SCIENTIFIC PAPER

Comparative Analysis of Water Network Minimization in Industrial Processes: Regeneration vs. Non-Regeneration Methods

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Abstract

The utilization of a regeneration method in water networks provides a distinct benefit by effectively decreasing the usage of fresh water and the release of wastewater; while also preventing the accumulation of contaminants, it is crucial to employ appropriate process decomposition strategies. In this study, our primary objective is to analyze the disparity between water networks that incorporate a regeneration unit and those that do not, in addition to addressing the primary objective of minimizing fresh water usage, our study focuses on examining the influence of different process decomposition strategies on the reduction of freshwater consumption using the concentration-mass load diagram as a tool for analysis. Moreover, we explore an approach for determining interim concentrations in multiple-contaminant water systems during the concentration decomposition process. Through the reduction of fresh water consumption, regenerated water flow rate, and contaminant regeneration load, we aim to minimize the overall impact on freshwater resources, we aim to synthesize an optimally designed regeneration recycling water network. We provide evidence of the feasibility and efficacy of our proposed approach by showcasing three case studies. The outcomes of selected literature examples indicate that the designs achieved through our work are comparable to those found in existing literature.

Keywords: Contaminant removal, Mathematical modeling, Optimization algorithms, Regeneration methods, Water network minimization.

Highlights:

- the regeneration method focuses on minimizing water network losses, such as leakage and inefficiencies
- it minimizes the risk of system failures and distributions in water supply
- the regeneration method contributes to environmental sustainability.

Introduction

Water network minimization plays a crucial role in enhancing the efficiency and sustainability of water distribution systems. By optimizing water consumption, and reducing losses, it 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[1]. By implementing this approach, we can ensure a reliable water supply for communities, promote water conservation, and work towards a more sustainable future. 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 [2]. Water consumption in Malaysia is predominantly driven by domestic and industrial activities, accounting for over 50% of the total water 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 [3].

The research focus on wastewater minimization has gained significant attention because of the crucial significance of water conservation and the imperative to decrease the discharge of wastewater. The incorporation of water systems plays a crucial role in attaining substantial reductions in both the consumption of fresh water and the discharge of wastewater by implementing practices such as wastewater reuse and regeneration recycling [4].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 underline the need for systematic tools for WWTP design[5]. The objective of wastewater management is to establish measures for environmental protection while considering economic and social concerns.

In light of the imperative to preserve water resources, the utilization of reused water represents a significant and strategic milestone towards achieving sustainable development. This approach offers the potential for substantial environmental, economic, and social benefits, By implementing consumption optimization measures and promoting water reuse, industries can potentially reduce their water consumption by 25 to 30% compared to current levels within the sector [6].To overcome the difficulties of cutting water usage in industrial processes without significantly altering the plant, to get around the challenges of reducing the amount of water used in industrial operations without drastically changing the plant. There is currently a considerable trend towards the implementation of pollution control approaches at the source, specifically through the reuse and/or recycling of wastewater.

The loop breaking technique has been discussed, highlighting how it can be adapted to manage flow rates and water losses[7]. A novel graphical method has been introduced to illustrate the relationship between supply and demand, focusing on concentration versus flow rate[8]. Achieving a global optimum in nonlinear mathematical programming[9], particularly with many variables, poses challenges. A new graphical approach addresses the distribution of wastewater quality while optimizing fresh water allocation[10]. Additionally, a method for creating water utilization networks in process plants aims to minimize fresh water and utility use[11].

The concept of concentration potential serves as a foundation for regeneration and recycling in water networks[12]. A methodical design approach has been developed to simultaneously manage energy and water systems, maximizing water reuse[13].

In practice, identifying the best strategies for reusing water between operations can be complex due to numerous mixing and reuse options. Since the early 1990s, various design methodologies have been proposed to systematically explore water reuse within networks, primarily based on limiting water profiles. This design philosophy has been successfully applied across various industrial sectors, demonstrating the benefits of integrated and system-wide analysis in water system design and operation.

The advantages of this method include targeting the maximum potential for water savings and simplifying the synthesis of water networks. This is done by manipulating information related to water conditions, such as flow rate and concentration, while not involving the specific conditions of process streams. This simplification provides a common, yet powerful, basis for integrated design frameworks, even if the mass transfer mechanisms for water use differ across operations.

Three primary applications for wastewater reuse in industry include cooling towers and HVAC systems, industrial processes and manufacturing, and energy production[14]. In industrial settings, treated wastewater can serve as a cost-effective and sustainable source for heating, cooling, and ventilation. It can function as a cooling agent, reducing freshwater intake and energy consumption, while also improving system efficiency and lowering maintenance costs.

However, it is essential to ensure that wastewater is appropriately treated and disinfected prior to use to prevent microbiological growth and minimize health risks. Effective design, maintenance, and operation of these systems are crucial for optimizing performance and safety.

Wastewater can also be utilized in energy production. Treated wastewater may be used as a cooling source to drive turbines for electricity generation or as a feedstock for biofuel

In this paper, the main focus is on the minimization of fresh water usage in water systems. To achieve this goal, the regeneration-reuse method is employed. The key aspect of this method is the determination of the specific contaminant that needs to be minimized. By analyzing the concentration of the contaminant at both the inlet and outlet points of the water system, appropriate measures can be taken to reduce its presence. The regeneration-reuse method offers several advantages. Firstly, it helps in preserving valuable freshwater resources by reusing treated wastewater instead of relying solely on fresh water sources. Secondly, it contributes to cost reduction, as recycling wastewater can be more economical compared to constantly using fresh water. Additionally, it provides environmental benefits by minimizing the discharge of contaminants into natural water bodies. By incorporating the regeneration-reuse method and considering the analysis of contaminant concentration, this paper aims to optimize water networks and achieve an optimal balance between water conservation, cost reduction, and environmental sustainability.

Problem Statement:

Design and optimize an integrated water minimization and regeneration network for an industrial manufacturing facility with the following objectives and requirements [15]:

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

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 objectives through effective integration of reuse, regeneration, and minimization strategies to reduce the plant's water usage, costs, and environmental impacts.

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

$$Lim\ CR = C0 * (1 - RR) \qquad (1)$$

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

Step 3: 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 prioritize the reuse of one source over the others. Equation 1 displays the source stream with the highest quasi allocation ratio value first [16,17,18]

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

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. (RKC) for Si, DJ
3) The source with the next-highest quasi-allocation amount should be selected if one source is unable to fully meet the demand. (Ri, j) value
4) Calculate the mass load for demand and source at a definite reuse key contaminant by equations:

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

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

There are three cases for mass load,

a. The source provides all of the water in it to the demand if the mass load of RKC for the source (MS) equals the mass load of RKC for the demand (MD). If the mass load of RKC for source is higher than the mass load of RKC for demand, in this situation, the source gives only the amount of water as follows:

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

And the other needed water is taken from fresh water

b. When the RKC mass load for the source is less than the RKC mass load for the demand. In this case, the source provides all the water needed to meet demand, and the source with the next-highest Ri, j value is used to provide the remaining water.

Step 4: after allocation, determine the updated concentrations at the intake and output for each process [18] as follows:

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

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

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

<u>Basically, the method consists of seven steps described in the following using regeneration method</u>

Step 1: determine the fresh water processes (FWPs), which their inlet concentration is zero

Step 2:

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 from equation (1)
3) determine type of processes:
    a. calculate the average of limiting concentration of regeneration
    b. if the concentration of contaminant lower than the average of limiting concentration take φ sign
    c. if the contaminant concentration is at least as high as the limiting concentration average take η sign
    d. if φ >η the process called below process (BP)
    e. if η>φ the process called above process (AP)

Step 3:

1) Using CPD values to determine the order in which processes should execute
2) determining CPD for (BP+FW) process by using equation [17,19].

$$CPD(Dj) = \sum_{i=1}^{Ns} min\ k = 1,2,3, \dots NC \left(\frac{CD\ lim\ i,k}{CSi,k}\right) \quad (8)$$

where, CD Lim I, k is limiting concentration of contaminant K in demand stream Dj, CSi, k is the concentration of contaminant K in source stream Si, Nc is the number of contaminants, NS is the source stream order

Step 4: 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 [16,17,18] from equation (2)

2) When Si is the allocation to DJ, the concentration reaching the limiting value first, will be called as reuse key contaminant (RKC) for Si, DJ

3) If the demand cannot be totally satisfied by one source, another source should be used which have next highest the quasi-allocation amount (Ri, j) value

4) Calculate the mass load for demand and source at a definite reuse key contaminant by equations (3) and (4)

a. In this case, the source provides all of the water in it to the demand if the mass load of RKC for the source (MS) equals the mass load of RKC for the demand (MD).

b. The source only provides the following amount of water in the event that the total mass load of RKC for the source is more than the mass load of RKC for the demand, from equation (5)

c. when the RKC mass load for the supply is less than the RKC mass load for the demand. In this case, the source provides all the water needed to meet demand, and the source with the next-highest Ri, j value is used to provide the remaining water.

Step 5: after allocation, determine the updated concentrations at the intake and output for each process as follows by using equations (6) and (7)

Step 6: calculation of inlet regeneration concentration by using equation:

$$C^{o}reg = \sum_{i}(F_{si}^{lim}\, C_{reg,s}^{lim})/\ \sum_{I} F_{si}^{lim} \quad (9)$$

Step 7: repeat Step 4 Design procedure of water using networks.

Algorithm:

Figure (1)

Case study:

Example (1): (multi contaminant, three processes)

This case study is taken from [19] with the information displayed in table (1), and the removal ration is (0%, 99.9%, 0%).

In this particular example, we consider a water network comprising three 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 [17].

Figure (2)

According to water network without regeneration

Based on the determined order of processes (P1, P3, P2), the allocation of process P1 involves a fresh water requirement of 45T/hr. The determination of the recycle and keep concentration (RKC) in process 3 is denoted as (B), calculated using equation (2). Subsequently, equations (3) and (4) are employed to obtain the values. It is observed that the mass source (S1) exceeds the mass demand (D3), indicating a requirement of 2.8 T/hr. of water from S1 to D3, as determined by equation (2.5). The total amount of fresh water required is 53.2 T/hr. Utilizing equations (6) and (7), the new inlet and outlet concentrations are calculated as follows: CN, I = (0.75, 20, 1.75) ppm and CNO = (100.75, 45, 9301.75).

Within process 2, two sources, S1 and S3, are present. By applying equation (2), source S1 is selected with an assigned RKC of B. Equations (3) and (4) are then utilized to determine the corresponding values. The analysis reveals that the mass source (S1) surpasses 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 (5). The total fresh water demand amounts to 8.5 T/hr. Employing equations (6) and (7), the new inlet and outlet concentrations can be calculated as follows: CN, I = (11.26, 300, 26.26) ppm and CNO = (111.25, 12500, 161.26).

The table S1 (Supplementary material) exhibits the definitive results achieved in example (1) for three distinct processes, each comprising three contaminants. These results were obtained by employing the RKC method for process sequencing and selection. This table facilitates the identification of the appropriate process that aligns with the desired quantities of regeneration water. Notably, it is observed that process 1 exclusively necessitates the use of fresh water. We have only one outlet stream P3, that stream will recycle

Figure (3)

The table S2 (Supplementary material) provides a comparative analysis between the utilization of a regeneration method and the absence of such a method. The disparity between the two approaches is evident, as the regeneration method necessitates a greater quantity of fresh water compared to the method without regeneration.

Table (2) describes the disparity between the prior research and our own study. Our employed methodology demonstrates a decreased fresh water flow and regenerated flow that is lower than what was observed in the earlier work.

Example: (2): (multi contaminant, five processes) This case study is taken from [20] using the information displayed in the table (3), including 5 processes, 3 contaminants and the removal ratio for regeneration is (0. 99.9%, 0)

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 [20].

Figure (4)

According to network without regeneration:

Based on the determined order of processes (P4, P1, P3, P5, P2), the allocation of process P1 and P4 requires a fresh water requirement of 50 T/hr. and 8 T/hr., respectively. The determination of the recycle and keep concentration (RKC) in process 3 is denoted as (B) in S4 after choosing between S1 and S4, calculated using equation (2). Subsequently, equations (3) and (4) 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 (5). The total amount of fresh water required is 46.4 T/hr. By utilizing equations (6) and (7), 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 (2), source S1 is selected with an assigned RKC of B. Equations (3) and (4) 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 (2.5). By employing equations (6) and (7), 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 (2), source S1 is selected with an assigned RKC of B. Equations (3) and (4) 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 (5). By employing equations (6) and (7), the new inlet and outlet concentrations can be calculated as follows: CN, I = (15, 400, 31.25) ppm and CNO = (115, 8000, 91.25).

Table S3 (Supplementary material) displays the conclusive outcomes obtained in example (2) involving five distinct processes, with each process consisting of three contaminants. These results were derived through the implementation of the RKC method for the purpose of process sequencing and selection. The table serves as a helpful tool for identifying the most suitable process that corresponds to the desired quantities of regeneration water. It is worth noting that process 1 and process 4 specifically require the utilization of fresh water exclusively.

Figure (5)

Table S4 (Supplementary material) presents a comprehensive comparative analysis investigating the use of a regeneration method versus the absence of such a method. The findings clearly demonstrate a notable discrepancy between the two approaches, with the regeneration method requiring a significantly larger volume of fresh water in comparison to the method that does not incorporate regeneration. This suggests that the regeneration process is more resource-intensive and demands a higher input of fresh water. It is important to consider the implications of this disparity when selecting and implementing a suitable method for water treatment or purification. Furthermore, additional research may be warranted to explore potential strategies for optimizing the regeneration process and minimizing the overall fresh water requirement.

Table 4 presents a comparison between the findings of previous research and our own study, highlighting the divergence between the two. Our adopted methodology showcases a reduction in both fresh water flow and regenerated flow, which are lower in magnitude compared to the observations made in the earlier investigation. This indicates that our approach has successfully achieved a more efficient utilization of fresh water and regeneration resources, surpassing the outcomes of the previous research. It is important to acknowledge the significance of these advancements in terms of water conservation and resource optimization.

Result and discussion

The optimization results of first case show that: process (1) determine the processes which feed the regeneration process by water (BP), and processes which take water from a regeneration process (AP), then we can determine the above and below limiting process by using equation (8), that determine P1 and P2 are BLPs and P3 is ALPS, then allocate of source to demand for BLPs that determine P1 will take fresh water as inlet concentration is zero, and determining RKC is B, Mass load calculation, introduce that MS> MD, SO water required from S1 to D2 is 25.5T/hr. and fresh water =8.5T/hr., by using equations (3),(4) and equation. respectively we can calculate old and new mass load after that we can determine new inlet concentration and new outlet concentration by using equations (6)(7). the values are (11.26,300,26.26) and (111.26,12500,161.26) respectively.

Calculation of inlet and outlet regeneration concentration by using equation (9) and values are (76.16,8089.72,115.24) and (76.17,8.089.72,115.24) respectively. According to calculation of priority factor for ALPs to determine the order of processes, Preg and P3.the allocate for ALPs and regeneration source, we can determine that RKC is contaminant A and MS less than MD, so regeneration source will give all water in it to demand of P3, fresh water is 2.5T/hr., calculate inlet and outlet concentration which values are (72.85,7.7,110.2) and (172.85,32.7,9410.3), there is only one stream, P3 will be recycled. Repeat steps until reach to allocation of P3 and regeneration source, in this situation MS less than MD, so S reg will give all water to the demand and there is no another source to take water from it, the amount of fresh water is 1.98T/hr., and inlet and outlet concentrations are (74.28,8.04,197.5), (174.28,33.04,9497.5).

The optimization results of second case show that: Using equations (2) and (8), 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 (2) 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 (3) and (4), respectively. The new inlet and outlet concentrations are determined using equations (6) and (7) 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 (2.9) are (85.53, 8309.55, 117.25) and (85.53, 8.30955, 117.25).

For P3, the RKC is determined as A from S reg, and since MD is greater than MS, all the water from S reg 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 S reg. 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 S reg will be recycled. In this case, the stream from S reg 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.

Conclusion

The primary focus of this study centers on minimizing the usage of fresh water in water systems. To accomplish this objective, the regeneration-reuse method is employed. A critical aspect of this method involves identifying the specific contaminant that necessitates reduction. Appropriate steps can be taken to reduce the contaminant's presence by determining its concentration at the water system's entry and output points. It provides environmental benefits by minimizing the release of contaminants into natural water bodies. By incorporating the regeneration-reuse method and considering the analysis of contaminant concentration, the primary objective of this paper is to optimize water networks and attain a harmonious balance between water conservation and environmental sustainability.

In this research, our primary objective is to analyze the disparity between water networks that incorporate a regeneration unit and those that do not, while also addressing the overarching concern of minimizing fresh water usage. Our goal is to create an optimally planned regeneration water network by minimizing the amount of freshwater used, the flow rate of regenerated water, and the load of contaminants during regeneration. Additionally, we propose simplifying the network structure by considering the objective of minimizing the number of interconnections among processes.

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Figure Captions

Figure (1): water network minimization flow chart

Figure (2): network design without regeneration

Figure (3): final network design with regeneration

Figure (4): network design without regeneration

Figure (5): the final water network design with regeneration

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

process	contaminant	Mass load (Kg/hr.)	C_{in} (ppm)	C_{out} (ppm)
Distillation	Hydrocarbon (A)	0.675	0	15
	H2S (B)	18	0	400
	SALT (c)	1.575	0	35
Hydro-desulphurization	Hydrocarbon (A)	3.4	20	120
	H2S (B)	414.8	300	12500
	SALT (c)	4.59	45	180
DE salter	Hydrocarbon (A)	5.6	120	220
	H2S (B)	1.4	20	45
	SALT (c)	520.8	200	9500

Table (2): Comparison between Different Methods for Example 1

	Minimum fresh water flow rate/t·h -1	**Minimum regenerated water flow rate/t·h -1**
Kuo and Smith	59.7	55.6
In this paper	55.48	53.5

Table (3): limiting data for example (2)

Process	**Contaminant**	**C_{in} (ppm)**	**C_{out}(ppm)**	**F_{max} (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	

Table (4): Comparison between Different Methods for Example (2)

	Minimum fresh water flow rate/t·h -1	**Minimum regenerated water flow rate/t·h -1**
Kuo and Smith	59.7	55.6
Liu et al.	59.7	55.5
Ying, Li; Jintao, Guan	59.7	56
In this paper	59.7	56

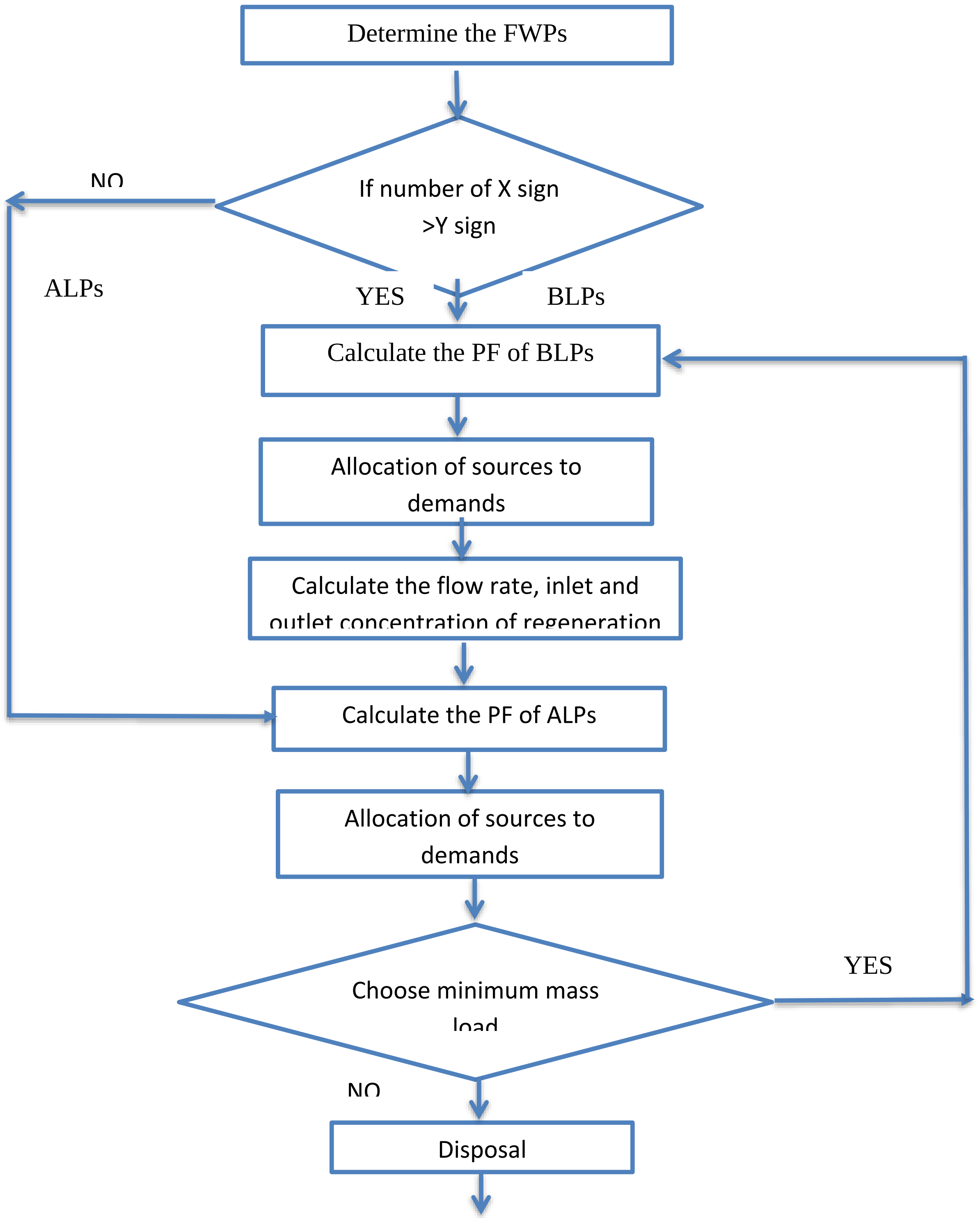
Determine the FWPs
If number of X sign
>Y sign
NO
ALPs
YES
BLPs
Calculate the PF of BLPs
Allocation of sources to
demands
Calculate the flow rate, inlet and
outlet concentration of regeneration
Calculate the PF of ALPs
Allocation of sources to
demands
Choose minimum mass
load
YES
NO
Disposal

Figure (1)

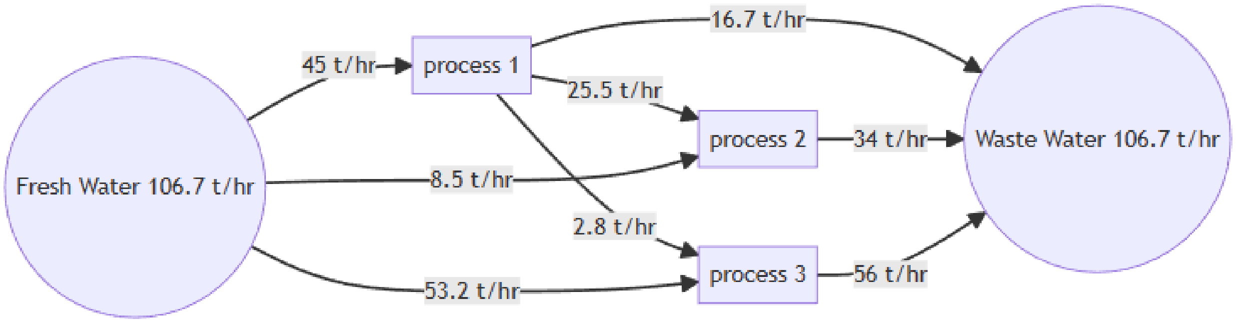
16.7 t/hr
45 t/hr
process 1
25.5 t/hr
process 2
34 t/hr
Waste Water 106.7 t/hr
Fresh Water 106.7 t/hr
8.5 t/hr
2.8 t/hr
process 3
56 t/hr
53.2 t/hr

Figure (2)

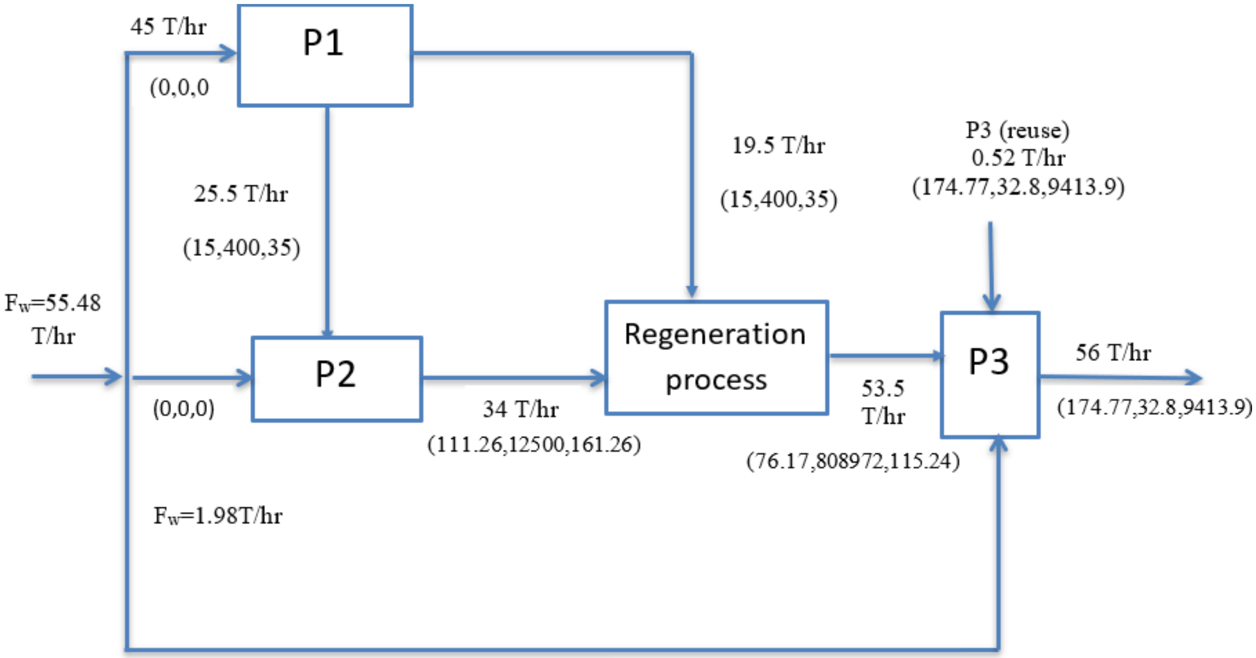
45 T/hr
(0,0,0
P1
25.5 T/hr
(15,400,35)
19.5 T/hr
(15,400,35)
P3 (reuse)
0.52 T/hr
(174.77,32.8,9413.9)
Fw=55.48 T/hr
(0,0,0)
P2
34 T/hr
(111.26,12500,161.26)
Regeneration process
53.5 T/hr
(76.17,808972,115.24)
P3
56 T/hr
(174.77,32.8,9413.9)
Fw=1.98T/hr

Figure (3)

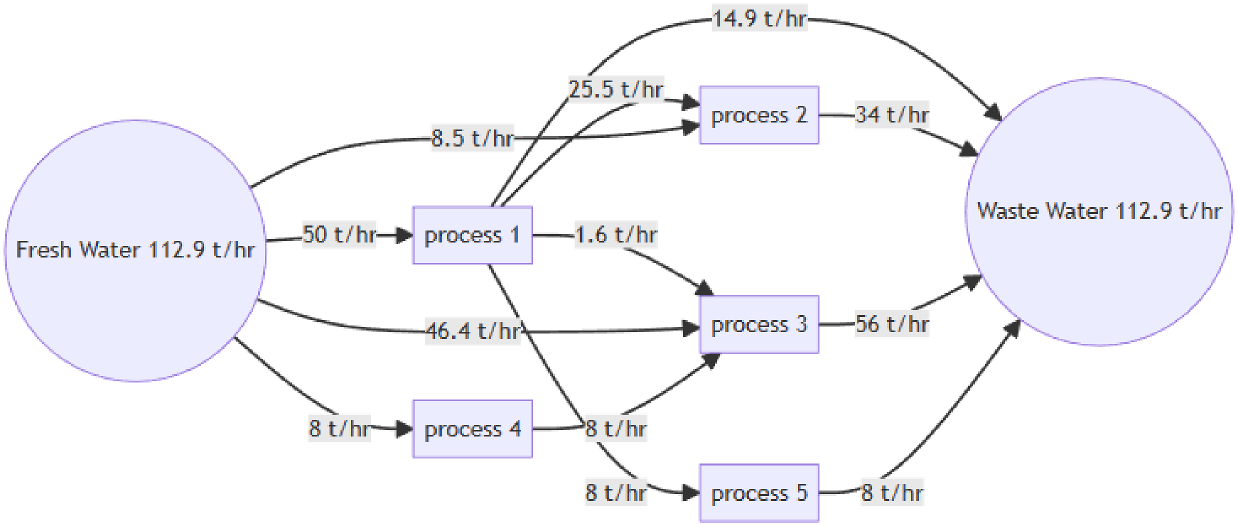
14.9 t/hr
25.5 t/hr
process 2
34 t/hr
8.5 t/hr
Waste Water 112.9 t/hr
Fresh Water 112.9 t/hr
50 t/hr
process 1
1.6 t/hr
46.4 t/hr
process 3
56 t/hr
8 t/hr
process 4
8 t/hr
8 t/hr
process 5
8 t/hr

Figure (4)

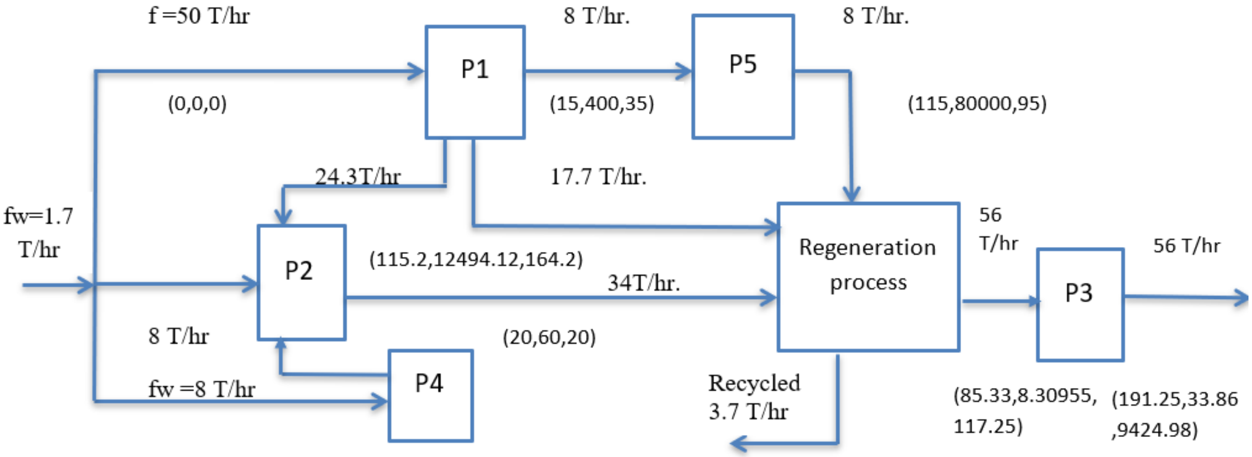
f =50 T/hr
(0,0,0)
P1
8 T/hr.
(15,400,35)
P5
8 T/hr.
(115,80000,95)
24.3T/hr
17.7 T/hr.
fw=1.7 T/hr
P2
(115.2,12494.12,164.2)
34T/hr.
Regeneration process
56 T/hr
P3
56 T/hr
8 T/hr
(20,60,20)
P4
fw =8 T/hr
Recycled 3.7 T/hr
(85.33,8.30955, 117.25)
(191.25,33.86 ,9424.98)

Figure (5)