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Azza Mohamed Khalifa [α], Nadia Ali Elsayed [σ] & Mostafa Awad [ρ]

Abstract- Effective water management is crucial for industrial operations to minimize freshwater consumption and wastewater discharge. This paper presents a comprehensive approach for optimizing water network design in the presence of multiple contaminants. The proposed methodology incorporates regeneration, reuse, and regeneration-recycle strategies to achieve optimal water usage and contaminant removal. The effectiveness of the proposed approach is demonstrated through case studies involving industrial processes with diverse contaminant profiles. The results show significant reductions in freshwater consumption and wastewater generation compared to conventional designs. By comparing a water network design without any regeneration methods to one that incorporates regeneration techniques, it is evident that the amount of freshwater required is significantly higher in the network without regeneration. The inclusion of regeneration strategies, such as reuse and regeneration-recycle, allows for the treatment and recirculation of process water streams, thereby reducing the demand for costly and resource-intensive freshwater intake.

The key difference lies in the ability of the regeneration-based network to efficiently manage contaminant levels and enable the reutilization of water within the system. Without regeneration, the water network would need to rely solely on freshwater makeup to dilute contaminants, leading to higher freshwater consumption. In contrast, the regeneration-enabled network can selectively remove contaminants and reintroduce the treated water back into the process, significantly decreasing the overall freshwater requirements, for example, The paper's first case study demonstrates that the fresh water consumption in the processes without regeneration is 112.9 tons per hour. However, by implementing regeneration in the same processes, the fresh water consumption decreases to 59.7 tons per hour. This comparison highlights the significant advantages of incorporating regeneration strategies into water network design. By optimizing the integration of treatment technologies and water recirculation pathways, industrial facilities can achieve substantial reductions in freshwater usage and minimize their environmental impact through more sustainable water management practices. This work provides a valuable decision-making tool for industrial water system designers and managers, facilitating the implementation of advanced water minimization techniques and promoting the adoption of circular economy principles in water resource management.

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Keywords: contaminant removal, mathematical modeling, optimization algorithms, regeneration methods, water network minimization.

I. Introduction

Water network minimization is a crucial strategy for enhancing the efficiency and sustainability of water distribution systems. By optimizing water consumption and reducing losses, this approach ensures the effective management of our precious water resources. This process is essential for achieving a balance between water supply and demand, conserving water, and mitigating the environmental impact of water distribution systems. Through the implementation of water network minimization, communities can enjoy a reliable water supply, promote water conservation, and work towards a more sustainable future[1].

The concept of the circular economy underscores the importance of minimizing the utilization of fresh resources through the implementation of the 3R strategies: reduce, reuse, and recycle. In Malaysia, water consumption is predominantly driven by domestic and industrial activities, accounting for over 50% of the total water usage. consumption. Therefore, it is imperative to implement measures to decrease water usage in these areas, as the wastewater generated can be regenerated, reused, or treated, thereby reducing the reliance on freshwater resources[2].

The research focus on wastewater minimization has gained considerable attention due to the critical importance of water conservation and the imperative to decrease the discharge of wastewater. The integration of water systems plays a pivotal role in achieving substantial reductions in both the consumption of fresh water and the discharge of wastewater by implementing practices such as wastewater reuse and regeneration recycling [3].

Wastewater treatment plants (WWTPs) play a crucial role in removing pollutants from water to meet water quality standards and regulations. The increasing significance of adhering to environmental standards and the inefficiencies resulting from inadequate designs and practices underscore the need for systematic tools for WWTP design[4]. The objective of wastewater management is to establish measures for environmental

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protection while considering economic and social concerns.

Minimizing water consumption in the process industry is crucial to reduce operating costs and minimize aqueous emissions to the environment[5]. Improving the efficiency of water use in the process industry can be achieved through process changes or upgrades that facilitate reduced water requirements for water-using operations. These individual process modifications can contribute to the reduction of water consumption at the site level. However, it is unlikely to achieve significant water savings through such focused investigations, as they are often limited to particular equipment or subsystems within the plant.

To fully realize the potential for water savings and maximize the efficiency of water usage in the plant, a holistic approach is required. This approach allows for system-wide analysis of water systems as a whole and supports the integrated management of water across the entire site. The key concept of this integrated water management is to maximize the reusability of water between water-using operations. The reusability of water can be improved by collecting water discharged from water-using operations and feeding it to other operations. The extent to which contaminated water can be reused depends on the acceptability of the contaminated water for each individual operation and the arrangement of water mixing between freshwater or other less-contaminated water from other operations. The reusability of contaminated water, as well as the acceptability of reused water for the operation, can be enhanced by regenerating contaminated water through effluent treatment processes and reusing (or recycling) it in other operations[6].

The loop breaking technique and explained how that technique can be adapted with restrictions on the flow rate used for each process as well as water loses[7], A novel graphical method that presents a supply and demand composite and shows concentration versus flow rate[8], Finding the global optimum of a problem rather of a local one was a challenge for nonlinear mathematical programming techniques, especially when dealing with problems with numerous variables[9], A new graphical approach, they discussed how to distribute the quality of the waste water that needs to be processed while also allocating fresh water as efficiently as possible[10], A novel method for creating water utilization networks in process plants that minimize the use of fresh water and utilities[11]. The concentration potential conceptions of the streams serve as the foundation for regeneration recycle water network with internal mains[12]. In order to maximize water reuse, a new methodical design approach has been developed for the simultaneous management of energy and water systems [13].

In practice, finding the most appropriate manner of reusing water between operations can be complex, as a large number of mixing and reusing options are available for the water systems. Since the early 1990s, various design methodologies have been proposed to systematically investigate water reuse and its implementation into a water network, primarily based on the concept of a limiting water profile.

This design philosophy has been successfully and widely applied to various industrial sectors, demonstrating the benefits of using an integrated and system-wide analysis in the design and operation of water systems. The successes lie in the methodological convenience and advantages associated with the use of a limiting water profile. The synthesis of water networks is made solely with the manipulation of information related to water conditions (i.e., water flowrate and concentration), while process streams and their conditions are not involved during the targeting and design of water networks. This simplification allows for a common, but powerful, basis for the integrated design framework of water-using operations, even though the mass transfer mechanisms for water use may not be the same across all operations. Another advantage of using this integrated method is the ability to target the theoretical maximum potential of water savings.

Three types of industrial applications:

There are three primary industrial applications for wastewater reuse: cooling towers and HVAC systems, industrial processes and manufacturing, and energy production[14].

In industrial settings, wastewater can be used as a cost-effective and sustainable water source for heating, cooling, and ventilation processes. The treated wastewater can function as a cooling agent, decreasing freshwater intake and reducing energy consumption. Reusing wastewater in cooling towers and HVAC systems can improve system efficiency, minimize maintenance costs, and decrease the risk of scaling and corrosion.

However, it is crucial to ensure appropriate treatment and disinfection of the wastewater before using it in these systems. This is necessary to prevent microbiological growth and minimize potential health risks. Proper system design, maintenance, and operation are essential to optimize performance and safety.

Wastewater can also be utilized in energy production applications. One approach is to use the treated wastewater as a cooling source, which can drive turbines to generate electricity. Alternatively, the wastewater can serve as a feedstock for biofuel production.

II. Problem Statement

Design and optimize an integrated water minimization and regeneration network for an industrial

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manufacturing facility with the following objectives and requirements[15]:

a) Objectives

Minimize freshwater intake from municipal sources by 50% or more through water reuse and regeneration.

Maximize water recovery from process drainages, wastewater streams, and other sources.

Minimize life cycle costs including capital expenses, operational costs, and water/wastewater utilities.

b) Requirements

Provide sufficient water supply to meet all process and non-potable fixture demands.

Regenerated water must meet quality standards for intended end uses such as cooling tower makeup, landscape irrigation, wash down, etc.

System must comply with all applicable health, safety, and environmental regulations.

The optimized solution should achieve the stated objectives through effective integration of reuse, regeneration, and minimization strategies to reduce the plant's water usage, costs, and environmental impacts.

c) Methodology

The procedure essentially consists of the four steps listed below, omitting the regeneration process[16]:

- *Step1:* Determine the fresh water processes (FWPs), which their inlet concentration is zero
- *Step2:* Calculation of the limiting concentration of the regeneration processes which don't take fresh water only

$$\text{Lim CR} = C0*(1-RR) \quad (1)$$

Where Lim CR is limiting concentration of regeneration, C0 is outlet concentration of process and RR is the removal ratio.

- *Step3:* Allocation of source and demand

1. Allocation of processes according to (CPD), if the CPD for a process equal zero, it will take fresh water only. When multiple source streams are available, we should priorities/ the reuse of one source over the others. Equation 1 displays the source stream with the highest quasi allocation ratio value first[17],[18],[19].

$$Ri,j = \min k = 1,2,3,\dots NC \left(\frac{Dlimj,k}{CSi,k}\right) \quad (2)$$

Where, Ri, j is the limiting quasi-allocation from Si to Dj

2. When Si is the allocation to Dj, Reuse critical contaminant is defined as the concentration that reaches the limiting value before any other.
3. The source with the next-highest quasi-allocation amount should be selected if one source is unable to fully meet the demand.
4. Calculate the mass load for demand and source at a definite reuse key contaminant by equations:

$$MD = FD*Ci \quad (3)$$

$$MS = FS*C0 \quad (4)$$

There are three cases for mass load,

a. If MS = MD, the source provides all the water to meet the demand.
b. If MS > MD, the source provides the amount of water where MS = MD, and the remaining demand is met using fresh water.
c. If MS < MD, the source provides all its water, and the remaining demand is met using the source with the next highest Ri,j value.

$$WR = (MD/CSOUT) \quad (5)$$

Step4: After allocation, determine the updated concentrations at the intake and output for each process[20], as follows:

$$CN,I = (C0,I*MN)/M0 \quad (6)$$

$$CN,O = C0,0-(C0,I-CN,I) \quad (7)$$

Where, Co is the outlet concentration, WR is the water required for each process, RKC is the reuse key contaminant, CN,I is new inlet concentration, Co,I is the old inlet focus, Old mass load is MO, and new mass load is MN., CN,O is new outlet concentration, CO,O IS old outlet concentration.

- Basically, the method consists of seven steps described in the following using regeneration method.

Step1: Determine the fresh water processes (FWPs), which their inlet concentration is zero.

Step2:

1. Determine the processes which feed the regeneration process by water (BP), and processes which take water from a regeneration process (AP)
2. Calculate the limiting concentration of the regeneration processes which don't take fresh water only
3. Determine type of processes:
4. Calculate the average of limiting concentration of regeneration

- If the concentration of contaminant lower than the average of limiting concentration take ϕ sign
- If the contaminant concentration is at least as high as the limiting concentration average take η sign
- If ϕ >η the process called below process (BP)

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- If η>ϕ the process called above process (AP)

Step3:

Using CPD values to determine the order in which processes should execute determining CPD for (BP+FW) process by using equation [14], [12], CPD(Dj)=

$$\sum_{i=1}^{Ns} min\ k = 1,2,3,\dots NC\ \left(\frac{CD\ lim\ i,k}{CSi,k}\right)$$

➢ *Step4:* Design procedure of water using networks, the design steps are as follows:

1) Allocation of processes according to order of priority factor (CPD), if the CPD for a process equal zero, it will take fresh water only. We should choose which source should be reused first when there are multiple streams of sources accessible. Equation 1 displays the source stream with the highest quasi allocation ratio value first.
2) When a source Si is allocated to a demand Dj, the concentration of the "reuse key contaminant" (RKC) reaching the limiting value first will be considered the RKC for the Si-Dj pair.
3) If the demand cannot be fully met by a single source, another source with the next highest "quasi-allocation amount" (Ri,j) value should be used to supplement the demand.
4) The mass load calculations.

➢ *Step5:* After allocation, the updated concentrations at the intake and output of each process are calculated.

➢ *Step6:* Calculation of inlet regeneration concentration by using equation:

$$C^o reg = \sum_i (F_{si}^{lim}\ C_{reg,s}^{lim}) /\ \sum_I F_{si}^{lim} \qquad (8)$$

Step7: The design procedure is then repeated from step 4 to optimize the water use network.

III. Algorithm

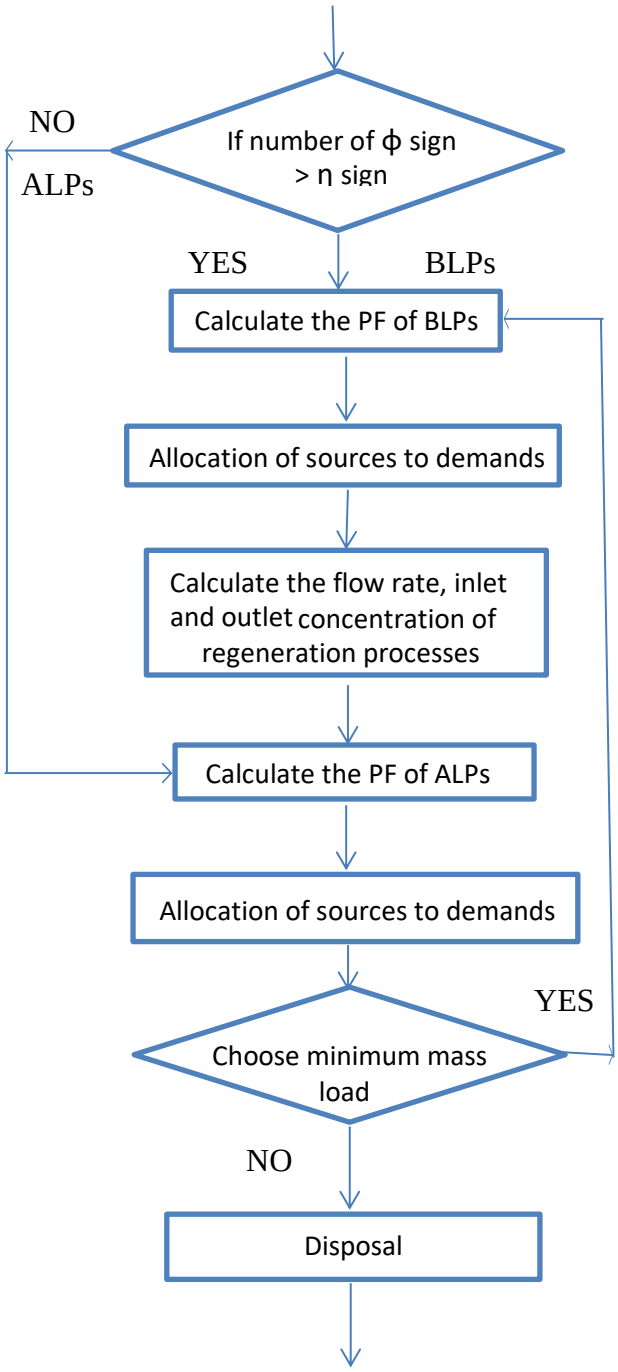


Fig. 3.1: Water network minimization flow chart

IV. Case Study

This case study is taken from [21] with the data shown in table (2.2), including 5 processes, 3 contaminants and the removal ratio for regeneration is (0. 99.9%, 0).

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Table 4.1: Limiting data for example (1)

Process	Contaminant	Cin (ppm)	Cout(ppm)	Fmax (T/hr)
P1	A	0	15	50
	B	0	400	
	C	0	35	
P2	A	20	120	34
	B	300	12500	
	C	45	180	
P3	A	120	220	56
	B	20	45	
	C	200	9500	
P4	A	0	20	8
	B	0	60	
	C	0	20	
P5	A	50	150	8
	B	400	8000	
	C	60	120	

In this particular example, we consider a water network comprising five processes, and each process involves three contaminants. Our objective is to design a water network that demonstrates the reduction of fresh water usage through two different methods: one without regeneration and the other with regeneration by using removal ratio. Furthermore, we will conduct a thorough comparison between these two approaches to assess their effectiveness and efficiency.

According to network without regeneration:

Based on the determined order of processes (P1, P2, P3, P4, P5, P6), the allocation of process P2 and P3 requires a fresh water requirement of 8.5T/hr and 46.4T/hr, respectively. The determination of the recycle and keep concentration (RKC) in process 4 is denoted as (B) in S4 after choosing between S1 and S4, calculated using equation (3). Subsequently, equations (4) and (5) are employed to obtain the values. It is observed that the mass source (S4) is lower than the mass demand (D3). In this situation, S4 provides all the water to D3, while D3 will obtain water from other sources, specifically S1, indicating a requirement of 1.6 T/hr of water from S1 to D3, as determined by equation (6). The total amount of fresh water required is 46.4 T/hr. By utilizing equations (7) and (8), the new inlet and outlet concentrations can be calculated as follows: CN,I = (3.29, 20, 3.86) ppm and CNO = (103.29, 45, 9303.86). Within process 5, two sources, S1 and S3, are present. Applying equation (3), source S1 is selected with an assigned RKC of B. Equations (4) and (5) are then used to determine the corresponding values. The analysis reveals that the mass source (S1) exceeds the mass demand (D5), indicating a requirement of 8 T/hr of water to be transferred from S1 to D2, as determined by equation (6). By employing equations (7) and (8), the new inlet and outlet concentrations can be calculated as follows: CN,I = (15, 400, 31.25) ppm and CNO = (115, 8000, 91.25).

Within process 2, three sources, S1, S3, and S5, are present. Applying equation (3), source S1 is selected with an assigned RKC of B. Equations (4) and (5) are then used to determine the corresponding values. The analysis reveals that the mass source (S1) exceeds the mass demand (D2), indicating a requirement of 25.5 T/hr of water to be transferred from S1 to D2, as determined by equation (6).

By employing equations (7) and (8), the new inlet and outlet concentrations can be calculated as follows: CN,I = (15, 400, 31.25) ppm and CNO = (115, 8000, 91.25).

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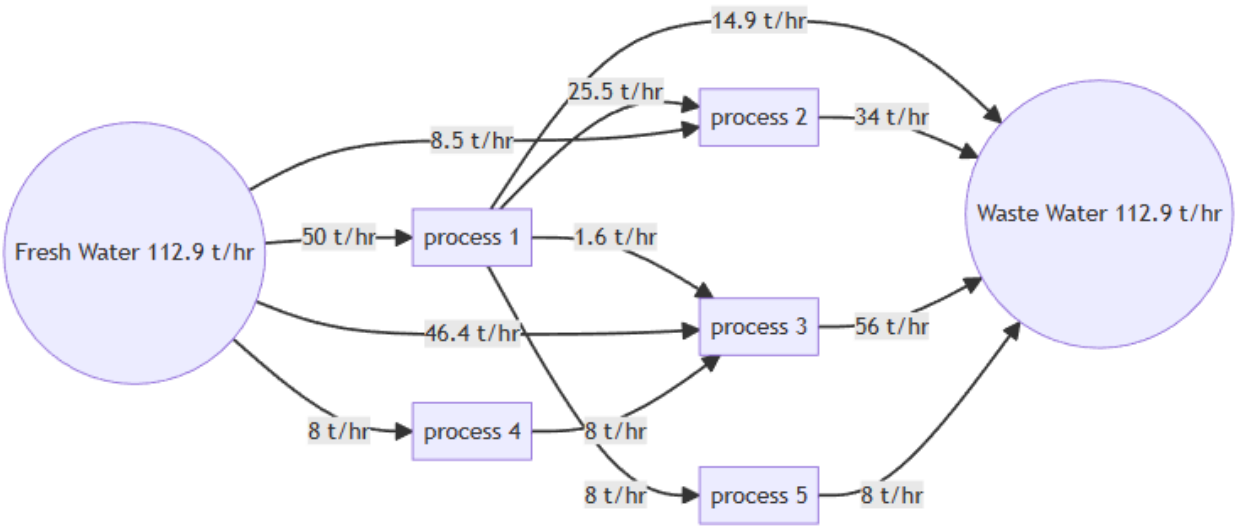


Fig. 4.1: Network design without regeneration

According to network with regeneration:

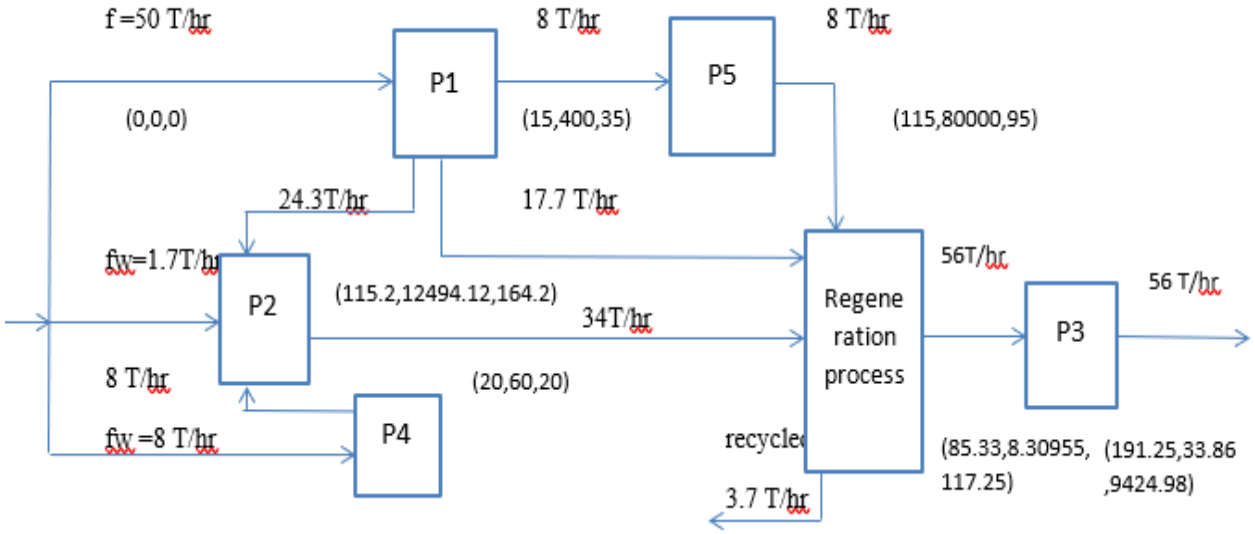


Fig. 4.2: The final water network design with regeneration

Table 4.2: Comparison table between using regeneration method and without regeneration method

	With using regeneration method	Without regeneration method
Fresh water(t/hr)	59.7	112.9

Table 4.3: Comparison between Different Methods for Example (2)

	Liu Z.Y.et al (2009b)	Our paper
Frsh water consumption	60.2	59.7
Method	Linear programming	Systematic approach(Regeneration recycle)

V. Case Study

Shows limiting data taken from [22]. In Table 5, The removal ratio values for the regeneration unit to remove contaminants A, B, C are all 90%.

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Table 5.1: Limiting data for example (2)

Process	Contaminant	Cin (ppm)	Cout(ppm)	Mass Load(g.hr^{-1})	F (T/Hr)
P1	A	300	500	180	0.9
	B	5000	11000	750	0.13
	C	1500	3000	100	0.07
P2	A	10	200	3610	19
	B	0	500	250	0.5
	C	0	1000	800	0.8
P3	A	10	1000	6000	6.06
	B	0	2000	15000	7.5
	C	0	3500	10000	2.86
P4	A	100	400	2000	6.67
	B	50	2000	800	0.41
	C	1000	3500	1000	0.4
P5	A	100	350	3000	12
	B	50	1800	1900	1.09
	C	1000	3500	2100	0.84
P6	A	85	350	3800	14.34
	B	300	6500	1100	0.18
	C	200	1000	2000	2.5

According to network without regeneration:

Based on the determined order of processes (P2, P6, P5, P4, P1, P3), the allocation of process P2 and P3 requires a fresh water requirement of 18.02 T/hr and 7.5 T/hr, respectively. The determination of the recycle and keep concentration (RKC) in process 6 is denoted as (C) in S2, calculated using equation (3). Subsequently, equations (4) and (5) are employed to obtain the values. It is observed that the mass source (D6) is lower than the mass demand (S2), indicating a requirement of 2.868 T/hr of water from S2 to D6, as determined by equation (6). The total amount of fresh water required is 11.47 T/hr. By utilizing equations (7) and (8), the new inlet and outlet concentrations can be calculated as follows: CN,I = (38, 100, 200) ppm and CNO = (303, 6300, 1000).

Within process 5, two sources, S2 and S6, are present. Applying equation (3), source S2 is selected with an assigned RKC of B. Equations (4) and (5) are then used to determine the corresponding values. indicating a requirement of 1.2 T/hr of water to be transferred from S2 to D5, as determined by equation (6). By employing equations (7) and (8), the new inlet and outlet concentrations can be calculated as follows: CN,I = (19, 50, 100) ppm and CNO = (269, 1800, 2600).

Within process 4, three sources, S2, S6, and S5, are present. Applying equation (3), source S2 is selected with an assigned RKC of B. Equations (4) and (5) are then used to determine the corresponding values. indicating a requirement of 0.667 T/hr of water to be transferred from S2 to D4, as determined by equation (6).

By employing equations (7) and (8), the new inlet and outlet concentrations can be calculated as follows: CN,I = (19, 50, 100) ppm and CNO = (319, 2000, 2600).

Within process 1, three sources, S2, S6, S4, and S5, are present. Applying equation (3), source S2 is selected with an assigned RKC of C. Equations (4) and (5) are then used to determine the corresponding values. indicating a requirement of 0.9 T/hr of water to be transferred from S2 to D1, as determined by equation (6).

By employing equations (7) and (8), the new inlet and outlet concentrations can be calculated as follows: CN,I = (190, 500, 1000) ppm and CNO = (390, 6500, 2500).

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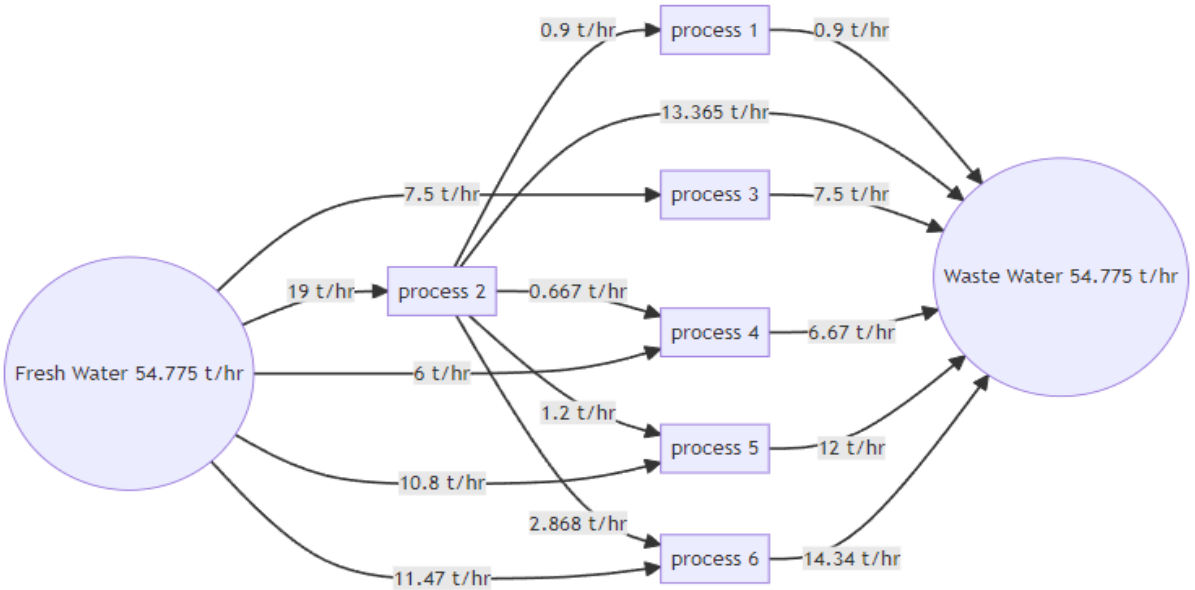


Fig. 5.1: Network design without regeneration

According to network with regeneration:

Table 5.2: Limiting data for limiting data for example (1)

Processes	Contaminants	Inlet conc (ppm)	Outlet conc(ppm)
P5	A	19	269
	B	50	1800
	C	100	2600
P6	A	37.62	302.62
	B	100.07	6300.07
	C	200	1000
P4	A	6	306
	B	50	2000
	C	31.48	2531.48
P1	A	36.69	236.69
	B	284.4	6284.4
	C	146.79	1646.79

Table 5.3: Inlet and outlet concentrations for regeneration-recycle method

Processes	Contaminants	Inlet conc (ppm)	Outlet conc(ppm)
P5	A	6.67	256.67
	B	50	1800
	C	31.67	2531.67
P6	A	36.93	301.93
	B	280.33	6480.33
	C	179.2	979.2
P4	A	6	306
	B	50	2000
	C	31.48	2531.48
P1	A	33.33	233.33
	B	266.67	6266.67
	C	166.67	1666.67

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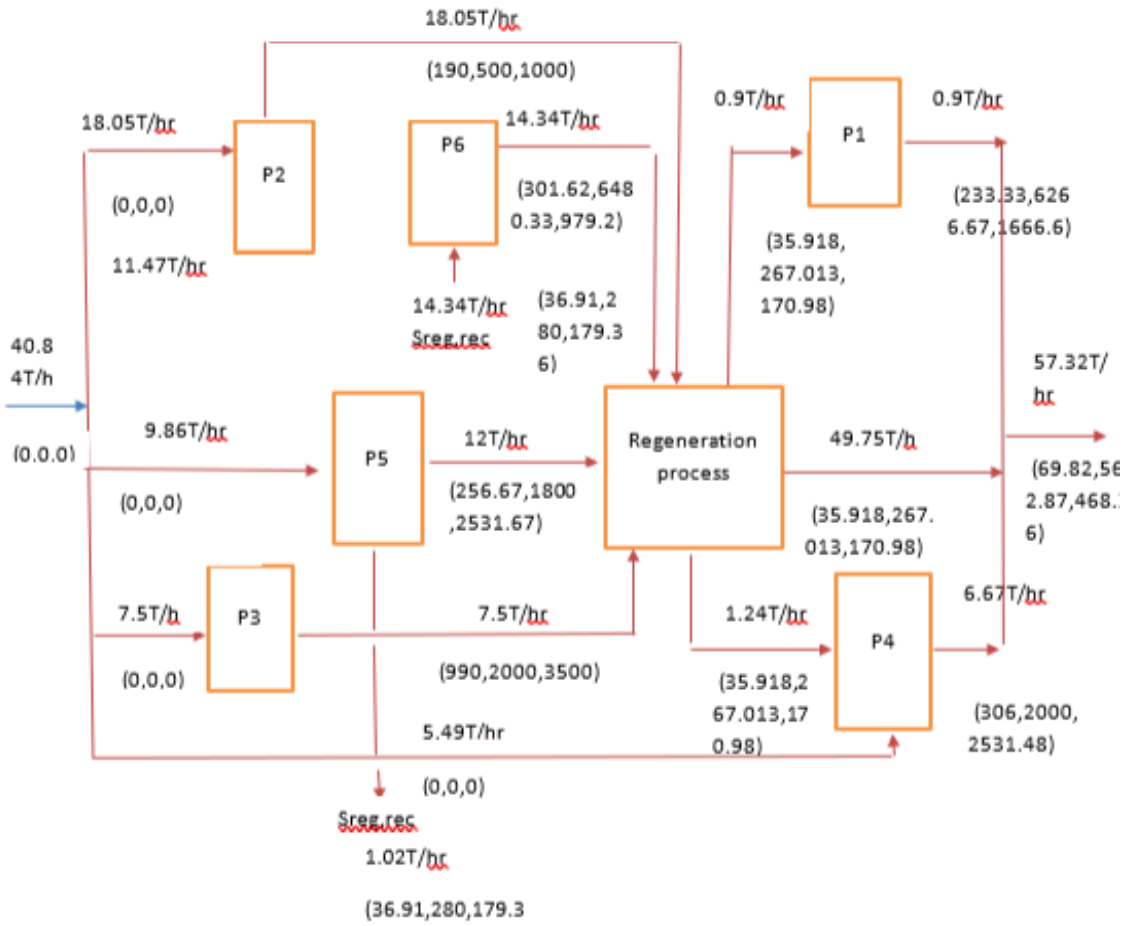


Fig. 5.2: The final water network design with regeneration

Table 5.4: Comparison table between using regeneration method and without regeneration method

	With using regeneration method	Without regeneration method
Fresh water(t/hr)	40.84	54.7775

Table 5.5: Comparison between Different Methods for Example (2)

	Zhaao H.P et al (2015)	Our paper
Frsh water consumption	53.826	40.84
Method	Linear programming	Systematic approach (Regeneration recycle)

VI. Result and Discussion

The optimization results of first case show that: Using equations (1) and (2), we can determine whether each process is an ABLP or a BLP. Processes P1, P4, P2, and P5 are identified as BLPs, while P3 is an ALP. By calculating the priority factor, we can establish the order of the processes as follows: P1, P4, P2, P5. For P1 and P4, fresh water is required as their inlet concentrations are zero and equal to 45 T/hr and 8 T/hr, respectively. Regarding P2, equation (3) is utilized to determine that the RKC is A for source S4. In this case, MD (mass demand) is greater than MS (mass source), indicating that all the water in S4 will be allocated to D2, amounting to 8 T/hr. S1 is selected as the source for P2, and the RKC is determined as B, resulting in a fresh water requirement of 2.2 T/hr. The old and new mass loads are calculated using equations (4) and (5), respectively. The new inlet and outlet concentrations are determined using equations (7) and (8) as Cin = (15.2, 294.12, 29.2) and Cout = (115.2, 12494.12, 164.2). For P5, S1 is chosen as S4 has been consumed. Hence, the RKC is B. The new and old mass loads are calculated, and the new inlet and outlet concentrations are obtained as (15, 400, 35) and (115, 8000, 95). The inlet and outlet regeneration calculations from equation (8) are (85.53, 8309.55, 117.25) and (85.53, 8.30955, 117.25).

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For P3, the RKC is determined as A from Sreg, and since MD is greater than MS, all the water from Sreg will be allocated to the demand, amounting to 59.7 T/hr. This value exceeds 56 T/hr, so there will be remaining water from Sreg. The old and new mass loads are calculated, and the new inlet and outlet concentrations are determined as (91.25, 8.86, 124.98) and (191.25, 33.86, 9424.98). By determining the minimum mass load, we can identify whether stream S3 or Sreg will be recycled. In this case, the stream from Sreg will be recycled. After repeating all the steps and calculating the inlet and outlet concentrations, it is observed that there is no need to recycle Preg because BLPs do not require any water from that recycled stream.

The optimization results of second case show that: Using equations (1) and (2), we can determine whether each process is an ABLP or a BLP. Processes P2, P3, P5, and P6 are identified as BLPs, while P1and P4 are an ALP. By calculating the priority factor, we can establish the order of the processes as follows: P2, P3, P5, P6. For P2 and P3, fresh water is required as their inlet concentrations are zero and equal to 18.05 T/hr and 7.5 T/hr, respectively. For P5 equation (3) is utilized to determine that the RKC is B for source S2. In this case, Ms (mass demand) is greater than Md (mass source), Water required from S4 is 1.2T/hr.

S2 is selected as the source for P6, and the RKC is determined as c, water required from S2 is 2.87 T/hr. calculating inlet and outlet regeneration calculation by using equation(9).

Cin reg= (369.07,2800,1793.6) and cout reg= (36.91,280,179.36)

For P4, the RKC is determined as B from Sreg, and since Ms is greater than Md, water required from sreg=1.18 T/hr, so there will be remaining water from Sreg.

For P1, the RKC is determined as A from Sreg, water required from sreg=7.31 T/hr, but we need only 0.9T/hr.

Recycled the stream which have minimum mass load, calculate ALPS mass load. We recycled the stream which has minimum mass load but that process has low flow rate near to be neglect, so we will take P reg.

So we will repeat steps from determining priority factor, we can establish the order of the processes as follows: P2, P3, P5, P6. For P2 and P3, fresh water is required as their inlet concentrations are zero and equal to 18.05 T/hr and 7.5 T/hr, respectively. For P5 equation (3) is utilized to determine that the RKC is B for source Sreg. In this case, Ms (mass demand) is greater than Md (mass source), Water required from Sreg is 2.14T/hr.

Sreg is selected as the source for P6, and the RKC is determined as B, water required from Sreg is 15.36 T/hr. calculating inlet and outlet regeneration calculation by using equation(9).

Cin reg= (351.98, 2670.13, 1709.8) and cout reg= (35.198,267.013,170.98)

For P4, the RKC is determined as B from Sreg, and since Ms is greater than Md, water required from sreg=1.24 T/hr, so there will be remaining water from Sreg. The old and new mass loads are calculated.

For P1, the RKC is determined as A from Sreg, water required from sreg=7.67 T/hr, but we need only 0.9T/hr.

VII. Conclusion

The primary aim of this study was to develop an optimized water network design that minimizes freshwater consumption through the strategic integration of regeneration, reuse, and regeneration recycle methodologies. By considering the presence of multiple contaminants within the industrial process, the proposed approach addresses the complex challenge of water management in a comprehensive manner.

The results of this work clearly demonstrate the benefits of adopting the advanced water network optimization techniques presented. Compared to a conventional water network design without any regeneration strategies, the inclusion of regeneration, reuse, and regeneration-recycle methods leads to significant reductions in freshwater intake requirements.

The optimization framework allows for the identification of the most cost-effective and environmentally sustainable water network configuration, Balancing the trade-offs between freshwater consumption, wastewater discharge, and the capital and operational costs of the water treatment infrastructure is a key challenge in optimizing water management in industrial processes. This requires carefully evaluating the various options and their implications. The ability to selectively remove contaminants and recirculate the treated water within the process is the key driver behind the superior performance of the regeneration-based water network.

This research provides industrial facilities with a valuable decision-support tool for designing and implementing water networks that minimize freshwater usage and promote the principles of a circular economy. By adopting the strategies outlined in this study, organizations can enhance their overall water sustainability, reduce their environmental footprint, and contribute to the responsible management of this critical natural resource.

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