. used a Life Cycle Assessment (LCA) to compare the environmental effectiveness of three CSO-reduction methods. The first strategy used decentralized infrastructure green technologies, whereas the second and third “grey” strategies addressed and contained overflows at the pipe end. Estimated greenhouse gas emissions (t CO_2-eq) from maintenance, operation, and construction phases, including energy consumption at the wastewater treatment plant, carbon sequestration, and vegetation shading over 50 years. The analysis covered the whole drainage area for the CSO discharge locations that were related to the WWTP. The analysis utilized a combination of

Economic Input-Output (EIO) and process LCA methodologies. In terms of environmental indicators, the first technique outperformed the other two alternatives. The green strategy emitted 19,000 t CO2-eq over 50 years, while other strategies released 85,000 t CO2-eq (detention) and 400,000 t CO2-eq (treatment and detention). The findings were significantly influenced by the associated emissions with the maintenance and operation activities required for the second and third strategies, in addition to the sequestered carbon and provided shading by vegetation in the first strategy, and suggested that watershed managers who want to reduce CSOs and carbon footprints could choose the green approach (De Sousa, Montalto, & Spatari, 2012).

Seggelke et al. studied a case study for Real-Time Control (RTC) integration in which the sewage system's fuzzy-based RTC approach and intake to the wastewater treatment facility were controlled simultaneously. Controlling the system attempts to reduce overflows. Online readings indicate a change in operation mode for the two pumping stations. The proposed approach allows for safe activation of free storage volume in the absence of positive efforts. To manage risk events in the treatment facility, the inflow is automatically lowered to a predetermined value when excessive inflows coincide with unfavorable events on the secondary clarifiers during rainstorm events. The RTC system has been functioning for approximately a year (Seggelke, Löwe, Beeneken, and Fuchs, 201). Mauricio-Iglesias et al. developed a generic approach to self-optimizing controller design. This controller is designed to keep the system close to optimal performance by selecting ideal regulated variables. The ideal performance definition was carried out using two optimization stages (deterministic and stochastic) to account for overflow during the rain event and projected overflow in future rain events. The methodology was successfully used to build the optimal control plan.

Liao et al. designed and simulated three overflow control scenarios. The findings of this investigation supported the hypothesis that LID measures its promising capabilities for minimizing overflow. However, the green scenarios, which were entirely made up of LID interventions, did not do as well in terms of overflow reduction as the gray-green scenarios. The cost-effectiveness of each scenario type was categorized into three categories: green scenario, gray-green scenario, and gray scenario. Because the storage tank was erected in the catchment example, the entire green scenario application was unreachable.

According to a thorough comparison and study, the gray-green scenario, which included a combination of rain barrels, bio-retention, and a storage tank, was the most practical. Schroeder et al. (2011) suggested an approach that relied on rainfall data to assess the efficiency of sewer overflow control systems. The results demonstrated the effectiveness of CSO control options, including enabling pipeline storage capabilities inside the structure. The catchment, where the measures are fully carried out, exhibited less than 40% of those CSO activity catchments since measures have yet to be fully realized (Schroeder et al., 2011). Urbanization, population increase, and modern consumer habits have led to greater residential flow into wastewater networks designed for fewer individuals, causing difficulties with Europe's aged infrastructure (Mahaut and Andrieu, 2019). Saudi Arabia has had some of the most rapid economic development in recent decades, with urbanization progressively increasing. As a result, the need for irrigation for all purposes has soared in an area with high temperatures and limited natural water resources. According to Qatrah, after the United States, Saudi Arabia has the world's third-highest per capita water usage.

Groundwater resources, water desalination, and minimal usage of treated effluent were used to close the water supply deficit. Thus, the presence of a wastewater treatment facility is critical in bridging the difference between water demand and supply. Treated wastewater is considered a significant component of Saudi Arabia's water resources, acting as the principal source of non-potable water for agricultural, industrial, and commercial applications (Weyrauch, 2010). By 2025, the Ministry of Water and Electricity intends to provide comprehensive sewage collection and treated wastewater services to every city with a population of more than 5,000 people. There are 33 wastewater treatment plants with a total capacity of 748 million cubic meters per year, with 15 more under construction. Recycling water has become increasingly popular in Saudi Arabia, both in the city and in the countryside. The wastewater that has been treated is primarily used for landscaping and irrigation, as well as industrial applications such as refining. Riyadh, Saudi Arabia's capital city, pumps 50 million cubic meters of water per year over 40 to 60 kilometers of altitude for the irrigation of 15,000 hectares of farmland (Phillips, P., 2012). The wastewater treatment method comprises mostly a sump pump, a tank for sewage, a biological filter, and a constructed wetland. The MP pump (SP) separates coarse materials from wastewater before pumping it to a two-chamber septic tank. The wastewater is gravity-fed through an Upflow Anaerobic Filter (UAF) and a Horizontal-Flow Constructed Wetland (HFCW).

Finally, the Level Tank (LT) maintains the water level in the constructed wetland. Wetlands can enhance the quality of wastewater by purifying it before it is released into open water. The most commonly used mathematical model for full-scale wastewater treatment plants is the Activated Sludge Model No. 1 (ASM1). The ASM1 model describes the biological removal of nitrogen and organic molecules and is statistically validated for optimal performance. The upgraded ASM model provides a more advanced mechanical explanation of biological processes. The activated sludge model represents one of the most important wastewater treatment methods, with over 90% of municipal wastewater treatment plants employing it.

Construction of Wetlands for Wastewater Treatment in Saudi Arabia Al-Nasr et al. (2023) investigated the feasibility of employing artificial wetlands as long-term wastewater treatment solutions in the Kingdom. According to the study, these devices offer low-cost, ecologically beneficial alternatives, particularly in flood-prone areas.

Evaluating the Performance of Oxidized Trench Systems in Saudi Arabia, Rafat (2023) conducted a comprehensive study to evaluate the performance of oxidized trench systems used in municipal wastewater treatment in the Kingdom of Saudi Arabia. The study included an analysis of data from 15 treatment plants distributed across different cities and demonstrated high compliance with regulatory standards, indicating the effectiveness of these systems in handling excess flows during floods.

4. Methodology

This study examines the efficacy of process control systems in Waste Water Treatment Plants (WWTPs) during overflow occurrences in Saudi Arabia using a mixed-methods approach that combines quantitative analysis, qualitative evaluation, and simulation modeling.

4.1. Design

Three stages of the approach are used: Phase 1 involves gathering data from WWTPs; Phase 2 involves analyzing overflow events and assessing system responses; and Phase 3 involves creating and simulating an optimized control framework.

4.2. Data Collection

Three typical WWTPs will be chosen from various Saudi Arabian locations (such as Riyadh, Jeddah, and Dammam) to account for climate, infrastructure, and overflow frequency variations. Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), and overflow records are examples of operational data.

- Logs from the control system: SCADA system records during periods of high input.
- Meteorological information: Saudi National Center for Meteorology rainfall duration and intensity.
- Interviews: Plant engineers and operators participated in semi-structured interviews.

4.3. Analysis

4.3.1. Analysis of Statistics

An examination of the relationship between the frequency of overflow and the intensity of rainfall .

- Sensor response time-series analysis before, during, and following overflow incidents.

4.3.2. Assessment of the Control System

- Evaluation of the effectiveness of manual override and SCADA during crucial occurrences. Delays in control and failure spots are identified.

4.4. Validation

At least one actual overflow event's worth of historical data will be used to validate the model. To evaluate the precision and dependability of the suggested control improvements, performance metrics from the simulation will be contrasted with real results.

4.5. Building Blocks for a Control System

Before delving into the numerous applications of mathematical models, it is useful to first examine the four components of a control system.

Sensors give real-time data on some of the output variables and disturbances that affect the process; appropriate control techniques aim to minimize deviations from the objectives; and actuators apply controller outputs to the plant.

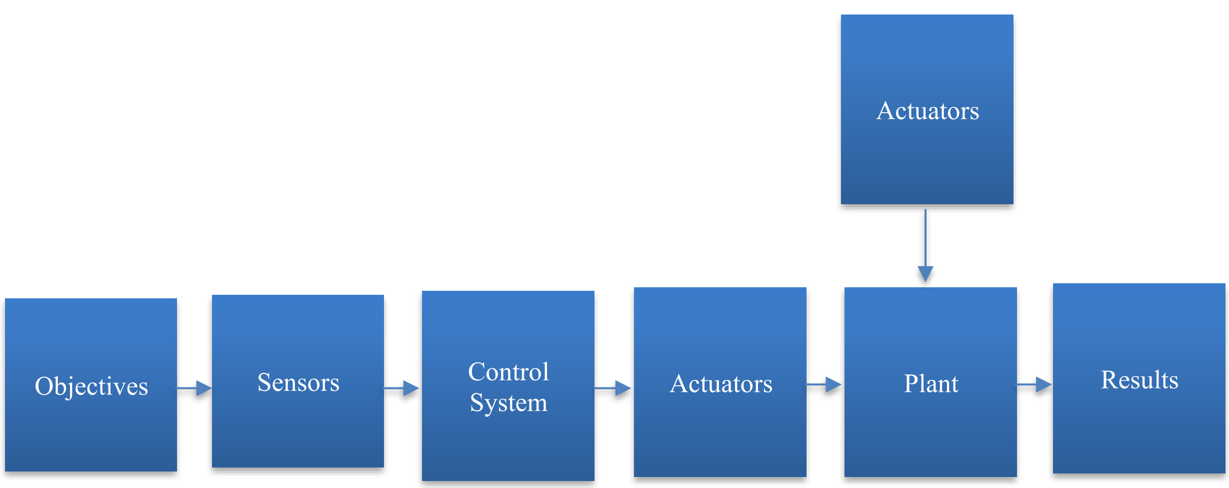

Fig. 2 Building blocks of a control system

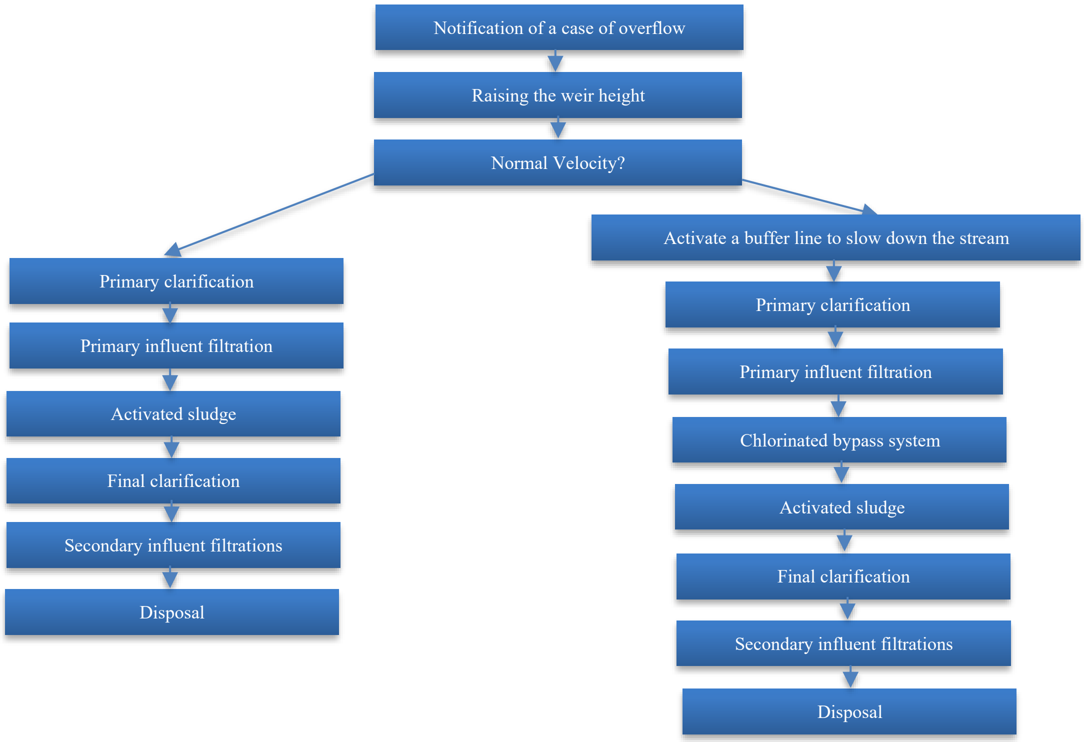

Fig. 3 Flow chart

5. Control System Structures

5.1. Conventional Feedback Control

Despite the reality that the method is MIMO, the varied timestamps of a wastewater treatment plant (ranging from minutes for DO dynamics to days for sediment composition) allow for the separation of several operations into distinct SISO controllers. On/off and PID control methods are essential when designing a SISO controller.

Numerous architects are familiar with the features and design ideas of these controllers due to their use in industrial contexts. The control procedure u(t) of a PID-control mechanism is computed using the following method, which takes into consideration the temporal development of the difference between intended and observed behavior:

$$u(t) = K_p\left[\in(t) + \frac{1}{\tau_i}\int_0^t \in(t)dt + \tau_d \frac{d_{\in(t)}}{dt}\right]$$

Each proportional, integral, and derivative action is assigned a weighted average coefficient Kp. Significant disruptions. It may be essential to obtain the necessary data. Potentially jeopardizing the entire process. A dependable process model can be used to predict plant behavior under a variety of disturbances while also tweaking the control system. This is the first time mathematical models have been utilized to help tune control systems.

5.2. Optimal Feedback Control

Methods have been devised to construct an optimal control system to construct a controller that maximizes the weighted average of an objective function J, which generally consists of tracking error () and the required effort (u).

$$J = \int_0^t \in(t)^2 + u(t)^2 dt$$

If a linear model adequately describes the process behavior, the traditional Linear Quadratic (LQ) regulator theory can be used to design an optimal feedback controller. Nonlinear models are the only logical approach to depict the dynamics of the process, making the problem substantially more difficult to solve.

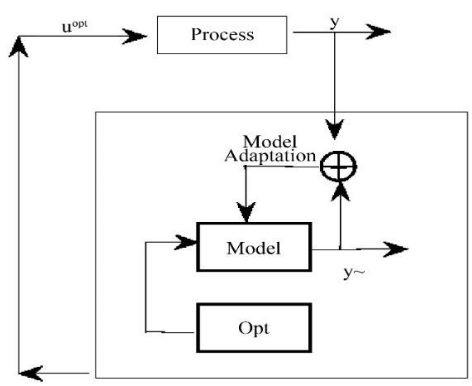

Fig. 4 Principle of MBPC

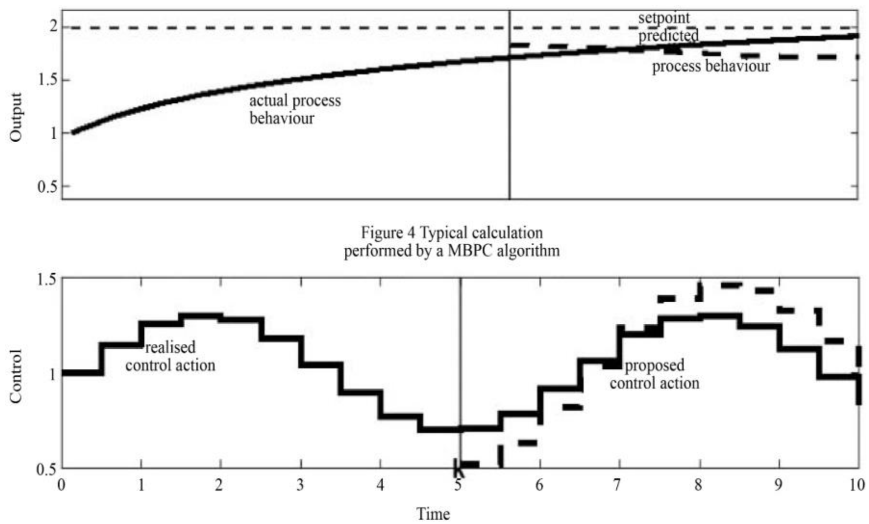

Fig. 5 shows a typical computation made by an MBPC algorithm

Numerical methods of search are used to identify an optimal sequence for the process model u Opt (t). Only the first step in the sequence is performed on the procedure, after which the optimization exercise is repeated to mitigate the effects of model incompatibility. Model updates can be used to reduce the gap between model predictions and real process behavior.

5.3. MIMO Control

The MIMO nature of the procedure, however, may contribute to efficiency advantages when controller design is taken into account. A great example is the capacity to regulate effluent nitrate with a nitrification laboratory with two inputs: carbon addition and oxygen supply. In addition, a full-scale WWTP was used to illustrate the cost-benefit ratio. A study conducted by Lech et al. (1978ab) found that interactions between control circuits in a wastewater treatment system could cause process destabilization. MIMO controller design aims to avoid any loop-to-loop interactions (Stephanopoulos, 1984).

5.4. Control of Nonlinear Processes

This controller sort is known as linearizing control because it begins with a nonlinear model and then uses it to produce a nonlinear controller that ensures linear closed-loop performance. The approach is as follows. In a nonlinear process model, suppose there is only one (linear) input and all states are measured or estimated.

$$\frac{dx}{dt} = f(x, t, \theta) + b.u$$

6. Results

Figure 6 shows a schematic illustration of our hypothetical plant, composed of two flowing water tanks. Tank 1 receives hot and cold water through automated controls. The purpose of our concept is to maintain the same temperature in tanks 1 and 2. The controller can retrieve both the source rules and the temperature readings that are accessible.

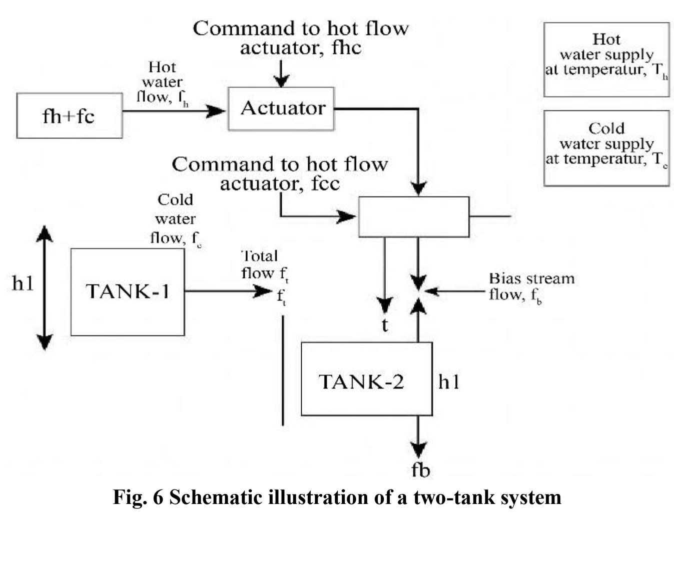

Fig. 6 Schematic illustration of a two-tank system

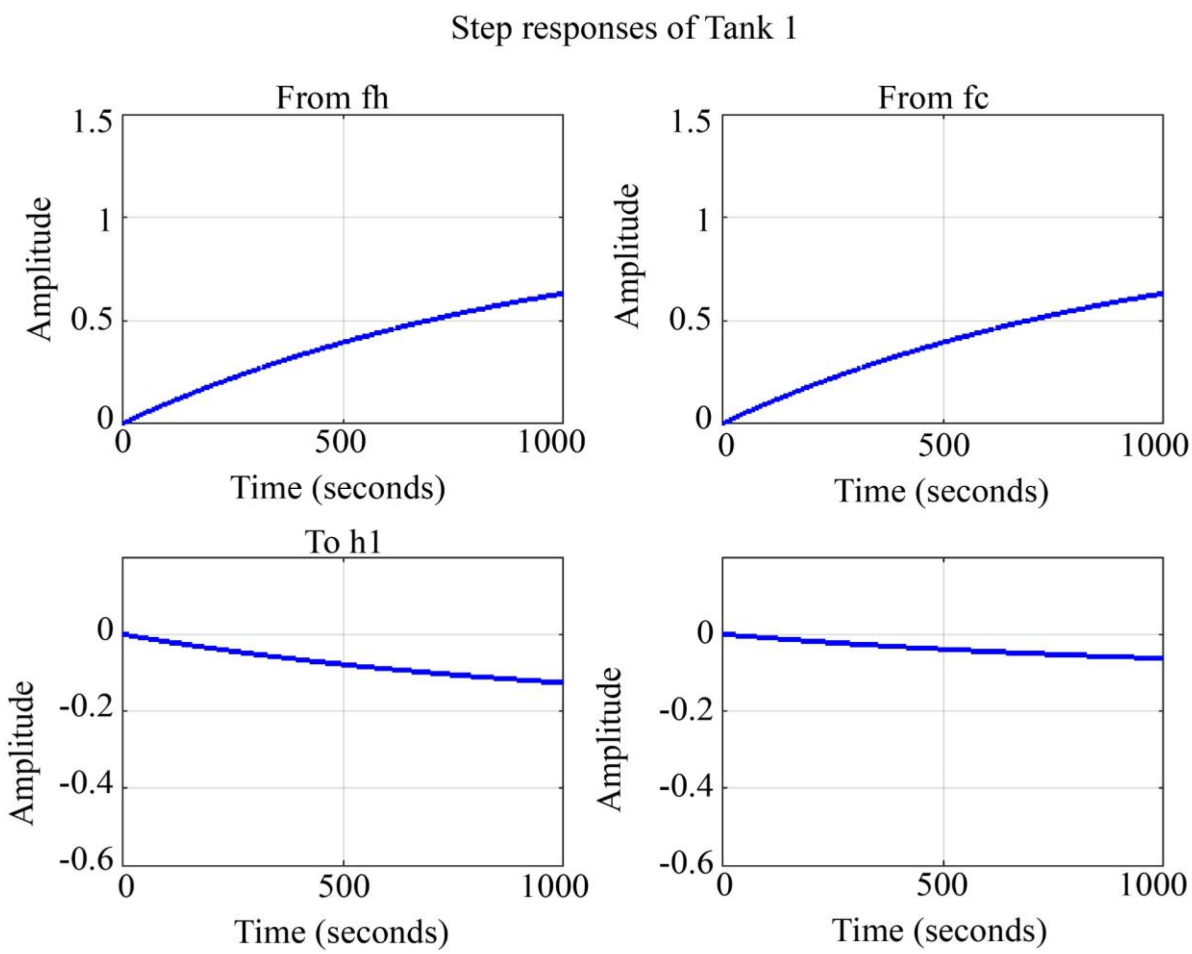

Fig. 7 Step responses of Tank 1

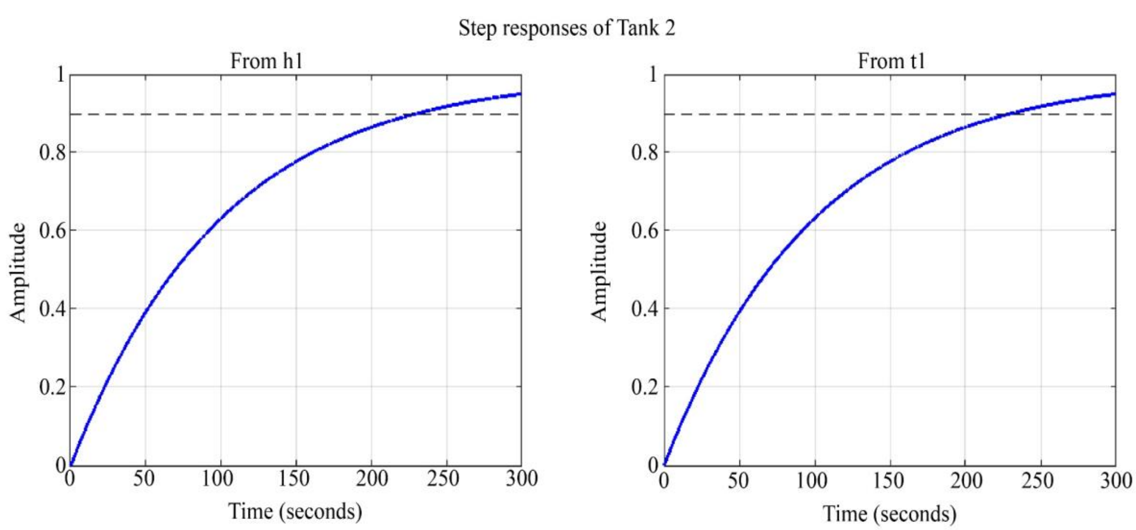

Fig. 8 Step responses of Tank 2

6.1. Actuator Models

The actuator system was initially configured with a single input (command signal) and two outputs (actuated signal and derivative). When creating the control regulations, we will use the derivative output to impose a rate limitation on the actuator.

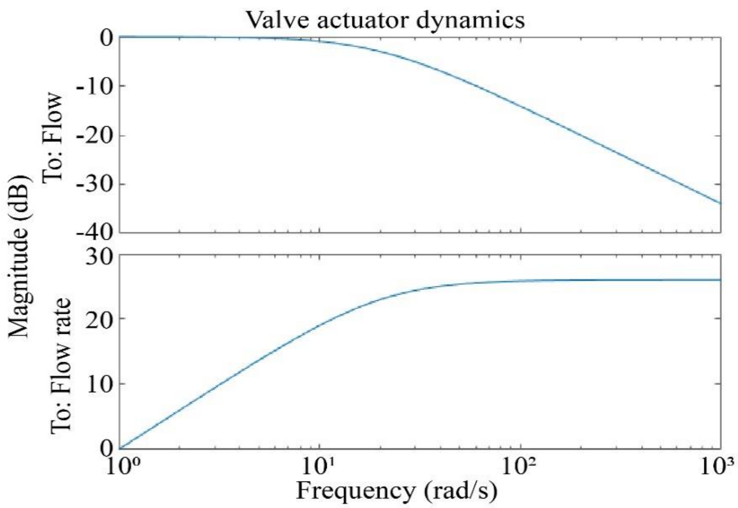

Fig. 9 Valve actuator dynamics

6.2. H-Infinity Controller Design

The controller k0 meets our criterion for frequency-domain tracking performance since it achieves the lowest closed-loop gain, which is around 0.9.

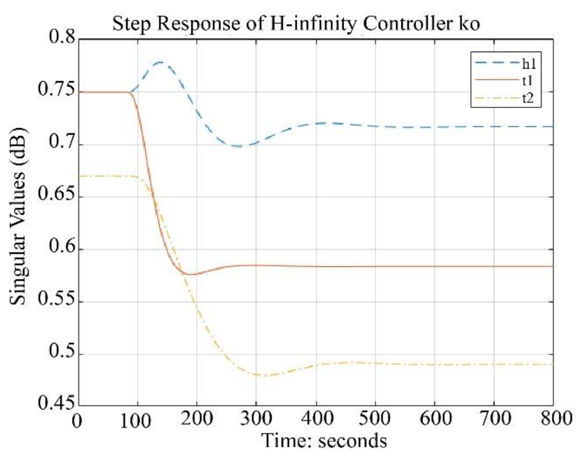

Fig. 10 Step response of H-infinity controller k0

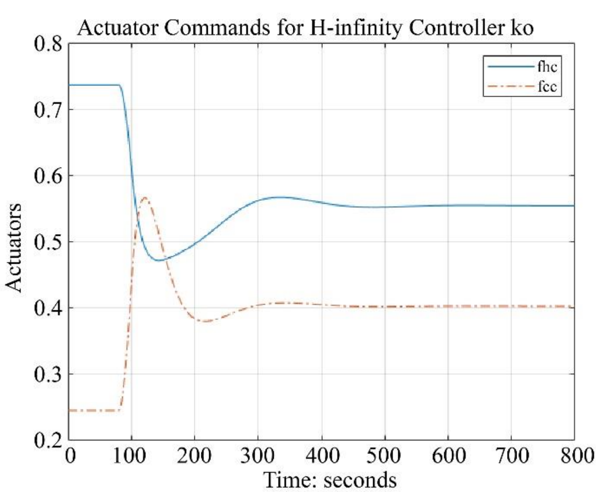

Fig. 11 Actuator commands for H-infinity controller k0

6.3. The Reliability of the H-Infinity Regulator

We can compare the worst-case performance across the model uncertainty set to the nominal closed-loop performance gamma0. (For more information, see “Uncertainty on Model Dynamics”).

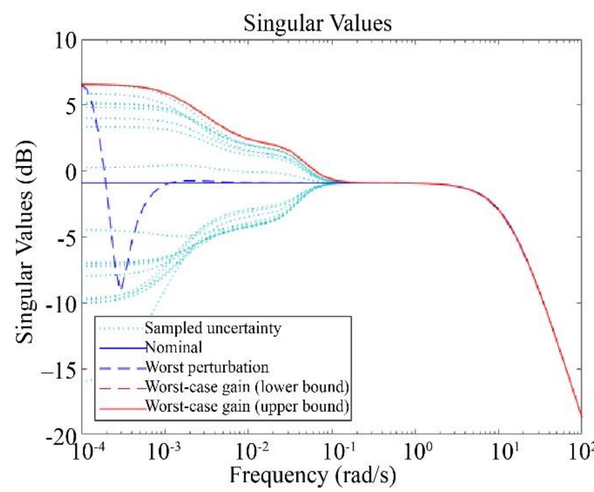

Fig. 12 Performance analysis for controller k0

7. Recommendations

This study is on process control in sewage treatment plants during flooding in Saudi Arabia. Proposes the following recommendations: Long-term control requires careful management of wastewater dumps and treatment plants to maintain lake levels within wetlands projects. To prevent subsurface pollution from the lake reaching Jeddah, all necessary measures should be implemented. It is crucial to implement remedial procedures to address the impact of such water on groundwater levels and quality. Integrated lake management is crucial for minimizing environmental impact and maximizing economic benefits. Storm water management infrastructure can be strengthened by creating storm water drainage networks to relieve strain on treatment systems during high rains (WorldBank,2020; Al-Mutairi&Al-Mashaan, 2019). Building emergency reserve barrels near treatment plants allows for storing excess flows and prevents the discharge of untreated water into the environment.

8. Conclusion

Effective process control is essential for ensuring the reliability and efficiency of wastewater treatment systems, especially during overflow events that challenge the operational capacity of treatment plants. These events, often triggered by extreme weather or system malfunctions, can compromise effluent quality and pose serious environmental risks. The integration of advanced control strategies-such as real-time monitoring, adaptive process control, and predictive modeling-has proven to be instrumental in enhancing system resilience.

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