Research Article

Sensitivity analysis of parameters affecting suspended growth in industrial wastewater treatment plants; with emphasis on economic performance criteria

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Abstract

Industrial wastewater treatment is of high priority due to the presence of an extraordinary concentration of dangerous pollutants. Similar to urban wastewater treatment plants, there are plenty of options while designing industrial ones which need various analyses and researches to choose correctly. One of the most efficient ways to solve this problem is to implement Economic and Sensitivity Analysis. This research has studied designing an industrial wastewater treatment plant utilizing three different biological treatment methods (including Sequential Batch Reactors (SBR), plug-flow activated sludge with a secondary clarifier, and step aeration activated sludge with a secondary clarifier). It also measures the sensitivity of performance cost parameters to factors affecting the suspended growth unit. The results of the economic analysis showed that using SBR has the highest construction cost of $ 70,200,000 and the highest total cost of 96,900,000. Sensitivity analysis showed that by adjusting design retention time and variance between heterotrophic microorganism decay rate and the reality, using activated carbon-based systems could significantly reduce total annual costs.

Introduction

A study of production policies in industrial countries around the world shows that strict and complex rules have been put in place to control environmental pollution to which paying attention and adhering, leads to the creation of a sustainable industry and economy. One of the most important tasks of managing industrial estates is to design, construct, and operating wastewater treatment plants (WWTPs) economically efficiently which is getting more understandable by looking at the lack of resources and the increase of industrial units [1-5]. Modeling, simulation, anticipation, and analysis of earlier data

are some of the operational solutions that can help to optimize the economic costs of WWTPs which could get complicated by unpredictable factors such as operational problems, especially in biological methods [6-8]. Every one of these complexities necessitates the sensitivity analysis of parameters affecting the economic performance of treatment plants to form a correct managerial perspective [9-11].

No one doubts the necessity of wastewater treatment due to its high amount of physical, chemical, and biological pollution which is only reachable through treatment plants. However, the high costs of these large-scale projects have led experts

to find the most appropriate process that, besides meeting quality parameters, optimally satisfies the technical, economic, and environmental goals [12-16]. On the other hand, each of these treatment plants and related processes has special characteristics and attitudes. Determining the strengths and weaknesses of each unit and process gives a proper outlook to managers and consultants through the design process [17-20]. One of the appropriate steps to create this attitude is to analyze the sensitivity of sub-indicators affecting the performance of each unit and its associated costs. The results of this analysis, along with comprehensive information on the current situation, lead to a smarter choice; An option that shows the least sensitivity in case of changes in delicate parameters [21-24].

In this regard, researches focusing on economic analysis with different attitudes have been conducted in Iran and all around the world. In a survey, Legos et al. (2013) analyzed the cost-performance of water treatment in two treatment plants of Paris. This study has integrated three types of Life Cycle Assessment methods including Recipe, StepWise, and Eco-Cost [25]. Kisło and Skoczko (2015) have economically evaluated the water treatment system of a large city in Poland between 2010 and 2012. This treatment plant has a capacity of 600 cubic meters per hour and eliminates parameters such as heavy metals and turbidity. It is worth mentioning that this treatment plant is fed from 19 wells and also carries out disinfection operations by using Ultra Violet (UV) disinfection system [26]. Niero, et al. (2014) while assessing the life cycle of 4 types of WWTPs, have implemented sensitivity and uncertainty analyses [29]. Also, Sin et al. (2011) utilized Global Sensitivity Analysis to evaluate operating models of WWTPs and to determine uncertainty factors [27]. Iturmendi, et al. (2012) during the investigation of biological wastewater treatment, have implemented Dynamic Global Sensitivity Analysis and estimated influential parameters in Waste Stabilization Ponds (WSP) [28].

The present study, by simulating a wastewater treatment plant in CapdetWorks 2.5 software, in the first step, examines the costs (construction and operation) of the treatment plant and compares them in case of using three suspended growth methods. The second step analyzes the sensitivity of the economic parameters constituting costs.

Materials and methods

Wastewater treatment means lowering the amount of existing organic, mineral, and biological agents in water to the allowable range which includes primary, secondary (biological treatment), and advanced treatment. The designation of these stages may be shorter or longer depending on the incoming wastewater and the selected treatment methods, but the existence of primary and secondary ones is definite [29]. There are different methods to perform each of these steps, which are associated and in combination with other steps during the design process [30]. Biological processes used for wastewater treatment are divided into two important groups of suspended growth and attached growth (biological layer). In suspended growth processes, microorganisms in charge of the treatment

process are kept suspended in a liquid by proper mixing [31]. Three suspended growth processes studied in this research are Sequential Batch Reactor (SBR), plug-flow activated sludge with a secondary clarifier, and step aeration activated sludge with secondary clarifier which is shown in Figures 1a-c respectively. The flow process diagram for plug-flow and step aeration-activated sludge is similar to the SBR diagram except for the suspended growth unit which is shown in Figure 1a. For further information, designing the treatment process and pollutant reduction system has been done based on Iran's 1994 standard of wastewater treatment plants effluent into the seasonal rivers.

Different industries have different sewage characteristics and levels of pollution; their entry into the environment without proper treatment causes severe damages. Therefore, this type of wastewater should be purified by appropriate treatment operations so that besides preventing environmental pollutions and the spread of various diseases, the effluent can be used for agriculture. The characteristics of industrial wastewater have major differences in comparison with municipal one, of which the most important is higher levels of COD (Chemical Oxygen Demand). On the other hand, there are noticeable amounts of specific pollutants such as heavy metals and pigments (based on existing industries) in this type of wastewater. Sewage reuse is one of the solutions used to manage water resources as well as preventing polluting. According to a large number of factories and industrial units in an industrial estate, the common method is to mix, assimilate and treat the wastewater of all workshops in one place.

Simulated characteristics of Influent, as presented in Table 1, are based on the influent of Toos and Kalat Industrial towns WWTPs; both are located in the suburbs of Mashhad. Other software requirements were considered following US design standards, which were largely in line with software defaults. The wastewater of Kalat industrial town, which is located at 14 km of Mashhad to Kalat road and comes from 400 factories and workshops, is treated with five separate treatment methods simultaneously in series, and the effluent is used for agricultural purposes. Also, the Toos industrial town of Mashhad, which is located 18 km from the city center, treats the wastewater produced by about 600 industrial units. Economic simulations and calculations of treatment plant operating costs were implemented using CapdetWorks 2.5 software. The sensitivity of the sub-indicators was also checked by the sensitivity analysis tool embedded in the mentioned software.

Results and discussion

Economic and sensitivity analysis was performed by establishing process diagrams for the three selected methods in Figure 1(a-c) and the treatment plant simulation using CapdetWorks 2.5 software and considering the input flow characteristics and temperature conditions according to Table 1. Based on economic analyses, using SBR has the highest construction cost of 70,200,000 dollars, and both activated sludge options have similar construction costs (Figure 2). Another economic criterion considered in this study is Present Value, which is one of the standard methods of evaluating
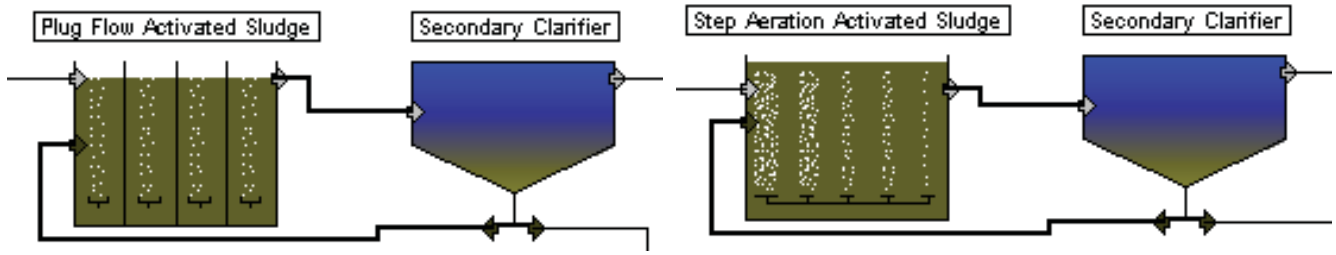
Figure 1: a. Flow process diagram of SBR (top); b. plug-flow activated sludge in suspend growth unit with secondary clarifier (bottom left); c. step aeration activated sludge in suspending growth unit with secondary clarifier (bottom right).

economic plans. In this method, the cash flow (income and expenses) is converted into the present value based on the time of occurrence (income or expense). Thus, the money value at the moment of spending and the amount of income is considered through the cash flow. Net Present Value is widely used in economic calculations, engineering economics, national budgets, micro and macroeconomics, trades, and industry. The highest present value belongs to the SBR option with 96,900,000 dollars (Figure 2).

Annual operating costs for proposed projects are divided into six categories including performance (manpower), maintenance, materials, chemicals, energy, and depreciation. Economic analysis of these parameters shows that a large part of annual operating costs is because of depreciation (equipment and structure), which costs $ 3,370,000 per year if the SBR is used, which is the highest among the annual depreciation costs of the three examined methods (Figure 3). The lowest annual cost has been allocated to required chemicals because the designed processes have little need for expensive chemicals. The plan related to using SBR in the suspended growth process has the highest depreciation, energy, performance, and maintenance cost among the 6 parameters of operating costs. Also, the plug-flow activated sludge system reached the highest cost of used materials annually. Furthermore, the highest cost of chemicals despite low amount usage is owed by step aeration activated sludge by 18,900 $ annually (Figure 3).

In the sensitivity analysis section, the dependence and sensitivity of 6 operating cost parameters are examined concerning the factors affecting the performance of the suspended growth unit. In the process sensitivity analysis, five factors of design retention time, maximum specific growth coefficient of heterotrophic microorganisms, heterotrophic microorganism degradation rate, maximum autotrophic microorganism specific growth rate, and autotrophic microorganism degradation rate were identified as factors affecting the suspended growth unit. Sensitivity analysis of 6 operating cost parameters using SBR showed that energy has the highest sensitivity (in this case, the most changes in the slope of the graph) to changes in design retention time (Figure 4). The highest sensitivity to the rate of heterotrophic microorganism decay is also caused by energy cost (Figure 5). Also, studies showed that the operating cost parameters were insensitive to other factors.

Table 1: Characteristics and temperature of influent (BOD: Biological Oxygen Demand; COD: Chemical oxygen demand).

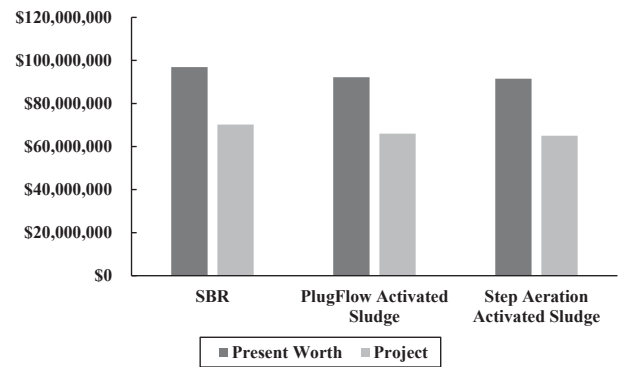| Parameter	Allocated amount	unit
Average flow	5000	m³/d
Minimum flow	3750	m³/d
Maximum flow	12000	m³/d
Suspended solids	450	ppm
% Volatile solids	75	%cc
BOD	1200	ppm
BOD Soluble	840	ppm
COD	4000	ppm
COD Soluble	2800	ppm
Average summer temperature	24	deg C
Average winter temperature	10	deg C

Figure 2: Comparison diagram of construction cost and present value for three proposed methods.

Sensitivity analysis of plug flow-activate carbon unit showed that operating cost parameters have the highest vulnerability to the changes in retention time and heterotroph microorganisms' decay rate. Among all, depreciation has the most sensitivity to the mentioned factors (Figures 6,7).

Similarly, for the last proposed WWTP scheme (step aeration-activated carbon) the same circumstances have happened. Depreciation showed the most sensitivity to retention time and heterotroph microorganisms' decay rate (Figures 8,9).

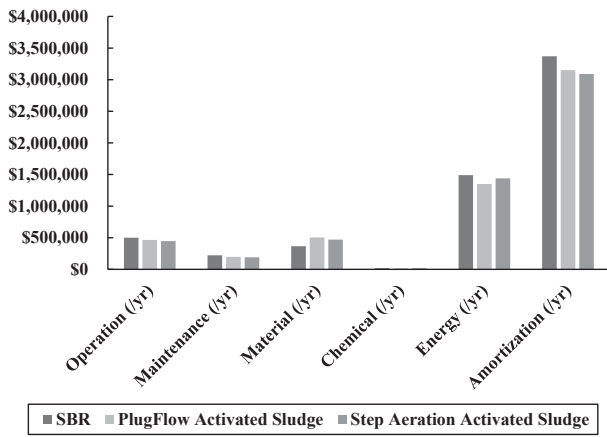by reviewing all these analyzes, it can be concluded that

Figure 3: Comparison diagram of annual performance cost parameters for proposed methods.

when using activated carbon–based systems, changes in design retention time and a contradiction of heterotrophic microorganism degradation rate to the reality, annual operating costs would undergo major changes. Most of these changes occur in energy costs and annual depreciation.

Conclusions

Wastewater treatment has seen different methods and systems due to its different characteristics. Therefore, environmental engineers see a wide variety of options in designing these infrastructures. Choosing the right option requires careful research and thorough familiarity with the processes in the first step. for the second step, they should make appropriate comparisons and analyses for the selected options to find a suitable estimation and strategy over the future
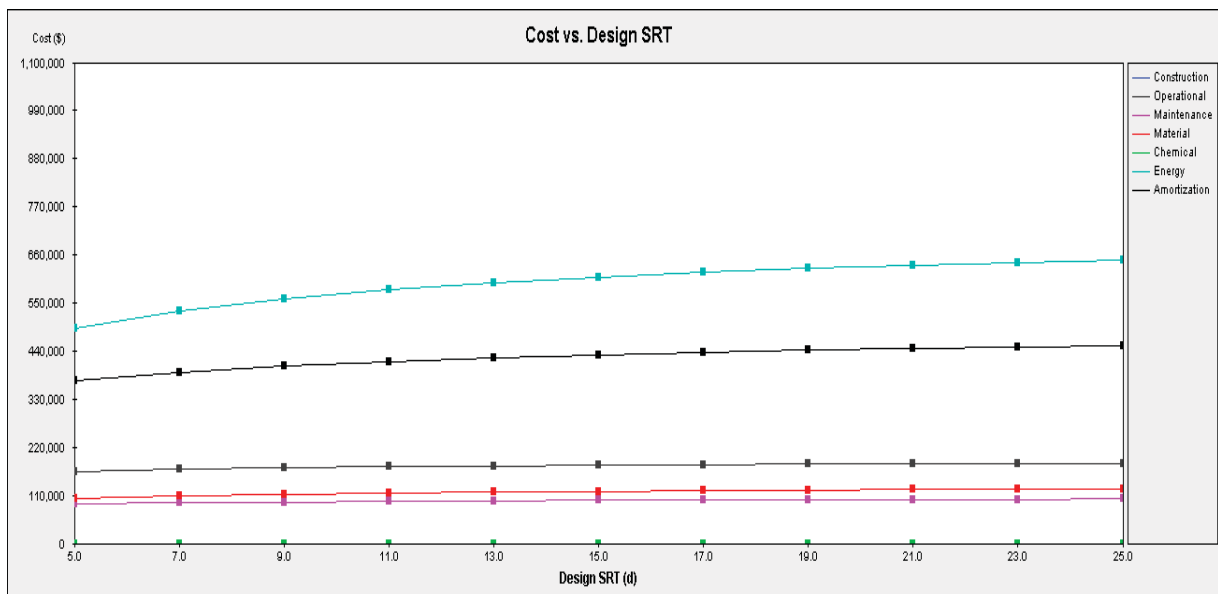
Figure 4: The sensitivity of operating cost parameters to retention time using SBR.
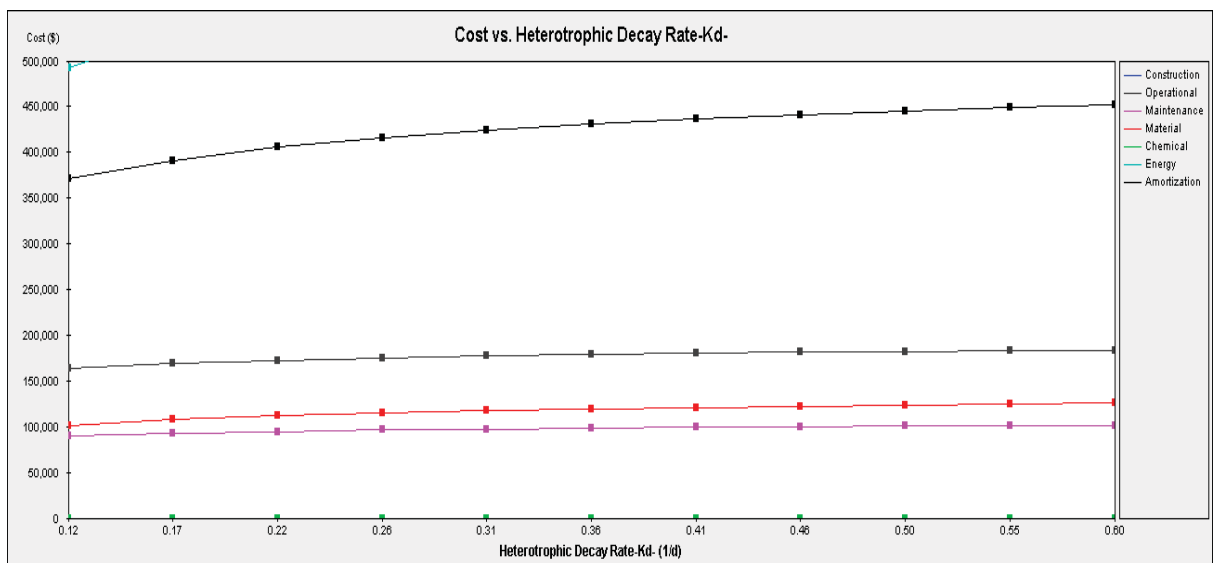
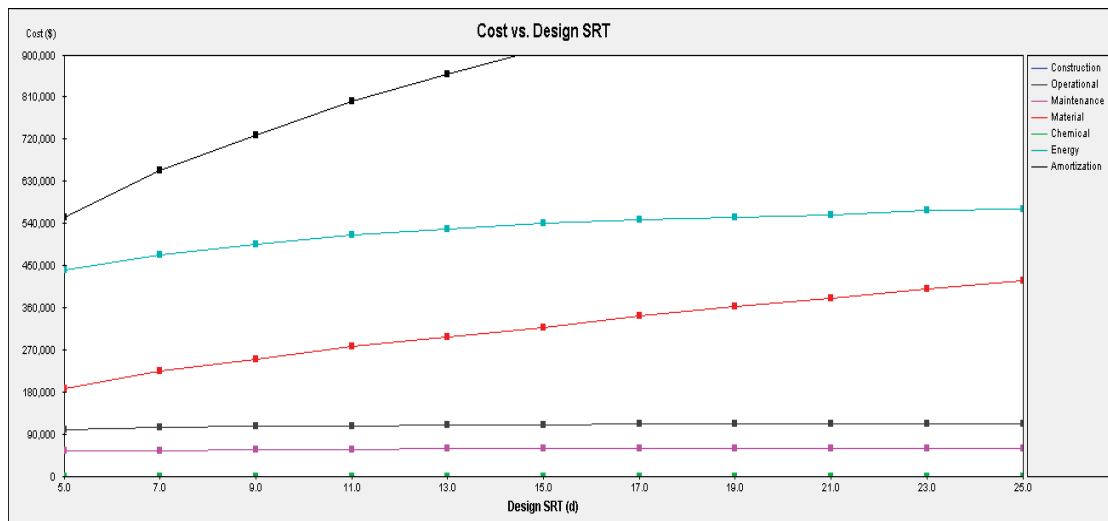**Figure 5:** The sensitivity of operating cost parameters to heterotrophic microorganisms decay rate using SBR.

Figure 6: The sensitivity of operating cost parameters to retention time using plug-flow activated sludge.
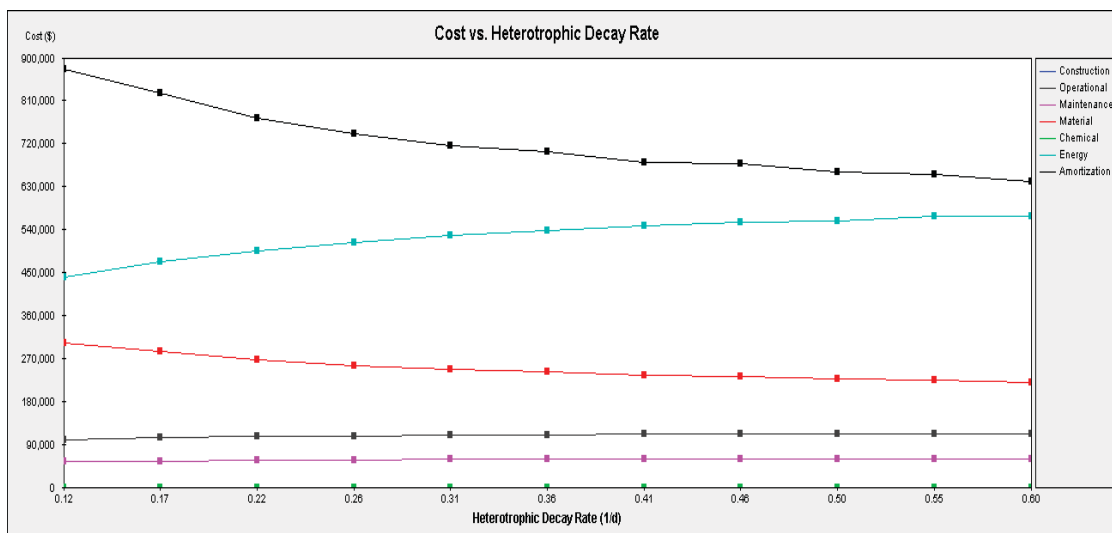

Figure 7: The sensitivity of operating cost parameters to heterotrophic microorganisms decay rate using plug-flow activated sludge.
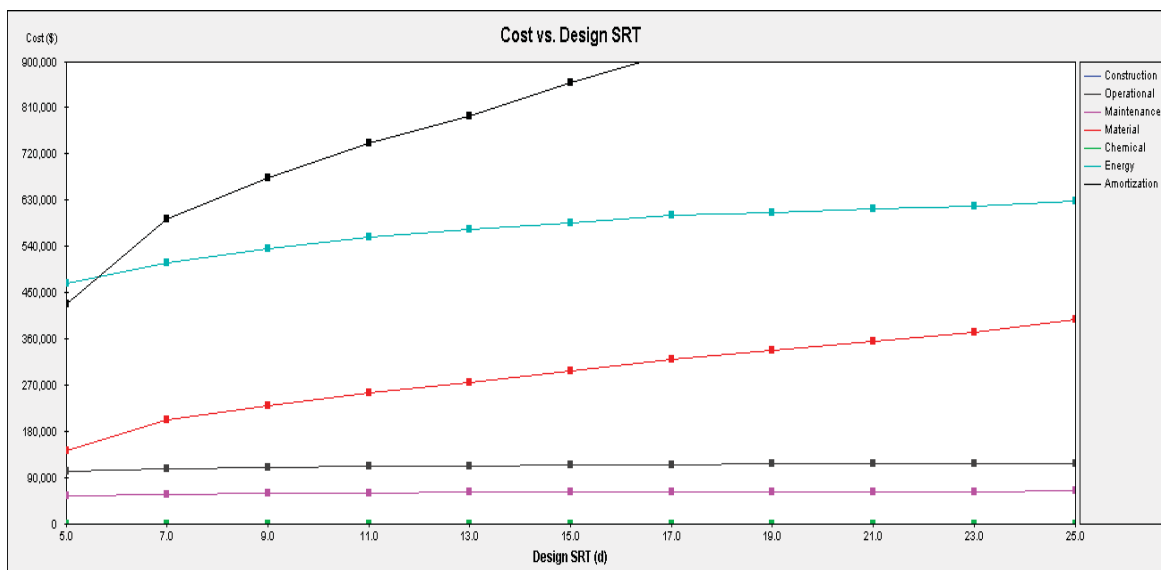

Figure 8: The sensitivity of operating cost parameters to retention time using step aeration-activated sludge.
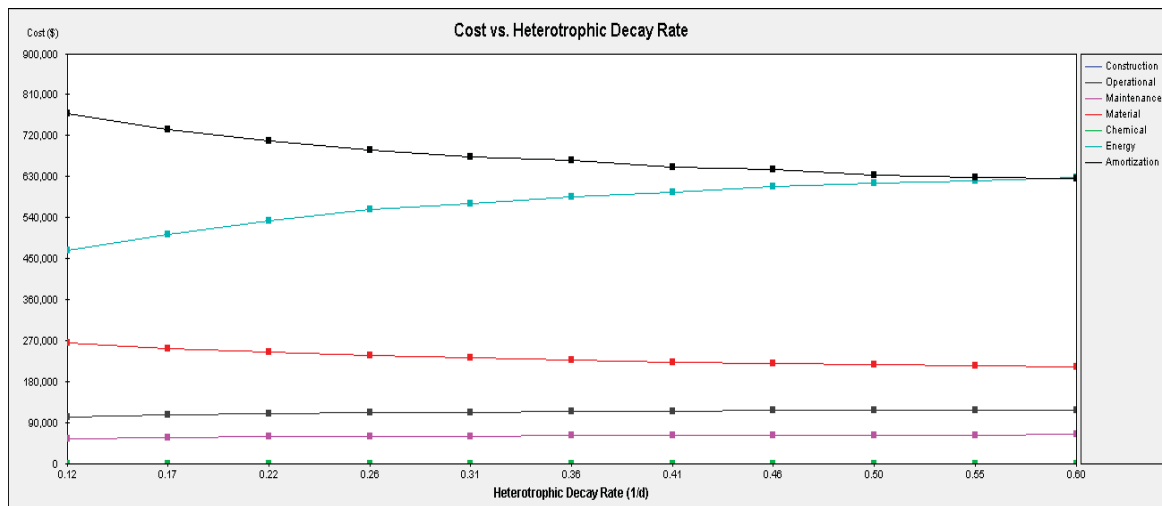
Figure 9: The sensitivity of operating cost parameters to heterotrophic microorganisms decay rate using step aeration activated sludge.

conditions. Economic and sensitivity analysis is one of the most efficient ways to mentioned strategies. The present study deals with economic and sensitivity analysis when using three different suspended growth methods. The annual operating costs for the proposed projects are divided into six categories including performance (manpower), maintenance, materials, chemicals, energy, and depreciation. By implementing sensitivity analyzes, it was also observed that by using activated carbon–based systems, changes in design retention time, and a contradiction of heterotrophic microorganism degradation rate to the reality, annual operating costs can be subject to major changes. Most of these changes happen in energy and annual depreciation costs.

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