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Conceptual Optimization of Water and Wastewater Network of a Gas Refinery with Considering Pressure Drop and Pumping Cost

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Abstract: This paper aims to introduce a constructive method for optimizing the supply of freshwater and wastewater in the process industry. Different conceptual methods such as Composite Table Algorithm (CTA), Extended Composite Table Algorithm (ECTA), Composite Matrix Algorithm (CMA) have been investigated to optimize water and wastewater network. Also, Mixed Integer Non-Linear Programming (MINLP) as a mathematical and Cuckoo Search (CS) as artificial inelegance approaches have been applied and compared with conceptual methods. In this study, pressure drop calculations and pump cost have been considered as well. In this regard, a computer program has been developed to compute the CTA, ECTA, CMA, and CS approach for a water and wastewater network. The MINLP method has been performed in the APSEN WATER software. A water and wastewater network of a gas refinery has been considered as a case study. Results show that between targeting approaches, the CMA method is a more powerful tool for optimum cost rather than CTA and ECTA. Finally, CMA, CS, and MINLP yield almost similar results. However, CS and MINLP are more time-consuming in comparison with targeting approaches.

keywords: CTA, ECTA, MINLP, CS, Water Network, Gas Refinery

1. Introduction

Freshwater has always been a rare natural resource and it is one of today's biggest problems. As water is consumed in various industries, it is necessary to optimize and minimize available water supply. With the rising costs of freshwater consumption and wastewater treatment, there is an essential requirement to amend the rate of water consumption in the process industry.

In the early 1980s, simultaneous energy crisis, pinch technology was introduced as a technique for designing a heat exchanger network. Pinch analysis was also considered as recovery energy. Heat integration was published by Linnhoff.

In general, pinch analysis is based on process integration and includes heat and mass designs. It has been used in various processes such as mass integration (El-Halwagi & Spriggs, 1998), water (Mann & Liu, 1999), (Wang & Smith, 1994) and hydrogen (Alves & Towler, 2002). Researchers like (Hallale & Liu, 2001), (Ataei & Yoo, 2010), (Nabi Bidhendi, Mehrdadi, & Mohammadnejad, 2010) and others have been working on water pinch technology, too.

To minimize water consumption in industrial processes, there are four possible methods namely, reuse, recycling, regeneration - reuse/ recycling and process changes. In reuse and recycling processes, the extent of contamination is important because the effluent of one plant is returned directly to another plant or the same process is recycled without treatment.

The fourth method involves the replacement of utilities that use water from other utilities. For example, water cooling is replaced with an air cooling system (Buehner & Rossiter, 1996).

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In the water pinch technique, the problems are divided into two types, a fixed flow (FF using the source and sink) and a fixed load (FL). The FL operation is based on mass transfer, like vessel cleaning, solvent extraction, gas absorption, etc. On the other hand, the problems of FF are various operations based on a massless transfer, such as a boiler, a cooling tower, filters, etc. For FF operation, Loss or gain occurs because the input rate is not equal to the output.

The initial graphical method, limiting the composite curve (LCC), was presented by Wang and Smith (Wang & Smith, 1995). This method was originally applied to the reuse and recycling of water systems for fixed load problems. It is possible to control a minimum of freshwater by diagnosing pinch point for reusing or recycling.

Material Recovery Pinch Diagram (MRPD) is another targeting method that was developed for FF issues. The MRPD was presented by two different teams (El-Halwagi, Gabriel, & Harell, 2003); (Prakash & Shenoy, 2005). The main flaw of this method is that just the visual solution and magnification graph are important.

Composite Table Algorithm (CTA) is a combination of graphical and numerical methods (Agrawal & Shenoy, 2006). CTA was developed for all types of problems and can simultaneously solve FL and FF operations. Although similar to the Water Cascade Diagram (WCD), CTA is less complicated and should be improved.

First, the concentration of the sink and source processes are getting more and more in order, after which the graphical representation of this method is obtained by LCC. CTA is used both graphically and numerically to handle various problems in the water system although regeneration problems cannot be satisfactory.

The Extended Composite Table Algorithm (ECTA) is an extension of the CTA with the development of numerical phases to control the water regeneration network (Bai, Feng, & Deng, 2007). All steps are similar to CTA. Only two levels are added to determine the regeneration flow rate (F_{reg}) and the concentration of the regeneration concentration (C_{reg}).

The post-regeneration concentration (C_0) is also taken into account. The next method is the composite matrix algorithm (CMA), which determines all possible decisions C_0. Eventually, the best C_0 is characterized by a minimum of water and optimization of the total cost of the water network (Parand, 2014).

In the other research, Pungthong & Siemanond proposed MINLP model for water and wastewater networks with considering multiple contaminants (Pungthong & Siemanond, 2015). All mathematical models are solved by DICOPT solver in GAMS software. This model gives better TAC than other previous studies.

Hong et al performed the optimization of heat-integrated water networks. It was a novel mathematical programming model to solve large scale problems and to use for separate and uniform treatment cases (Hong, Liao, Jiang, Wang, & Yang, 2016).

Salgot and Floch developed wastewater treatment and water reuse based on risk assessment. One of the main developments in the reuse world is risk assessment (Salgot & Folch, 2018).

A stochastic programming method has been applied by Naderi and Pishvaee to integrated water and wastewater network design (Naderi & Pishvaee, 2017). In this regards, two-level stochastic programming based on an accelerated benders decomposition algorithm is developed. Results illustrate the advantages of the extended stochastic programming model and the efficiency of the solution method.

Velasquez-Orta et al introduced retrofitting scenarios to target climate changes for wastewater networks. Energy demand and CO2 emission for a wastewater network were predicated (Velasquez-Orta, Heidrich, Black, & Graham, 2018).

Design of heat integrated water networks with considering multiple contaminants has been proposed by Zhao et al.

By using the proposed method, the obtained structures of the network were simple, and the total annual costs were comparable with other literature in this field (Zhao, Yang, & Liu, 2019).

Multi-agent hybrid particle swarm optimization (MAHPSO) to optimum network planning of wastewater treatment has been proposed by Ye et al. MAHPSO can solve problems with mixed variables and nonlinear relationships. The results compared with hybrid PSO & genetic algorithm (Ye, Chen, Jing, Zhang, & Liu, 2019).

In the other research, souifi and souissi performed water and energy - saving simultaneously in cooling water networks Using Pinch Approach (Souifi & Souissi, 2019). The main parameter of the proposed approach is the conversion of the cooling demands to its equivalent demand. In this regard, Demand-Composite Curve was introduced base on targeting concept.

As shown, in the previous literature in this field, the pressure drop and pumping costs have not been considered in the optimal design of water and wastewater networks. In addition, the comparison between different approaches to optimal design have not been performed. Also, CTA, ECT and CMA targeting methods have been not applied in a gas refinery case. Furthermore, Cuckoo search algorithm was not applied to the optimal design of such systems.

In this study, different new conceptual, mathematical and cuckoo search approaches have been employed to the optimal design of water and wastewater network of a gas refinery. Also, the pressure drop and pumping cost have been considered in the optimization model. To minimize water and wastewater, one part of a unit operation which is related to a gas refinery is chosen, and three graphical/numerical methods CTA, ECT, CMA targeting approaches are considered for this process. Also, MINLP and CS have been performed and evaluated. Finally, the appropriate method is discussed.

2. Case Study

The study is applied to a unit of an oil refinery for multi contaminants. This process is a segment of sour gas sweetening. The process of water absorption is located before Amine gas treating. Temperature can be one of the contaminants in the process, but in this research, it is not considered. The simplified process flow diagram of a water network in refinery has been shown in Fig1.

Total discharge of contaminants is 55.54 ppm, 368.66 ppm, and 312.42 ppm, for TOC, Soluble and Solids, respectively. Each inlet and outlet flow have a specific amount of contamination.

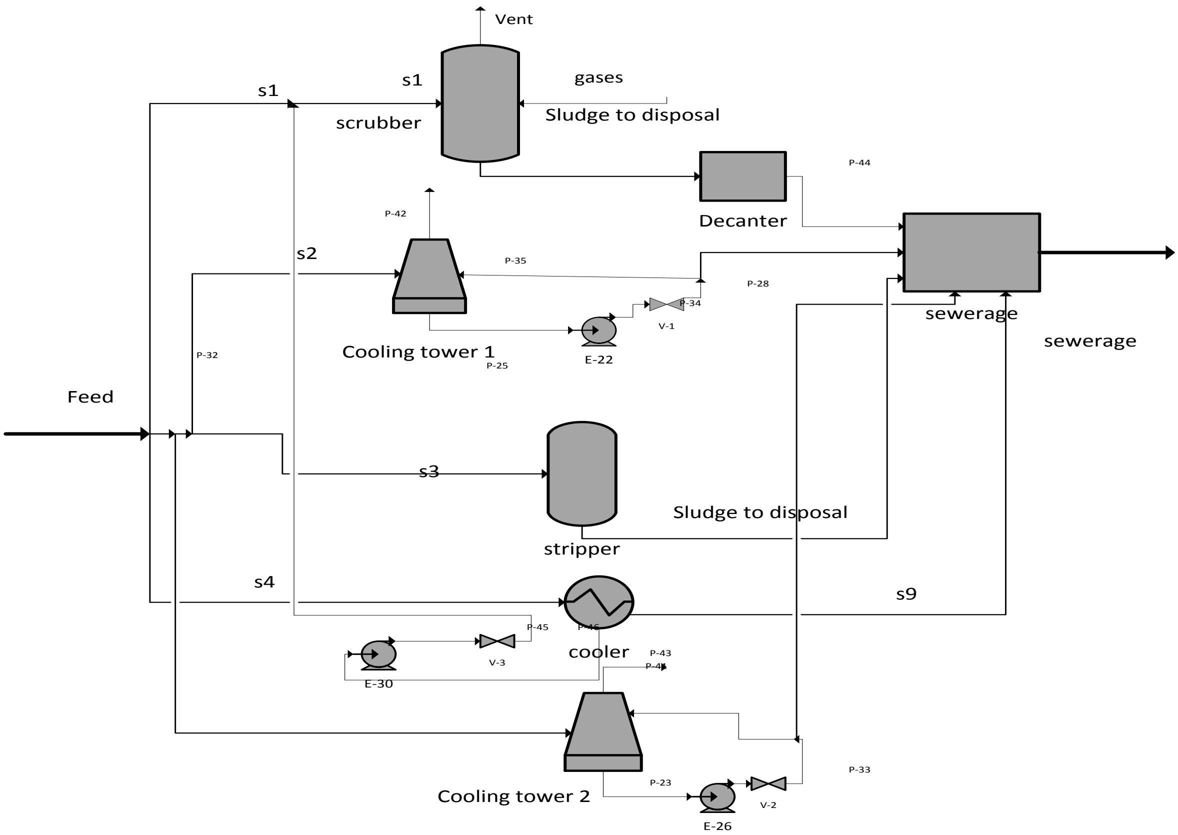

Figure 1. Water Network of selected Gas Refinery

3. Methodology

3.1. Problem Definition

Generally, problems are arranged in two types: FF and FL. Removal contamination is the main objective in FL problem, where water flow is used as a lean stream to separate mass load. In the FF problem, the inlet and outlet flow rates are not equal. This method surveys the process from the sink and source perspective. There is a possibility to convert FL model to FF and vice versa. In FL problems, inlet and outlet flow rates can be considered as sinks and sources of the FF model. Total water regeneration system includes process sinks or sink streams, process sources or source streams and regeneration unit. First of all, process sinks which are known as processes require water or inlet water streams. F_j and C_j are flow rate and inlet concentration, respectively. Besides, process sources are originally outlet wastewater streams which are reuse or recycle to process sinks. F_i and C_i are Flow rate and outlet impurity concentration. Regeneration unit is placed in the water regeneration system to partially purify process sources. Fixed post-regeneration concentration (outlet concentration from the regeneration unit (C_0)) and removal ratio (RR) are two main factors which are assessed in the regeneration unit (Parand, 2014).

$$RR = \frac{C_{reg} - C_0}{C_{reg}} \tag{1}$$

If the process sources (outlet wastewater streams) are not satisfied for the process sinks after regeneration unit in both aspects of quality (contaminant mass load) and quantity (flow rate), the external Freshwater source enters into network water.

In ECTA method, the flow rate of freshwater (F_{fw}), wastewater flow rate (F_{ww}), regenerated water (F_{reg}), the concentration of wastewater (C_{ww}) and post-regeneration concentration (C_0) are key parameters. It is necessary to mention that the contaminant concentration of freshwater can be zero ($C_{fw} = 0$) or impure ($C_{fw} \neq 0$) (Parand, 2014).

3.2. Extended Composite Table Algorithm (ECTA) Model:

According to the Flowsheet, data is extracted, and Limiting Data is listed in Table 1. Limiting data is adjusted by the FL problem. To apply the ECTA for the FL problems, first of all, it is necessary to convert the Limiting Data from FL problem to FF problem (by the process sinks and sources). Hence, inlet streams to processes are sinks (P1in, P2in, and P5in) and outlet streams from processes are sources (P1out, P2out, ... and P5out).

The converted Limiting Data are shown in Table 1. ECTA consists of eight steps; the first six steps are targeted for minimum freshwater for reuse-recycle.

Table 2 shows the extended composite table algorithm. As it is shown in column 2, concentration has an ascending trend and the arbitrary value is added (larger than other). The interval net flow rate ($NetF_k$) is calculated in column 3. For each concentration interval, the difference of the sum of process source flow rate from the sum of process sink flow rate is assessed. It is vitally important to notice that there is not any loss or gain for the FL problem which is converted to FF problem. In column 4 Δm_k interval impurity loads are indicated, which are computed by multiplying the net flow rate and the difference of contaminant concentration levels. To calculate cumulative load ($C_{um}\Delta m_k$), the first input is assumed zero and (Δm_k) sum with each column, respectively. Next column is the interval freshwater (F_{fw}), and the flow rate is related to reuse/recycle. F_{fw} can be calculated in Table 3. In this column, the maximum value is known as the minimum amount of fresh water needed.

For the regeneration section, the minimum regeneration flow rate is set as a target, and it is indicated as the interval regenerated water flow rate (F_{reg}). Since the total regeneration system is assumed, the regeneration flow rate is equal to freshwater flow rate. The largest value in this column is known as a principal F_{reg}. The last column is the interval regeneration concentration (C_{reg}). The maximum value in this column is determined as minimum regeneration concentration. The associated concentration level is known as regeneration pinch concentration (C_{preg}). Wastewater flow rate (F_{ww}) and contaminant concentration are calculated. In the absence of water loss, F_{fw} is equal to F_{ww} .

Table1. Limiting water data according to source and sink

Sink	F_{skj}	C_{skj}	Source	F_{SRi}	C_{SRi}
P1in	13.5	50	P1out	13.5	1011.99
P2in	77.77	50	P2out	18	77.77
P3in	250	50	P3out	18	250
P4in	50	50	P4out	13.5	50
P5in	150	50	P5out	27	150

Table 2. Extended Composite Table Algorithm

K	C_k	Net F $_k$(ton/h) (ton/h)	Delta M	Cum Delta M	F_{fw}	F_{reg}	C_{reg}
1	50			0	0	0	
2	77.77	76.5	2.124405	2.124405	27.3165102	15.6736388	
3	150	58.5	4.225455	6.34986	42.3324	22.6780714	150
4	250	31.5	3.15	9.49986	37.99944		188.9007
5	1011.99	13.5	10.286865	19.786725	19.552293		-119.485
6	1050	0	0	19.786725	18.8445		-157.495

Table 3. key parameters of ECTA and CMA (Parand, 2014)

	ECTA	CMA
C_0	A proper C_0 is given	$C_{0_n} = {C_0}^{min} + \Delta$ ${C_0}^{min} \le C_{0,n} \le {C_0}^{max}$ $\forall n \in N' = 1,2,3,\ldots, \frac{{C_0}^{max} - {C_0}^{min}}{\Delta} + 1$
F_{fw}	$F_{fw} = \frac{C_{um}\,\Delta m_k}{(C_k - C_{fw})}$	$F_{fw} = \frac{C_{um}\,\Delta m_k}{(C_k - C_{fw})}$
F_{reg} & C_{reg}	$F_{reg,k} = \frac{C_{um}\Delta m}{2C_k - C0}$ $C_{reg,k} = \frac{C_{um}\Delta m_k - F_{reg}(C_k - C_0)}{F_{reg}}$	$MF_{reg,k} = \frac{C_{um}\Delta m}{2C_k - C_{0,n}}$ $\forall n,k \rightarrow C_{0,n} \le C_k \le C_{pr}$ & $\forall n \in N'$ $MC_{reg,nk} = \frac{C_{um}\Delta m_k - F_{reg,n}(C_k - C_{0,n})}{F_{reg,n}}$ $\forall k,n \rightarrow C_{pr} \le C_k$ & $\forall n \in N$
F_{ww} & C_{ww}	$F_{fw} - F_{ww} = \sum_j F_j - \sum_i F_i$ $(Ff_w \times Cf_w) - (F_{ww} \times C_{ww}) - (F_{reg} \times (C_{reg} - C_0)) = \sum_j F_j C_j - \sum_i F_i C_i$	$F_{fw_n} - F_{ww_n} = \sum_j F_j - \sum_i F_i$ $-(F_{ww_n} \times C_{ww_n}) - (F_{reg_n} \times (C_{reg_n} - C_{0_n})) = \sum_j F_j C_j - \sum_i F_i C_i$

According to the Limiting data, $C_{preg}. C_{reg}$ *and* C_{pfw} can be determined from the diagram of LCC and water composite curve.

3.3. Composite Matrix Algorithm (CMA):

Composite Matrix Algorithm is represented to determine the possible range of C_0 for total water regeneration network. The difference between ECTA and CMA method is the range of C_0, which is increased from ${C_0}^{min}$ to ${C_0}^{max}$. Regeneration flow rate is calculated for each C_0, and the maximum value of C_0 is associated with minimum regenerated flow rate. There is a matrix of C_0 and F_{reg}. Furthermore, the maximum value is chosen in each column.

It should be noted that there is an ascending trend of C_0. By raising C_0, the minimum amount of freshwater flow rate increases, and the freshwater flow rate approaches the LCC and eventually crosses it. For higher value than ${C_0}^{max}$, water supply line will cross the LCC. The first six stages are the same as the ECTA. 0

There are two new stages to identify the regenerated water flow rate matrix and regeneration concentration matrix.

First of all, as mention before, in the CMA method, there is a range of C_0 which must be calculated. ${C_0}^{max}$ Cannot be higher than C_{pr}.

Steps of targeting maximum post-regeneration concentration are demonstrated in Fig.2.

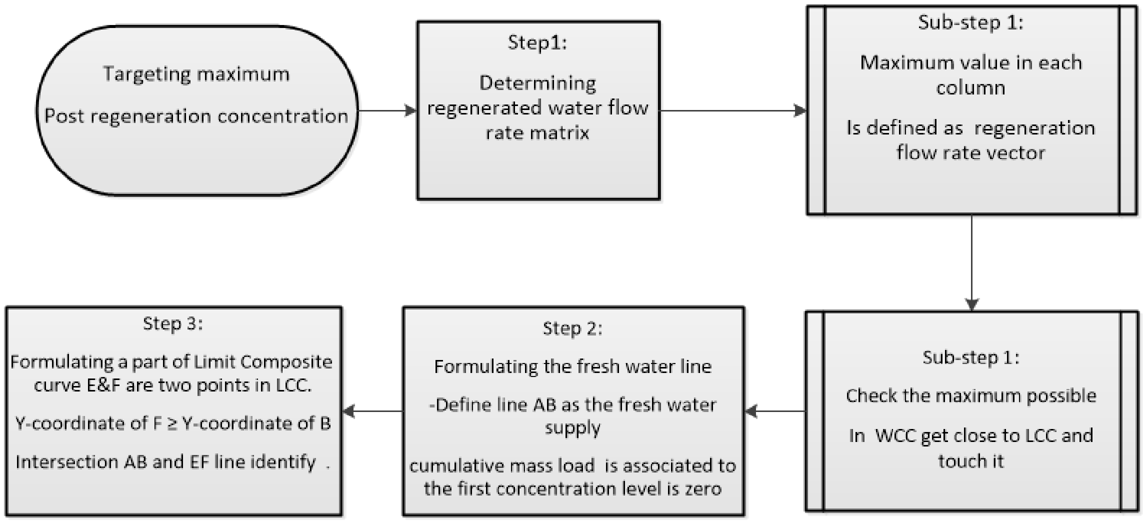

Figure 2. targeting maximum post-regeneration concentration

$$\forall n.k \rightarrow C_{0.n} \le C_k \quad \& \quad \forall n \epsilon N' \quad \& \quad \forall k \ge 2 \tag{2}$$

$$0 \le y - intersect - C_{0.n} \le \varepsilon$$

$$A = |^{C_{um}\Delta m}_{C_{fw}} \quad . \quad \forall k = 1 \tag{3}$$

$$B = |^{(C_{0.n} - C_{fw}) \times F_{reg.n}}_{C_{0.n}} \quad . \quad \forall n \epsilon N \tag{4}$$

$$E_n = |^{C_{um}\Delta m_{k-1}}_{C_{k-1}} \tag{5}$$

$$F_n = |^{C_{um}\Delta m_k}_{C_k} \quad \forall n \epsilon N \tag{6}$$

$$\forall n, k \rightarrow C_{0,n} \le C_k \quad \& \quad \forall n \epsilon N' \quad \& \quad \forall k \ge 2 \tag{7}$$

$$0 \le y - intersect - C_{0,n} \le \varepsilon \tag{8}$$

The matrix of regenerated water flow rate MF_{reg} is computed as Table 3 shows. It is presumed that the total regeneration system is applied because of $F_{fw} = F_{reg}$.

The matrix of regenerated water flow rate is set, and C_{pfw}s for random C_0 are calculated. Table 4 shows the randomization of C_0.

The maximum value in each column is determined as F_{reg} and the corresponding concentration with F_{reg} is known as freshwater pinch concentration $C_{p_{fw}}$.

$$\rightarrow F_{fw_{741}} = F_{reg_{741}} = [21.86 \quad 22.64 \quad 23.48 \quad 25.36 \quad 27.56]^T \tag{9}$$

$$C_{p_{fw}} = [150 \quad 150 \quad 150 \quad 150 \quad 150] \tag{10}$$

To calculate the possible regeneration concentration of the first row of Table 3 is applied. The matrix of feasible regeneration concentration is formed, which the maximum value of each column determines C_{reg}, and the associated concentration levels are known as regeneration concentration pinchC_{preg}.

$$\rightarrow C_{reg_{741}} = [194.6 \quad 190 \quad 184.6 \quad 174.6 \quad 164.7]^T \tag{11}$$

Table 4. MF_{reg} is calculated for random C_0

No	$C_0 = 10$	$C_0 = 20$	$C_0 = 30$	$C_0 = 50$	$C_0 = 70$
C_k=50	0	0	0	0	0
C_k=77.77	14.56	15.67	16.88	20.8	24.78
C_k=150	21.86	22.64	23.48	25.36	27.56

3.4. Regeneration Reuse/Recycle Approach

Generally, the total water system is divided into three subsystems as shown in Fig.3; 1- water utilization units 2- wastewater regeneration units 3- wastewater treatment units. Each unit of subsystems impose some expense and finding the most efficient method is considered to reduce expenditure and consumption of fresh water simultaneously.

The most important and key parameter in the total cost function is post-regeneration concentration. When C_0 is low (higher RR), the quality of regenerated water goes up, and it gives more opportunities to reuse it in many other water-using operations. Through increasing the quality of regenerated water, the demand for freshwater supply reduces and consequently leads to a reduction of the volume of wastewater disposal. Therefore, the decline of C_0 which leads to increase in the costs of regeneration, imposes a high load of treatment of wastewater for regeneration. However, there is a reduction in freshwater consumption and effluent disposal. The target is to find optimum C_0, which minimizes the total cost of the water network.

3.5. MINLP Method

In this research, mixed-integer non-linear programming (MINLP) as the mathematical optimization method has been applied for finding the optimum solution. The objective function is the minimum cost. In this regards, GAMS Software has been used to find the optimum solution.

3.6. CS Approach

The CS algorithm is utilized for the water optimization and wastewater network. In the CS, three steps are followed (Fig.4) (Khoshgoftar Manesh & Ameryan, 2016):

1. In each repetition, each cuckoo bird begets one egg and retracts it in an accidental host nest.
2. The eggs which have the best quality remain and continue in the subsequent production.
3. The number of the host nest is predetermined and eggs are recognized and killed by the host with a paϵ [0,1] possibility.

To simplify the approach, the fraction pa of n nest exchanges for new random solutions. To apply CS in the maximization problem, the solution fitness value can be in proportion to the fitness function value. Moreover, the fitness function is used for other approaches, namely genetic algorithm, particle swarm optimization, etc. In this algorithm, repetitive solutions are altered with new and better solutions. An egg in a nest is a solution, and a cuckoo bird is new a. Initial cuckoo population sized P, are generated, hg randomly (Khoshgoftar Manesh & Ameryan, 2016).

$$h_p = R.\times rand + V_{min} \quad (12)$$

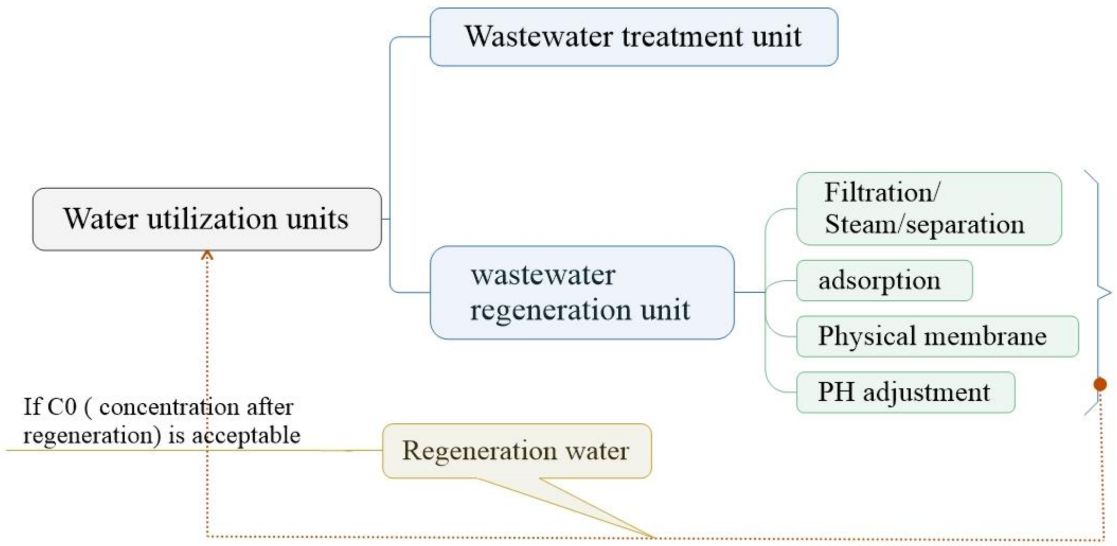

Figure 3. Schematic of the regeneration unit

Levy flight is an adventitious movement which has the specificity of an immediate jump step chosen via Power Law distribution function. By considering CS, a Levy flight is computed by Mantegna algorithm to find local and global optima.

The following formula is the first step:

$$S = [s_1, \dots, s_2] = U_1 / (abs(U_2))^{1/\chi} \quad (13)$$

U_1 and U_2 are n-dimensional arrays distributed in [0, σ]. And [0,1]. σ will be calculated as follows:

$$\sigma = \left(\frac{\Gamma(1+\chi)\sin(\pi\chi)}{\Gamma\left((1+\chi/2)\chi^{(1-\chi)/2}\right)}\right. \quad (14)$$

While χ is a constant value between 1 and 2, in many studies χ is assumed 1.5. The Gamma function is expressed as follows(Yang & Suash, 2009):

$$\Gamma(\varepsilon) = \int_0^{\infty} e^{-c}\, m^{\varepsilon-1} dm \quad (15)$$

Also, γ is computed considering the best remaining current solution.

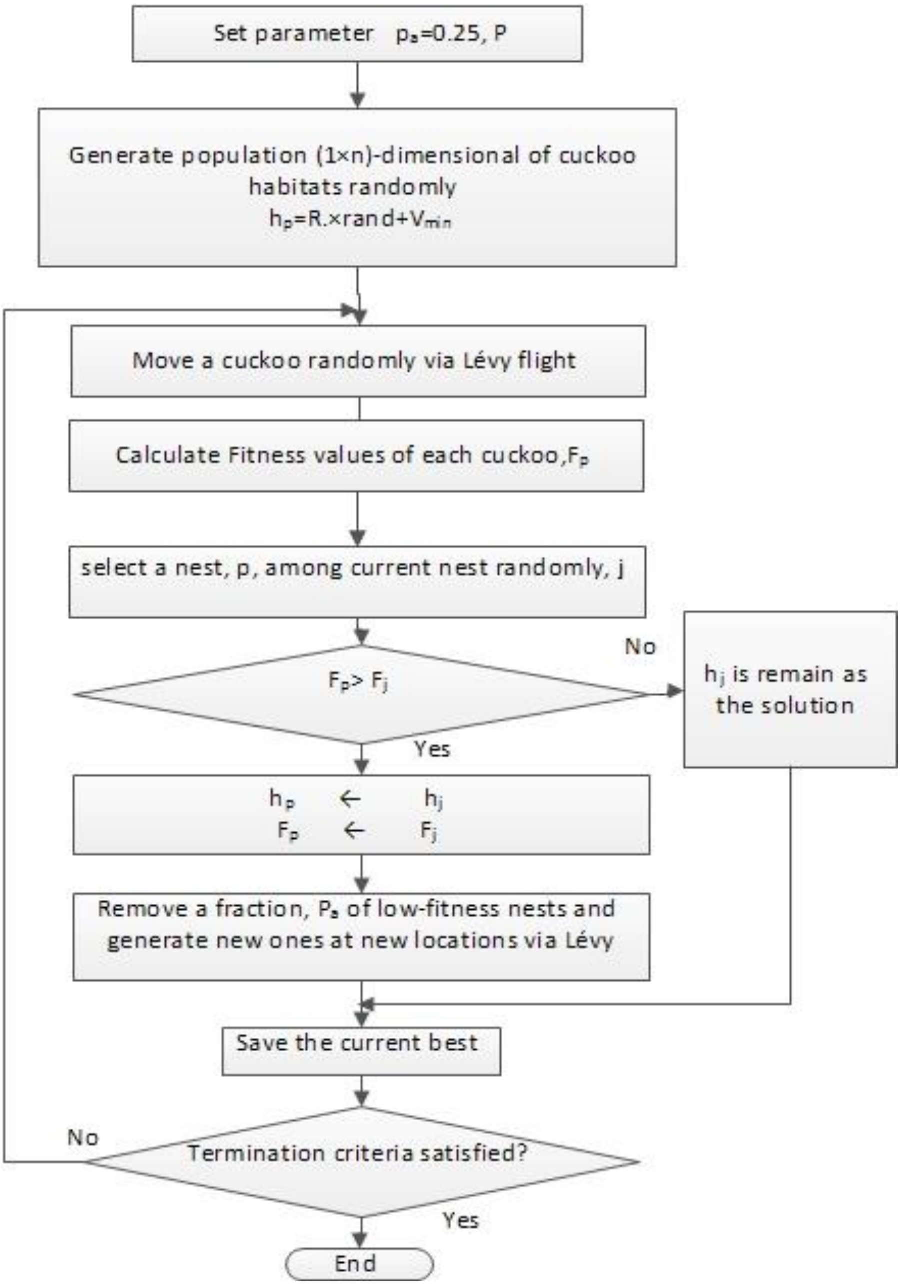

Figure 4. The Algorithm of Cuckoo Search (Yang & Suash, 2009)

$$\gamma = 0.01 \times S.\times (h_p - h_b) \quad (16)$$

The value 0.01 is a typical length scale.

$$h'_p = h_p + \gamma.\times R_n \quad (17)$$

The accidental R_n numbers are n-dimensional arrays in the range from 0 to 1. Also, $h_p^{'}$ is the next solution.

3.7. Cost Functions

The cost function is an essential factor in optimizing the water network system. The total cost of the water system includes the freshwater cost (CF), regenerated water cost (CR), and wastewater disposal (CD). Table 5 shows all cost function (Feng & Chu, 2004).

Total regeneration cost is adopted from (Parand, Yao, Pareek, & Tadé, 2014). It is a function of regeneration flow rate and post-regeneration concentration. F_{reg}, C_0, and contaminant regeneration load (M_{reg}) are the main parameters that affect the cost of regeneration unit. The contaminant regeneration load is calculated as follows (Parand et al., 2014):

$$M_{reg} = F_{reg} \times (C_{reg} - C_0) \quad (23)$$

Generally, total regeneration cost increases to provide high-quality regeneration water for reusing and recycling water. As it was mentioned, the highest performance of the regenerator never guarantees the optimization of the total cost.

${C_0}^{max}$ is found from the CMA method. α, β and γ are constant empirical regeneration cost correlation and the values of them are set at 15, 0.14 and 1.75, respectively.

To calculate CD, both the effluent volume and concentration are taken into account. The famous Mogden Formula which is based on the volume and concentration is applied.

Where R= Reception Charge, V=Primary Treatment Charge, and M=Treatment Charge, where effluent goes to sea outfall, B_v=Biological Treatment Charge, V_m= Preliminary Treatment Charge for discharge to outfalls, B=Biological Oxidation Charge, S=Sludge Treatment Charge, O_s=Chemical Oxygen Demand of Settled Sewage, S_s=Suspended Solids Concentration in Crude Sewage.

According to the Mogden Formula 2016-2017, the cost parameters are R=32cent/ton, V=17cent/ton, S_s=490 ppm, B_v=5.02cent/ton, B=14.04cent/ton and S=16.99cent/ton (Kim, 2012).

3.8. Optimization by Targeting Approaches

To find an ideal solution among three targeting methods, the TOPSIS method is applied. TOPSIS is a famous method for multiple attribute decision making (MADM). The technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a multi-criteria decision analysis method which was first presented by Yoon (Yoon & Hwang, 1981). The underlying concept of the TOPSIS method is defined by the shortest geometric distance from the positive ideal solution (PIS) and the longest geometric distance from the negative ideal solution (NIS). For instance, PIS maximizes the benefit and minimizes the cost, whereas the NIS maximizes the cost and minimizes the benefit. It is assumed that each criterion requires being maximized or minimized.

To determine a positive ideal solution among CTA, ECTA, and CMA, TOPSIS is applied. Identifying weights for each criterion is important. Weights are set according to the importance of a criterion. Weights are between 0 to 1, thus, weighting was introduced from AHP (Analytical Hierarchy Process) technique to quantify the relative importance of the different selection criteria.

Table 5. Cost function

Total cost	$\mathrm{CT}_n = \mathrm{CF}_n + \mathrm{CR}_n + \mathrm{CD}_n$ $\forall n \in N$	(18)
Regenerated water cost	$CR_n = \alpha \times F_{reg,n}^{\beta} \times \left((\frac{{C_0}^{max}}{C_{0,n}})^{\gamma} \right)$ $\forall n \in \mathrm{N}$	(19)
Wastewater disposal cost	$CD = R + M + V + B_v + B\frac{O_t}{O_s} + S\frac{S_t}{S_s}$	(20)
Freshwater cost	$\mathrm{CF} = \frac{8600h}{yr} \times \frac{1\$}{ton} \times \frac{ton}{h}$	(21)
Piping cost	$CP_n = \text{Base Cost} + \text{Non Base Cost}$	(22)

3.9. Piping Cost

Considering the piping cost in the total cost function plays a key role in the economic trade-offs. The piping cost impacts on the design of a water network directly. Total piping cost consists of two parts: 1-The basic cost which comprises with purchase of pipe, pipefitting and preparing 2-None-basic Cost which includes pipe racks cost, field installation cost, and equipment, engineers and workers' costs. The piping cost (CP) is shown in Table 5. The approximate length of the pipe can be specified using each possible connection, along with the materials of construction.

Short-cut piping cost method is the swift solution to predict the cost of piping and pipefitting of a processing unit. There are two types of Installation the: the first one is simple straight which is applied to convey raw materials from storage to a process module, and another one is the complex systems which are the plumbing connected to a distillation column or heat exchanger.

For simple straight pipe in 1993, Lindley and Floyd reported the base cost for more than 30 types of pipe in 3 various sizes of diameter 5, 10 and 15 cm. They calculated the price of carbon steel pipe, Schedule 40 and 5-cm (2 in.) nominal diameter to be $1,711 for a 500-ft long (152.4-m) section. By dividing $1,711 by 152.4, the basic price is calculated $11.23/m in 1993. For instance, the minimum price for the year 2018, is evaluated by multiplying the minimum cost by $(\frac{x}{350})$ which is 350 (The CE Plant Cost Index) for 1993 and x (CE PCI) for 2018.

For simple straight method, Ulrich and Vasudevan represented a correlation for installation factor(Ulrich, Vasudevan, & Ulrich, 2004).

$$F_{Bm.a} = 11.6D^{-.84} - 1.13F_{m.a} \quad (24)$$

$F_{m.a}$ =Material factor for material "a"(the quotient of the base cost $Cp_{.a}$for piping material divided by $Cp_{.cs}$the minimum cost of carbon steel pipe having the same diameter),

$F_{Bm,a}$ = Bare module installation factor for material "a"(ratio of the bare module installed cost to purchase price of carbon steel), dimensionless

D = Diameter nominal, which is considered 5, 10 and 15 cm.

In complex piping system, an elbow or tee is assumed for every 3m and one valve for every 7.5 m. The installation factor equation for complex networks is as follows:

$$F_{bm.a} = 2 - 0.024D - 0.001D^2 + 1.22F_{m.a} - 0.011D.F_{m.a} - 0.015D.(F_{m.a})^{-2} \quad (25)$$

Two systems can be used simultaneously to calculate the piping cost.

And finally:

$$C_{B.m} = F_{Bm.a} \times C_{p.a} \quad (26)$$

$C_{B.m}$= capital cost of a process modules$^{\$}/_{m}$.
$C_{p.cs}$ = the base cost or purchase cost of piping material a $^{\$}/_{m}$.

4. Results

Freshwater supply cost is calculated by assuming the operation hours of the water system 8600 h/yr and the freshwater supply cost is 1 $/ton. The calculation has been performed based on Fig 1, Table 1 and Table 2 based on water and wastewater network a gas refinery to achieve the optimum solution.

Figure 5 indicates the relationships between the total cost, CF, CR, CD, and C_0. The interaction between all functions of cost can be - observed. The economic trade-off between freshwater, wastewater disposal, and regeneration cost have been carried out in the optimization model.

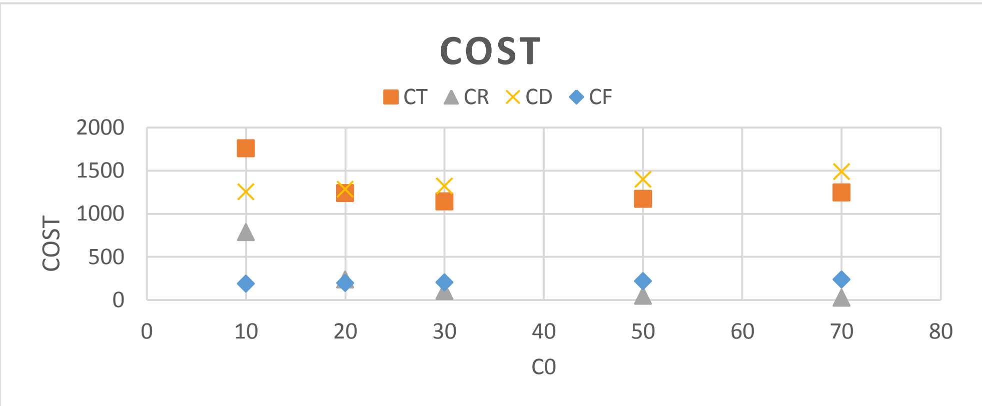

Figure 5. Cost Function

The optimum point is C_0=30 and the minimum total cost is 1142.19. At this optimum C_0, the minimum total cost leads to the reduction of freshwater supply, disposal treatment, and regeneration cost. By declining $C_{0.p}$, increasing CR is expected to raise the total cost.

The main parameters of the case study for evaluation of different approaches are freshwater, wastewater and regeneration flow rates, wastewater concentration, post-regeneration concentration, removal ratio, freshwater costs, regenerative cost, total cost, and convergence speed.

Table 6 reveals the comparison among three targeting approaches, MINLP and CS methods.

According to the data, ECTA and CMA methods have a smaller demand for freshwater. In the CMA method, more freshwater is needed and, in turn, higher wastewater is generated in contrast with ECTA method. However, the total cost of the CMA is lower than the other methods. Thus, CMA guarantees the optimum cost. As shown, the convergence speed of CS algorithm is lowest. Furthermore, conceptual algorithms have the fastest speed to achieve a global solution. To indicate a positive ideal solution among CTA, ECTA, and CMA, TOPSIS is used as it is shown in Table 7.

As shown in the results, CMA is the best solution given of cost among other targeting approaches. CS and MINLP methods have similar results. Nonetheless, CS and MINLP are more time-consuming compared with other methods. CS is the worst method given the speed of convergence.

It is demonstrated that post-regeneration concentration and contaminant regeneration load are the key parameters to optimize the cost function. Economic trade-offs include freshwater cost, regenerated water cost, wastewater disposal cost, and piping cost. It is shown that short-cut piping cost is an efficient method to estimate the piping cost for pre-design. Also, TOPSIS is applied to find a positive ideal solution among the three methods. The results indicate that CMA is a positive ideal solution and CTA is a negative ideal solution.

Table 6. Comparison with different approaches

	CTA Method	ECTA Method	CMA Method	MINLP Method	CS Method
Freshwater flow rate	42.26	22.67	23.48	23.10	23.22
Wastewater flow rate	42.26	22.67	23.48	23.10	23.22
Regeneration flow rate	---	22.67	23.48	23.10	23.22
Wastewater concentration (ppm)	21.468	703.97	688.10	688.10	688.10
Post-regeneration concentration (ppm)	---	20	30	30	30
Removal ratio	---	89%	84%	84%	84%
Freshwater cost k$/yr.	436.363	194.962	201.928	202.1	202.31
Wastewater cost k$/yr.	67.184	99.29	102.84	104.21	103.82
Regeneration cost	---	234.95	101.71	102.15	102.34
Total cost	503.547	529.212	406.478	408.46	408.47
Convergence Speed	Very Fast	Very Fast	Very Fast	Fast	Medium

Table 7. the criteria and weights

	FWFR	CFW	WWFR	CWW	RFR	CR
CTA	42.26	363.44	42.26	184.67	0	0
ECTA	22.67	194.96	22.67	99.29	22.67	234.95
CMA	23.48	201.93	23.48	102.84	23.48	101.71
	min	min	min	min	max	min
Weights	0.15	0.17	0.18	0.2	0.15	0.14

5. Conclusion

To minimize and optimize water supply and wastewater in oil refinery three different targeting methods are implemented: Composite Matrix table, Extended Composite Table and Composite Matrix Algorithm. In addition, to have a better comparison among different approaches, MINLP and CS methods are examined and evaluated. Each of them has its features. Regarding reusing and recycling, CTA is proper and to consider regeneration unit, ECTA and CMA are employed. Moreover, the difference between ECTA and CMA is considered. In ECTA the proper point is set as post-regeneration concentration, in contrast, CMA method gives the opportunity to choose the optimum post-regeneration concentration between the feasible ranges of post-regeneration concentration which lead to optimize regeneration cost and minimize the final total cost.

References

Agrawal, V., & Shenoy, U. V. (2006). Unified conceptual approach to targeting and design of water and hydrogen networks. *AIChE Journal, 52*(3), 1071-1082.

Alves, J. J., & Towler, G. P. (2002). Analysis of refinery hydrogen distribution systems. *Industrial & Engineering Chemistry Research, 41*(23), 5759-5769.

Ataei, A., & Yoo, C. (2010). Simultaneous energy and water optimization in multiple-contaminant systems with flowrate changes consideration.

Bai, J., Feng, X., & Deng, C. (2007). Graphically based optimization of single-contaminant regeneration reuse water systems. *Chemical Engineering Research and Design, 85*(8), 1178-1187.

Buehner, F. W., & Rossiter, A. P. (1996). Minimize waste by managing process design. *CHEMTECH-WASHINGTON DC-, 26*, 64-64.

El-Halwagi, M. M., Gabriel, F., & Harell, D. (2003). Rigorous graphical targeting for resource conservation via material recycle/reuse networks. *Industrial & Engineering Chemistry Research, 42*(19), 4319-4328.

El-Halwagi, M. M., & Spriggs, H. D. (1998). Solve design puzzles with mass integration. *Chemical engineering progress, 94*, 25-44.

Feng, X., & Chu, K. (2004). Cost optimization of industrial wastewater reuse systems. *Process Safety and Environmental Protection, 82*(3), 249-255.

Hallale, N., & Liu, F. (2001). Refinery hydrogen management for clean fuels production. *Advances in Environmental Research, 6*(1), 81-98.

Hong, X., Liao, Z., Jiang, B., Wang, J., & Yang, Y. (2016). Simultaneous optimization of heat-integrated water allocation networks. *Applied Energy, 169*, 395-407. doi: https://doi.org/10.1016/j.apenergy.2016.01.059

Khoshgoftar Manesh, M. H., & Ameryan, M. (2016). Optimal design of a solar-hybrid cogeneration cycle using Cuckoo Search algorithm. *Applied Thermal Engineering, 102*, 1300-1313. doi: https://doi.org/10.1016/j.applthermaleng.2016.03.156

Kim, J.-K. (2012). System analysis of total water systems for water minimization. *Chemical Engineering Journal, 193*, 304-317.

Mann, J. G., & Liu, Y. A. (1999). *Industrial water reuse and wastewater minimization*: McGraw Hill; New York: McGraw Hill, 1999.

Nabi Bidhendi, G. R., Mehrdadi, N., & Mohammadnejad, S. (2010). Water and wastewater minimization in Tehran oil refinery using water pinch analysis. *International Journal of Environmental Research, 4*(4), 583-594.

Naderi, M. J., & Pishvaee, M. S. (2017). A stochastic programming approach to integrated water supply and wastewater collection network design problem. *Computers & Chemical Engineering, 104*, 107-127. doi: https://doi.org/10.1016/j.compchemeng.2017.04.003.

Parand, R. (2014). Water and wastewater optimization through process integration for industrial processes.

Parand, R., Yao, H. M., Pareek, V., & Tadé, M. O. (2014). Use of pinch concept to optimize the total water regeneration network. *Industrial & Engineering Chemistry Research, 53*(8), 3222-3235.

Prakash, R., & Shenoy, U. V. (2005). Targeting and design of water networks for fixed flowrate and fixed contaminant load operations. *Chemical Engineering Science, 60*(1), 255-268.

Pungthong, K., & Siemanond, K. (2015). MINLP Optimization Model for Water/wastewater Networks with Multiple Contaminants. In K. V. Gernaey, J. K. Huusom & R. Gani (Eds.), *Computer Aided Chemical Engineering* (Vol. 37, pp. 1319-1324): Elsevier.

Salgot, M., & Folch, M. (2018). Wastewater treatment and water reuse. *Current Opinion in Environmental Science & Health, 2*, 64-74. doi: https://doi.org/ 10.1016/j.coesh.2018.03.005

Souifi, M., & Souissi, A. (2019). Simultaneous Water and Energy Saving in Cooling Water Networks Using Pinch Approach. *Materials Today: Proceedings, 13*, 1115-1124. doi: https://doi.org/10.1016/j.matpr.2019.04 .079

Ulrich, G. D., Vasudevan, P. T., & Ulrich, G. D. (2004). *Chemical engineering process design and economics: a practical guide* (2nd ed.). Durham, N.H.: Process Pub.

Velasquez-Orta, S. B., Heidrich, O., Black, K., & Graham, D. (2018). Retrofitting options for wastewater networks to achieve climate change reduction targets. *Applied Energy, 218*, 430-441. doi: https://doi.org/10.1016/ j.apenergy. 2018.02.168

Wang, Y., & Smith, R. (1994). Wastewater minimisation. *Chemical Engineering Science, 49*(7), 981-1006.

Wang, Y., & Smith, R. (1995). Waste-water minimization with flow-rate constraints. *Chemical engineering research & design, 73*(8), 889-904.

Yang, X., & Suash, D. (2009, 9-11 Dec. 2009). *Cuckoo Search via Lévy flights*. Paper presented at the 2009 World Congress on Nature & Biologically Inspired Computing (NaBIC).

Ye, X., Chen, B., Jing, L., Zhang, B., & Liu, Y. (2019). Multi-agent hybrid particle swarm optimization (MAHPSO) for wastewater treatment network planning. *Journal of Environmental Management, 234*, 525-536. doi: https://doi.org/10.1016/j.jenvman.2019. 01.023

Yoon, K., & Hwang, C.-L. (1981). *Multiple attribute decision making: methods and applications*: SPRINGER-VERLAG BERLIN AN.

Zhao, H.-P., Yang, Y., & Liu, Z.-Y. (2019). Design of heat integrated water networks with multiple contaminants. *Journal of Cleaner Production, 211*, 530-536. doi: https://doi.org/10.1016/j.jclepro.2018.1 1.210