A systematic approach for design of distributed wastewater treatment systems

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Abstract

Due to increasingly strict environmental regulations, the cost of handling various waste streams is gradually rising. Therefore, it is crucial to minimize unnecessary stream merging when designing distributed wastewater treatment systems, to reduce the overall treatment flow rate whenever possible. In a distributed wastewater treatment system, the wastewater streams are separated for treatment and only combined when necessary. This results in a significant reduction in the total treatment flow rate compared to traditional centralized treatment systems where all the streams are merged before treatment. Design of a distributed wastewater treatment system can be accomplished using pinch analysis and mathematical programming approaches. This paper suggests a straightforward approach for designing such networks, with the following steps in the design process: First, the primary function of each treatment unit is determined. Next, using the pinch method, the lowest treatment quantity is determined for the primary pollutant for each unit. Finally, a three-unit group is selected, with the pinch stream partially treated, the streams above the pinch completely treated, and the stream below the pinch completely bypassed. Two literature case studies demonstrate the viability and effectiveness of this strategy.

Keywords: Multiple pollutants; process synthesis; pinch analysis; water networks.

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1. INTRODUCTION

One important area of study in process synthesis is water network synthesis. The integration of a wastewater treatment system, which is the most important aspects of managing water resources, has drawn increasing attention due to rising wastewater discharge and stricter environmental regulations. The development of a water distribution system using water pinch method and mathematical optimization has been the focus of a significant number of research studies. Pinch analysis techniques and mathematical programming techniques can be used to integrate distributed wastewater treatment systems.

The pinch analysis approach was first presented [1] for the purpose of designing distributed wastewater treatment facilities. After using a graphical method to determine the objective minimum treatment flow rate, many principles based on pinch location were put forth to create a design that would achieve the goal. Thereafter, numerous initiatives were made to advance and enhance those strategies [2].

A targeting strategy was described for the entire water system, which includes wastewater treatment, regeneration, and reuse of water. Using graphical and algebraic approaches, the relationships between the various components of the system were examined [3]. Targeting the lowest treatment flow rate for systems with flow loss required an extension of the algebraic and graphical methods [4].

In order to address the issue of unnecessary stream mixing in distributed wastewater treatment systems, pinch stream identification was utilized as an analytical approach for systems dealing with a single contaminant [5]. The design of such systems often involves a process that reduces pollutant concentrations and increases treatment flow rates downstream, leading to undesired stream mixing. Therefore, minimizing unnecessary stream mixing is of utmost

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importance. To achieve this, accurate and statistically sound measurements of stream mixing are crucial. In this context, the concept of total treatment flowrate potential (TTFP) was introduced as an indicator to determine the optimal operating order of treatment processes [6]. A method for establishing heuristic rules to ascertain the treatment processes' operating order was proposed [7]. Since rule-based approaches lack quantitative indicators, they are not well suited for more complicated systems. Total mixing influence potential (TMIP), a numerical indicator, was introduced to try and minimize needless stream mixing. It was intended to identify the optimal sequence of treatment procedures for a wastewater treatment network containing several contaminants [8].

For sophisticated wastewater treatment system integration, mathematical programming techniques are the primary instruments. The design of multi-contaminant wastewater treatment networks (WTNs) was given a subsequent relaxed solution to a nonconvex nonlinear problem [9]. The optimization of wastewater treatment systems was demonstrated using a two-step approach. Completing the non-linear programming model is the second phase, while creating a linear programming model to generate initials is the first [10].

A straightforward yet reliable optimization approach was provided, by constructing a superstructure using pinch analysis and the wastewater degradation concept [11].

Based on genetic algorithms, an integrated water network (IWN) that combines water-using units (WUs) and treatment units (TUs) is optimized by aiming for maximum treated water reuse and, thus, minimal freshwater use. The related water network (WN) topologies are generated using various scenarios and examined, and broad conclusions are given for each example [12].

A staged wastewater treatment (WWT) strategy was put out, consisting of three to four consecutive phases: preliminary, primary, secondary, and tertiary. In the early stages of design, a comprehensive list of all potential networks of technologies and their connections was generated using mathematical modelling and optimization methods to build this methodical approach to designing wastewater treatment networks [13].

It was suggested that the formulation and resolution of an optimization problem using nonlinear programming and a mono-objective function that takes sustainability's environmental component into account would solve the sustainable wastewater treatment network design dilemma [14].

A decision support method was outlined for the planning of regional wastewater systems. To determine the best arrangements for the position, kind, and scale of the system's wastewater treatment facilities and infrastructure, optimization models are employed. It was demonstrated that the benefits of using optimization models may be extended to wastewater system regional planning [15].

For the entire water network with several contaminants, an iterative design process was suggested, in which wastewater treatment, regeneration, reuse/recycling, and reuse are all considered at the same time. Suggested design process is detailed step-by-step, and it is evident how important engineering is. Both the total annual cost and the freshwater use are competitive [16].

A combined conceptual and mathematical programming approach-based integrated methodology has been presented for the design of sustainable wastewater treatment plants (WWTPs). The objective was to provide and test a unique integrated strategy using multiobjective optimization to design sustainable WWTPs for a multipollutant scenario [17,18].

The focus should not be solely on the role of wastewater treatment plants in reducing freshwater consumption or removing pollutants before they are discharged into the environment. Instead, it is essential to consider the potential benefits that can be derived from the pollutants generated during the treatment process. Specifically, these pollutants can be repurposed as fertilizers in agriculture, thereby contributing to sustainability and enhancing the overall efficiency of the treatment plants [19].

In another study, the total wastewater treatment network system's economic and environmental viability was assessed by utilizing the life cycle assessment and life cycle assessment techniques. While the conventional wastewater treatment system (CWTS) was less ecologically friendly, the total wastewater treatment network system (TWTNS)was more fiscally favourable. From the perspective of eco-design, which aims to comprehensively enhance environmental, life cycle assessment (LCA) and life cycle costing (LCC) methods, it was shown that the TWTNS was not eco-efficient when the ratios of the total environmental effect scores and economic costs throughout the life cycle in the TWTNS to those in the CWTS were equally compared [20].

The present paper aims to design wastewater treatment networks with the lowest flow rate while simultaneously adhering to environmental standards and regulations regarding the concentration of pollutants discharged into the environment.

2. EXPERIMENTAL

2. 1. Problems statement

A collection of wastewater streams with known concentrations of multiple of contaminants is provided. Furthermore, a collection of treatment units is provided, each of which can eliminate one or more impurities. Designing a treatment system to efficiently remove a specific contaminant is necessary to adhere to environmental regulations.

2. 2. Design procedures

Step 1

The primary pollutant for each treatment unit should be identified as the one that has the highest removal ratio. This is because the principal pollutant in a treatment plant with multiple pollutants is the one that corresponds to the highest removal ratio.

Step 2

By using equation (1), calculate the lowest flow rate required to remove a specific contamination from a single stream. Then, add up all these flow rates to calculate the overall lowest flow rate necessary for a particular treatment plant to remove a certain contaminant from all streams.

$$F_{\mathrm{i,j}}^{\mathrm{k}} = F_{\mathrm{i}} \frac{C_{\mathrm{i,j}}^{\mathrm{in}} - C_{\mathrm{env,j}}^{\mathrm{lim}}}{C_{\mathrm{i,j}}^{\mathrm{in}} RR_{\mathrm{j}}} \tag{1}$$

Step 3

The total minimum flow rates for each treatment plant are established, and the smaller the total treatment flow rate value of a process, the higher its priority in implementation.

Step 4

Arrange the streams in each treatment plant from the highest to the lowest of pollutant *j* concentration. Then, use equation (2) to determine the lowest removal mass load needed as:

$$M_{\mathrm{j}}^{\mathrm{rem}} = \sum m_{\mathrm{i,j}} - C_{\mathrm{env,j}}^{\mathrm{lim}} \sum f_{\mathrm{i}} \tag{2}$$

where

$m_{\mathrm{i,j}}=F_{\mathrm{i}}C_{\mathrm{i,j}}$

Step 5

Determine the stream that flows through the pinch point, equation (3).

$$\sum_{\mathrm{i=1}}^{\mathrm{p-1}} m_{\mathrm{i,j}} \prec M_{\mathrm{TP_{i,j}}} \leq \sum_{\mathrm{i=1}}^{\mathrm{p}} m_{\mathrm{i,j}} \tag{3}$$

where:

$$M_{\mathrm{TP_{i,j}}} = \frac{M_{\mathrm{j}}^{\mathrm{rem}}}{RR_{\mathrm{j}}}$$

Step 6

Calculate the pinch stream S_{p} by the $\mathrm{TP_k}$ treatment flow rate and the pinch stream S_{p} by the $\mathrm{TP_k}$ bypass flow rate using equations (4) and (5), respectively.

$$F_{\mathrm{TP_{k,pt}}} = \frac{M_{\mathrm{TP_{k,j}}} - \sum_{\mathrm{i=1}}^{\mathrm{p}} m_{\mathrm{i,j}}}{C_{\mathrm{p,j}}} \tag{4}$$

$$F_{TP_{\mathrm{k,pb}}} = F_{\mathrm{p}} - F_{TP_{\mathrm{k,pt}}} \tag{5}$$

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Step 7

Determine the treatment unit's minimum treatment flow rate by equation (6):

$$F_{TP_k} = F_{TP_{k,pt}} + \sum_{i=1}^{p-1} F_i \tag{6}$$

where: ΣF_i is the flow rate for all streams above the pinch point.

3. CASE STUDIES

3. 1. Case one

Tables 1 and 2 displays the figures for Case one, sourced from literature [6]. The maximum allowable concentration for the pollutant A, B and C in the environment is adopted as 100 ppm.

Table 1. Streams data for Case one [6]

Stream	Flow rate, t h^{-1}	Concentration, ppm		
		A	B	C
S_1	20.00	600.00	500.00	500.00
S_2	15.00	400.00	200.00	100.00
S_3	5.00	200.00	1000.00	200.00

Table 2. Treatment process data for Case one [6]

Treatment plant	Removal ratio, %		
	A	B	C
TP_1	90.00	0.00	0.00
TP_2	0.00	99.00	0.00
TP_3	0.00	0.00	80.00

Step 1

Determine the major pollutant for each treatment plant: the main pollutant for TP_1 is A, for TP_2 is B, and for TP_3 is C.

Step 2

Calculate the flow rate required to treat a given pollutant j in a given stream *i*: total minimum flow rates required by a given treatment plant to remove a given pollutant from all streams are shown in Table 3, calculated by using equation (1)

Table 3. Flow rate values for TP_1, TP_2, and TP_3.

Flow rate, t h^{-1}					
TP_1		TP_2		TP_3	
A		B		C	
$F^1_{1,A}$	18.52	$F^2_{1,B}$	16.16	$F^3_{1,C}$	20.00
$F^1_{2,A}$	12.50	$F^2_{2,B}$	7.58	$F^3_{2,C}$	0.00
$F^1_{3,A}$	2.78	$F^2_{3,B}$	4.55	$F^3_{3,C}$	3.13
$\sum F^1_{T,A}$	33.80	$\sum F^2_{T,B}$	28.28	$\sum F^3_{T,C}$	23.13

For example, the flow rate $F^1_{1,A}$ is calculated as presented by equation (7):

$$F^1_{1,A} \frac{20(600\text{-}100)}{600 \times 0.9} = 18.52 \text{ t h}^{-1} \tag{7}$$

Step 3

In this step, the performing order for implementing the treatment unit is determined based on the results in step 2 as TP_3, then TP_2, and finally TP_1.

Step 4

The lowest removal mass load for all pollutants is calculated according to equation (2) based on the data presented in Tables 4, 5, and 6.

Table 4. Stream data for the pollutant C before TP_3 (Case one)

Stream	f_i / t h^{-1}	$C_{i,C}$ / ppm	$m_{i,C}$ / g h^{-1}	$\Sigma m_{i,C}$ / g h^{-1}
S_1	20	500	10000	10000
S_3	5	200	1000	11000
S_2	15	100	1500	12500
Sum	40		12500	

Table 5. Stream data for the pollutant B before TP_2 (Case one)

Stream	f_i / t h^{-1}	$C_{i,B}$ / ppm	$m_{i,B}$ / g h^{-1}	$\Sigma m_{i,B}$ / g h^{-1}
S'_3	1.87.00	1000.00	1870.00	1870.00
S'_1	23.13	567.66	13129.97	14999.98
S_2	15.00	200.00	3000.00	17999.98
Sum	40.00		17999.98	

Table 6. Stream data for the pollutant A before TP_1(Case one)

Stream	f_i / t h^{-1}	$C_{i,A}$ / ppm	$m_{i,A}$ / g h^{-1}	$\Sigma m_{i,A}$ / g h^{-1}
S''_1	1.51	545.87	824.26	824.26
S''_3	23.49	518.34	12175.81	13000.07
S_2	15.00	400.00	6000.00	19000.07
Sum	40.00		19000.07	

Taking into account the limiting pollutant concentration of 100 ppm, the lowest mass loads that have to be removed can be calculated by equation (1) and the values presented in Tables 6, 5, and 4, yielding the values:

M_A^{rem} =15000.07 g h^{-1}, M_B^{rem} = 13999.98 g h^{-1}, and M_C^{rem} =8500 g h^{-1}, respectively.

Step 5

Streams that correspond to the pinch point can be determined as follows. Considering removal rates presented in Table 2 and the calculated values of the lowest mass loads by using equation (3a). The mass load of pollutant C at the entrance of TP_3 is:

$$M_{TP_{3,C}} = 8500 / 0.8 = 10625 \text{ g h}^{-1}$$

The obtained value is between the mass loads in S_1 and S_2 for TP_3 and by using equation (3), *i.e.* 10000 < 10625 < < 11000 g h^{-1}. Therefore, S_3 will be the pinch stream, which requires partial treatment and partial bypass. By carrying out the same procedure for TP_2 and TP_1, the pinch streams will be S'_1 and S_2, respectively.

Step 6

Portions needed to be treated and bypassed from the pinch stream are calculated by equations (4) and (5) resulting in values:

$F_{TP_{3,pt}}$ = 3.13 t h^{-1}, $F_{TP_{3,pb}}$ = 1.87 t h^{-1}, $F_{TP_{2,pt}}$ = 21.62 t h^{-1}, $F_{TP_{2,pb}}$ = 1.51 t h^{-1}, $F_{TP_{1,pt}}$ = 9.17 t h^{-1} and $F_{TP_{1,pb}}$ = 5.83 t h^{-1}

Step 7

Minimum treatment flow rates per treatment unit are calculated by using equation (6) resulting in values:

F_{TP_1} = 23.13 t h^{-1}, F_{TP_2} = 23.49 t h^{-1} and F_{TP_3} = 34.17 t h^{-1}

Figure 1 displays the completed design that was produced throughout this work.

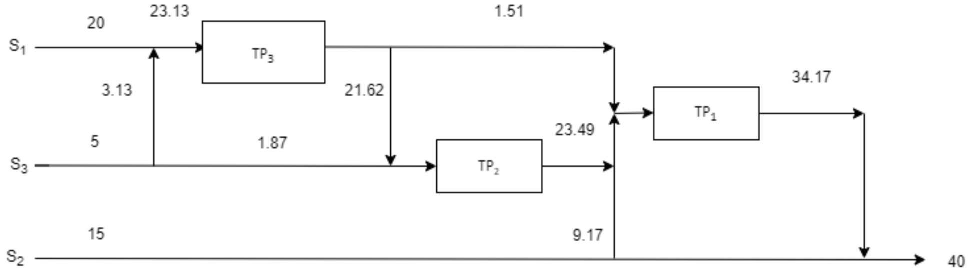

Figure 1. Optimal design network (Case one)

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3. 2. Case two

Table 7displays the figures for Case two, sourced from a study reported in literature [7]. The maximum allowable concentration for the pollutant A, B, C, D, E and F in the environment is taken as 100 ppm. Tables 7, and 8 present figures in the stream and treatment processes for the Case two.

Table 7. Streams data for the Case two [7]

Stream	Concentration, ppm						Flow rate, t h^{-1}
	A	B	C	D	E	F	
S_1	1100.00	500	500	200.00	800.00	100.00	19.00
S_2	40.00	0.00	100.00	300.00	910.00	200.00	7.00
S_3	200.00	220.00	200.00	500.00	150.00	0.00	8.00
S_4	60.00	510.00	500.00	200.00	780.00	100.00	6.00
S_5	400.00	170.00	100.00	300.00	900.00	0.00	17.00

Table 8. Treatment process data [7]

Treatment plant	Removal ratio, %					
	A	B	C	D	E	F
TP_1	99.00	0.00	0.00	0.00	0.00	0.00
TP_2	0.00	99.00	0.00	0.00	0.00	0.00
TP_3	0.00	0.00	99.00	0.00	0.00	0.00
TP_4	0.00	0.00	0.00	99.00	90.00	0.00
TP_5	0.00	0.00	0.00	0.00	99.00	99.00

Step 1

Determine the major pollutant and compute the lowest treatment flow rate for each treatment plant. Table 8 shows that TP_1, TP_2, and TP_3 can only remove pollutants A, B, and C, respectively. Process TP_4 can eliminate two pollutants, E and D, with removal ratios of 90 and 99 %, respectively. Therefore, the major pollutant in TP_4 is D. Since pollutant F has mass loads in all streams that are below the maximum allowable environmental limit, as shown in Table 7, it is unnecessary to consider this contaminant. Hence, the major pollutant of TP_5 is E.

Step 2

Tables 9 and 10 show the minimum total flow rates required for the treatment plant k to remove the pollutant j from all streams.

Table 9. Flow rate values for TP_1, TP_2, and TP_3

Flow rate, t h^{-1}					
TP_1		TP_2		TP_3	
A		B		C	
$F^1_{1,A}$	17.45	$F^2_{1,B}$	15.35	$F^3_{1,C}$	15.35
$F^1_{2,A}$	-10.61	$F^2_{2,B}$	0.00	$F^3_{2,C}$	0.00
$F^1_{3,A}$	4.04	$F^2_{3,B}$	4.41	$F^3_{3,C}$	4.04
$F^1_{4,A}$	-4.04	$F^2_{4,B}$	4.87	$F^3_{4,C}$	4.85
$F^1_{5,A}$	12.88	$F^2_{5,B}$	7.07	$F^3_{5,C}$	0.00
$\sum F^1_{T,A}$	19.72	$\sum F^2_{T,B}$	31.70	$\sum F^3_{T,C}$	24.24

Table 10. Flow rate values for TP_4 and TP_5

Flow rate, t h^{-1}							
TP_4				TP_5			
D		E		E		F	
$F^4_{1,D}$	9.60	$F^4_{1,E}$	18.47	$F^5_{1,E}$	16.79	$F^5_{1,F}$	0.00
$F^4_{2,D}$	4.71	$F^4_{2,E}$	6.92	$F^5_{2.E}$	6.29	$F^5_{2,F}$	3.54
$F^4_{3,D}$	6.46	$F^4_{3,E}$	2.96	$F^5_{3,E}$	2.69	$F^5_{3,F}$	0.00

Flow rate, t h^{-1}							
TP$_4$				TP$_5$			
D		E		E		F	
$F^4_{4,D}$	3.03	$F^4_{4,E}$	5.81	$F^5_{4,E}$	5.28	$F^5_{4,F}$	0.00
$F^4_{5,D}$	11.45	$F^4_{5,E}$	16.79	$F^5_{5,E}$	15.26	$F^5_{5,F}$	0.00
$\sum F^4_{T,D}$	35.25	$\sum F^4_{T,E}$	50.95	$\sum F^5_{T,E}$	46.31	$\sum F^5_{T,F}$	3.54

Step 3

In this step, the performing order for implementing the treatment unit is determined based on the results in step 2 and we can say that the performing orders will be TP$_1$, TP$_3$, TP$_2$, TP$_5$, and TP$_4$.

In Tables 11 to 15, the streams are arranged based on the concentration of the pollutant that needs to be removed in each treatment process. The arrangement begins with the highest concentration and proceeds to the lowest concentration. This ordering is essential to identify the pinch point, which helps determine the streams that will undergo treatment in each treatment process. Additionally, it aids in calculating the mass load that is removed by each treatment unit.

Table 11. Streams data for the pollutant A before TP$_1$ (Case two)

Streams	$C_{i,A}$ / ppm	f_i / t h^{-1}	$m_{i,A}$ / g h^{-1}	$\Sigma m_{i,A}$ / g h^{-1}
S$_1$	1100	19	20900	20900
S$_5$	400	17	6800	27700
S$_3$	200	8	1600	29300
S$_4$	60	6	360	29660
S$_2$	40	7	280	29940
Sum		57	29940	

Table 12. Stream data for the pollutant C before TP$_3$ (Case two)

Streams	$C_{i,C}$ / ppm	f_i / t h^{-1}	$m_{i,A}$ / g h^{-1}	$\Sigma m_{i,A}$ / g h^{-1}
S$_4$	500.00	6.00	3000.00	3000.00
S'$_1$	400.57	27.96	11199.94	14199.94
S$_3$	200.00	8.00	1600.00	15799.94
S$_2$	100.00	7.00	700.00	16499.94
S$_5$	100.00	8.04	804.00	17303.94
Sum		57.00	17303.94	17303.94

Table 13. Streams data for the pollutant B before TP$_2$ (Case two)

Stream	$C_{i,B}$ / ppm	f_i / t h^{-1}	$m_{i,B}$ / g h^{-1}	$\Sigma m_{i,B}$ / g h^{-1}
S$_2$	457.58	7.00	3203.06	3203.06
S'$_4$	443.13	27.77	12305.72	15508.78
S$_3$	220.00	8.00	1760.00	17268.78
S''$_1$	170.00	6.19	1052.30	18321.08
S'$_5$	0.00	8.04	0.00	18321.08
Sum		57.00	18321.08	

Table 14. Streams data for the pollutant E before TP$_5$ (Case two)

Stream	$C_{i,E}$ / ppm	f_i / t h^{-1}	$m_{i,E}$ / g h^{-1}	$\Sigma m_{i,E}$ / g h^{-1}
S'$_2$	1077.32	34.77	37458.42	37458.42
S'$_5$	910.00	8.04	7316.40	44774.82
S''$_1$	900.00	6.19	5571.00	50345.82
S$_3$	150.00	8.00	1200.00	51545.82
Sum		57.00	51545.82	

Table 15. Streams data for the pollutant D before TP_4 (Case two)

Stream	$C_{i,D}$ / ppm	f_i / t h^{-1}	$m_{i,D}$ / g h^{-1}	$\Sigma m_{i,D}$ / g h^{-1}
S_3	500.00	8.00	4000.00	4000.00
S''_1	318.31	4.49	1429.21	5429.21
S''_2	310.98	44.51	13841.72	19270.93
Sum		57.00	19270.93	

Step 4

The lowest mass load required for each pollutant to be removed is calculated according to equation (2) and the data presented in Tables 11-15 as:

M_A^{rem} = 24240 g h^{-1} (Table 11), M_C^{rem} = 11603.94g h^{-1} (Table 12), M_B^{rem} = 12621.08 g h^{-1} (Table 13), M_E^{rem} = 45845.82 g h^{-1} (Table 14), M_D^{rem} = 13570.93 g h^{-1} (Table 15).

Step 5

By using equation (3), the mass load at the inlet of TP_k and the corresponding pinch streams are calculated and summarized in Table 16.

Table 16. Determining the pinch stream

Pollutant	TP_k	M_{TP_k} / g h^{-1}	Pinch stream
A	1	24484.85	S_5
B	2	12748.57	S'_4
C	3	11721.15	S'_1
D	4	13708.01	S''_2
E	5	46308.91	S''_1

Step 6

Portions needed to be treated and bypassed from the pinch stream are calculated by equations (4) and (5) yielding the values:

$F_{TP_{1,pt}}$ = 8.96 t h^{-1}, $F_{TP_{1,pb}}$ = 8.04 t h^{-1}, $F_{TP_{2,pt}}$ = 27.77 t h^{-1}, $F_{TP_{2,pb}}$ = 0.00 t h^{-1}, $F_{TP_{3,pt}}$ = 21.77 t h^{-1}, $F_{TP_{3,pb}}$ = 6.19 t h^{-1}, $F_{TP_{4,pt}}$ = 26.62 t h^{-1}, $F_{TP_{4,pb}}$ = 17.89 t h^{-1}and $F_{TP_{5,pt}}$ = 1.70 t h^{-1}, $F_{TP_{5,pb}}$ = 4.49 t h^{-1}

Step 7

Minimum treatment flow rates per treatment unit are calculated by using equation (6) yielding values:

F_{TP_1} = 27.96 t h^{-1}, F_{TP_2} = 34.77 t h^{-1}, F_{TP_3} = 27.77 t h^{-1}, F_{TP_4} = 39.11 t h^{-1} and F_{TP_5} = 44.51 t h^{-1}

Figure 2 displays the completed design that was produced throughout this work.

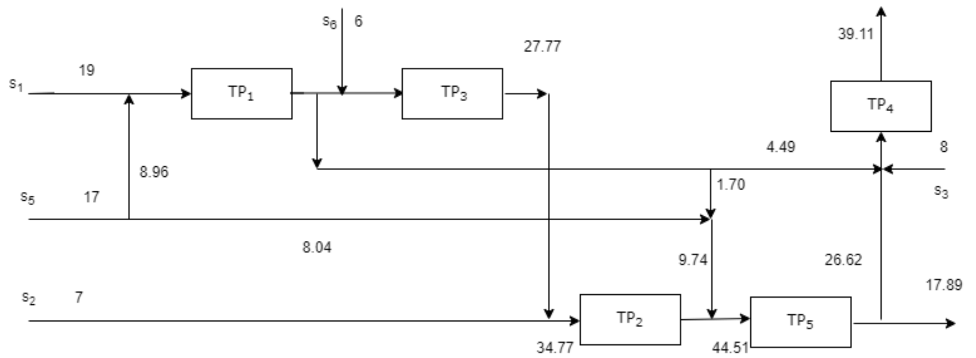

Figure 2. Optimal design network (Case two)

4. RESULTS AND DISCUSSION

The main objective of this work is to reduce the concentration of pollutants discharged into the environment while simultaneously decreasing the flow rates in the treatment units.

This approach yields results that are comparable to those reported in the literature, both in terms of reducing pollutant concentration and flow rate, particularly when the number of treatment units or streams is low. This is evident from the comparison of results for Case one in Table 17.

However in Case two, we observe that this objective was not fully achieved due to an increase in the number of treatment units and the number of streams. This leads to a higher occurrence of stream mixing, resulting in an increase in the flow rate. This is clearly evident in the increased flow rate in Case two as shown Table 18.

Thus, Therefore, the proposed approach delivers satisfactory results when the number of streams or treatment units is low. However, when number of streams or treatment units is high, it still provides satisfactory results, making it suitable as an initial model in mathematical optimization.

Table 17. Comparison of results for the Case one obtained in the present work and reported in the source study [6]

	Discharging concentration, ppm			Total flow rate, t h^{-1}
	A	B	C	
This work	99.97	99.99	100	80.79
Shi and Liu [6]	99.97	99.99	100	80.79

Table 18. Comparison of results for the Case two obtained in the present work and reported in the source study [7]

	Discharging concentration, ppm					Total flow rate, t h^{-1}
	A	B	C	D	E	
This work	100	52	100	100	100	174.12
Liu *et al.* [7]	100	100	100	89.69	100	134.75

The presented approach aims to sequence treatment units based on flow rates. Treatment units with the lowest total flow rate are prioritized, followed by those with higher flow rates. The initial total flow rate for each treatment unit is determined by summing the required flow rates for treating each stream individually. If the required flow rate is zero, it indicates that the stream does not require treatment (when the stream's inlet concentration of the pollutant is equal to the environmentally permissible limit concentration of the pollutant). Conversely, if the flow rate value is negative, it means that the stream not only does not require treatment but also allows for reducing the flow rate in other streams necessary for treatment in the unit.

5. CONCLUSION

In this study, a straightforward strategy for designing a distributed treatment system is presented. One of the main aspects emphasized in this strategy is the reduction of stream mixing, which is considered crucial in minimizing the overall treatment requirement of the system. The streams in the treatment system that are above the pinch are totally treated, while the streams in the pinch are only partially treated. The pinch technique is applied to compute the lowest treatment quantity for every unit for its primary pollutant. Two case studies are provided to demonstrate the effectiveness of the proposed strategy. Moreover, the approach is characterized by its simplicity and technical nature. The computational effort required is not significantly affected by the quantity of streams, pollutants, or treatment facilities.

6. NOMENCLATURE

$F_{i,j}^{k}$	- The flow rate of process k to remove pollutant j in stream i
$F_{T,j}^{k}$	- The minimum total flow rate of process k to remove pollutant j in all streams
F_i	- Flow rate of stream i
$C_{i,j}^{in}$ / ppm	- Stream i's inlet concentration of pollutant j
$C_{env,j}^{lim}$ / ppm	- Environmentally permissible limit of pollutant j in S_i
$C_{i,j}$ / ppm	- Concentration of pollutant j in S_i
RR / %	- Removal ratio
M_j^{rem}	- The lowest mass load of pollutant j needed to be removed

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$F_{TP_{k,pt}}$	- Flow rate of S_p needed to be treated by TP_k
$F_{TP_{k,pb}}$	- Flow rate of S_p not needed to be treated by TP_k
F_{TP_k}	- The minimum treatment flow rate of treatment unit k
S_p	- Stream point
$C_{p,j}$	- Concentration of pollutant j at stream point
$M_{TP_{k,j}}$	- Mass load of pollutant j at the entrance of TP_k
$m_{i,j}$	- Mass load of pollutant j in S_i
TP_k	- Treatment plant k
S_i	- Stream i
P	- Process

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Sistematski pristup projektovanju distribuiranih sistema za prečišćavanje otpadnih voda

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Izvod

Zbog sve strožije regulative u zaštiti životne sredine, troškovi rukovanja različitim tokovima otpada postepeno rastu. Zbog toga je ključno minimizirati nepotrebno spajanje tokova prilikom projektovanja distribuiranih sistema za prečišćavanje otpadnih voda, kako bi se smanjio ukupni protok tretiranih voda kad god je to moguće. U distribuiranom sistemu za prečišćavanje otpadnih voda, tokovi otpadnih voda se odvajaju za tretman i kombinuju samo kada je to potrebno. Ovo rezultira značajnim smanjenjem ukupnog protoka u poređenju sa tradicionalnim centralizovanim sistemima za tretman gde se svi tokovi spajaju pre tretmana. Dizajn distribuiranog sistema za prečišćavanje otpadnih voda može se postići korišćenjem pinč (engleski *pinch*) analize i pristupa matematičkog programiranja. Ovaj rad predlaže jednostavan pristup za projektovanje takvih mreža, sa više koraka u procesu projektovanja: Prvo se određuje primarna funkcija svake jedinice za tretman. Zatim, primenom pinč (*eng*. pinch) metode se za svaku jedinicu utvrđuje najmanja količina za tretman za primarni zagađivač. Konačno, bira se grupa od tri jedinice, pri čemu se pinč tok delimično tretira, tokovi iznad pinč toka potpuno obrađuju, a tokovi ispod pinča se potpuno zaobilaze. Dve studije slučaja iz literature pokazuju održivost i efikasnost ovog pristupa.

Ključne reči: višekomponentni zagađivači; sinteza procesa; pinč analiza; mreže tokova vode

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