Environmental Energy and Economic Research (2018) 2(2): 89-99
DOI 10.22097/eeer.2018.147506.1038

# Presenting a Suitable Algorithm for Optimization of Water Consumption in Water Pinch Analysis (A Case Study: Shahid Tondgooyan Oil Refining Co., Tehran)

**Gholamreza Nabi Bidhendi [a*], Arezoo Shafikhani [b]**

[a] School of Environment, College of Engineering, University of Tehran, Tehran, Iran
[b] Alborz Campus, University of Tehran, Iran

Received: 8 October 2017 /Accepted: 12 March 2018

**Abstract**
Since less than 1% of world waters are potable, minimizing water consumption is a significant issue. The aim of this study is to present a suitable algorithm for optimization of water consumption in water pinch analysis. In this regard, the results of computer algorithm are verified by the results of previous studies. As a case study, dissolved solid pollutants are taken into consideration. The results indicated that using a water pinch method decreased the amount of this pollutant up to 8.5% in potable water in comparison with raw water. Moreover, by assuming a unit with ten operations in parametric studies, it is observed that with changing one of the influential factors without any change in other parameters, the effects of output concentration changes will be more than flow and input concentration changes. The results of this research can be used functionally in refineries and all the water consumption centers.

**Keywords:** Minimization, Water pinch method, Flow intensity, Input and output concentrations, Water consumption.

## Introduction and Objectives

Since less than 1% of world waters are potable, minimization of water consumption via pinch technology is considered to be a significant issue in industry, especially industrial wastewater. Pinch technology was first introduced by Linnhoff. One group introduced a technology based on thermodynamic methods which has the lowest energy level in different networks (Mughees and Al-Ahmad, 2015). This technology has always been the best solution for finding suitable energy patterns in various procedures. Water pinch technology refers to a kind of integrated mass exchange in final water consumer. However, this technology will not disrupt the main use of these networks, since it is utilized in that network (Linnhoff and Eastwood, 1997; Sun and Luo, 2011).Water pinch technology consists of three analysis, combination, and update parts which

* Corresponding author Email: ghhendi@ut.ac.ir

include reduction and flow intensity of potable water along with network modification. (Linnhoff et al., 1982).

Using this technology, engineers can have an overview about quality analysis, minimum flow intensity of potable water, wastewater production of water consumption operations, and minimum amount of output water for purification before designing and executing the real systems. Moreover, this technology presents a guideline which can be used for combination of water consumptions networks, output purification systems, and economical update of existing facilities which are utilized for minimum discharge (debit*). Researchers have tried to minimize potable water consumption in those industries which have high water consumption rate. This high rate leads to some problems which are caused by water shortage, damages of wastewater discharge into the environment, increased costs of potable water supply, and wastewater treatment (Priva and Bandyopadhyay, 2017; Shahruddin et al., 2017). Wang and Smith introduced a pinch technology based on heat integration. In this technology, it is assumed that each water consumption operation contains mass exchange procedures. Related curves of each operation are drawn based on maximum values of input and output concentrations. Then, water supply lines are depicted. Except zero contact points which is located in the origin, the next point is called pinch point. They presented two methods for a minimum discharge (debit) design. The first method is based on minimum effective force which indicates concentration differences of various flows as minimum flow. The second method is based on minimum water resources and uses loading cross sections. In each cross section, only that amount of water is consumed which is efficient for network survival. In this method, some curves are drawn according to pollutant concentrations and mass flux capacity (Wang and Smith, 1994, 1995; Winterbone and Turan, 2015). Dohle (1996) analyzed the limitations of Wang and smith's studies and introduced a new method based on them. For example, some processes, such as washing, extracting, etc. can easily be modeled by Wang and Smith's method, while other processes, such as reactors, boilers, and coolers are not considered to be mass exchange operations. Therefore, in order to model some of the operations, multiple water flows with various densities enter and exit them. In this method, in order to solve the existent problems, the combined curve should be drawn for all of the entering flows. Sorin (1999) introduced an evolutionary table and utilized numerical methods for minimization of fresh water and wastewater without graphical solutions. If there is more than one pinch point, this method cannot be efficient. Halale (2002) discussed excess water diagram, which its limitations are long term trials and multiple errors. Yen proposed a model based on waterfall tables. This method is used for continuous and semi-continuous processes. In this model, time is presented in semi-continuous processes. It can determine the amount of required drinking water of the system and can easily find pinch points. However, it has its own limitations as well (Tan et al., 2007). Gomes (2006) introduced a modified version of method based on water resource diagrams. This method can be used for multi-pollutant processes (Castro et al., 1999). Manan and Liu (1999) have focused on two graphical and table methods. In these methods, reuse processes are done more easily and they can be applied on multi-pollutant processes. Manan used water pinch analysis on an urban system along with waterfall analysis (Manan et al., 2006). El-Halwaji discussed the concept of wastewater start network and its role in mass integrity in order to analyze general allocation of pollutants (El-halwagi et al., 1990, 2006, 2016 & 2017). Olesen and Polley revised the guidelines of Wang and Smith with their simple pollutant methodology. They introduced a method which includes geographical and tubing conditions of the factory (Olesen and Polly, 1997). Some people introduced mathematical planning for

* French equivalent of "discharge"

maximum industrial water reuse (Dohle et al, 1996; Hansen et al, 2018). Kuo used pinch analysis for designing treatment plants with point output (Kuo and Smith, 1998). Alva-Argaez expanded the works of Wang and Smith. They have focused on the output of treatment plants in mathematical planning method (Alva-Argeaz et al. 2006). Recently, many studies have been done with the aim of optimization of water consumption and application of water pinch processes (Akeem et al., 2017). The aims of these studies are reduction of wastes in petrochemical, starch, sugar, textile industries (Yesaswini and Saravanathamizhan, 2018; Paudel et al., 2017; Sardiñas et al, 2017).

As an example of petrochemical industries, Balla used water pinch analysis in order to reduce water usage of refineries from 212 tones/h to 121 tones/h. Therefore, wastewater production reduced from 73.4 tones/h to 24.93 tones/h (Balla et al., 2017). As another example, Nabi Bidhendi reduced water consumption of one of the refineries in Tehran up to 26% using water pinch technology (Nabi Bidhendi et al., 2010). The data of this sample will be presented in next sections as algorithm input and will be analyzed extensively.

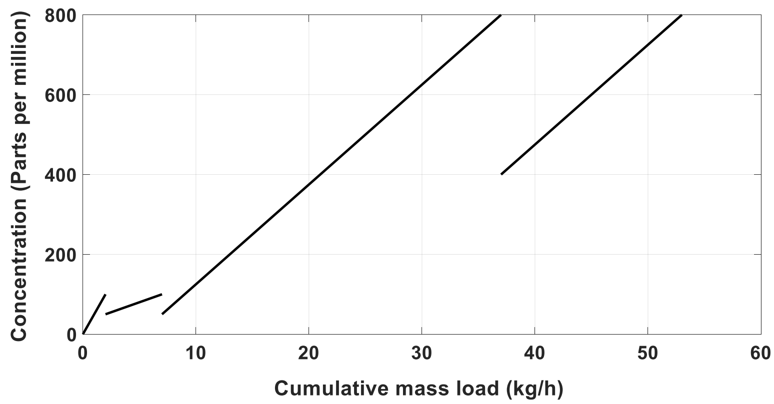
In this paper, pinch analysis is represented via MATLAB programming, and its results are compared with graphical method in order to be verify the written program. The presented method aims to increase the accuracy of graphical drawings and reduce calculation and estimation time. It also aims to find a solution for removing limitations of input operations. Moreover, the effects of changes in different factors, such flow intensity, input, and output concentrations, on pinch point are analyzed in order to determine which factor has a more significant role in pinch point changes. By these data, and modification of input and output masses, we can reduce water consumption and integrate different processes.

## Materials and Methods

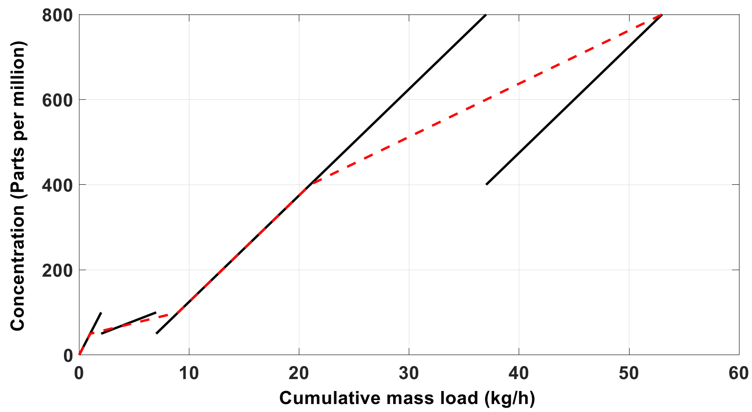
Wang and Smith's method start with a table which includes water restriction data. This table is designed for each process by determining mass load of M pollutant and maximum permissible concentration of $C_{w\ max}$ pollutant in input and output water flows. Mass exchange of dilute systems is considered to be a concentration linear function, and restriction data are presented in the diagram of Figure (1-a). Restriction diagrams are used for drawing combined concentration curves. The combination of operations is indicated in combined curve of Figure (1-b). Combined curve highlights the critical point of water consumption in a specific unit. These critical points are close to pinch point and require minimization of water flow. According to Figure (1-c), this combined curve is matched with water supply line. Concentration of input pollutant of water supply line is considered to be zero, and water supply line crosses the start point (Wang & Smith, 1994, 1995).

The final step after drawing combined concentration curve is determination of minimum flow intensity of raw water which done via raw water pinch. Raw water pinch is so significant for wastewater minimization, since the system does not need higher than pinch concentrations for raw water. In higher than pinch concentrations, water flow can be provided from other parts of the system. Therefore, minimum flow intensity in water reuse is lower than raw water usage in the system. After drawing combined concentration curves, minimum raw water flow can be estimated easily by drawing a water supply line on this curve and by considering the following items:

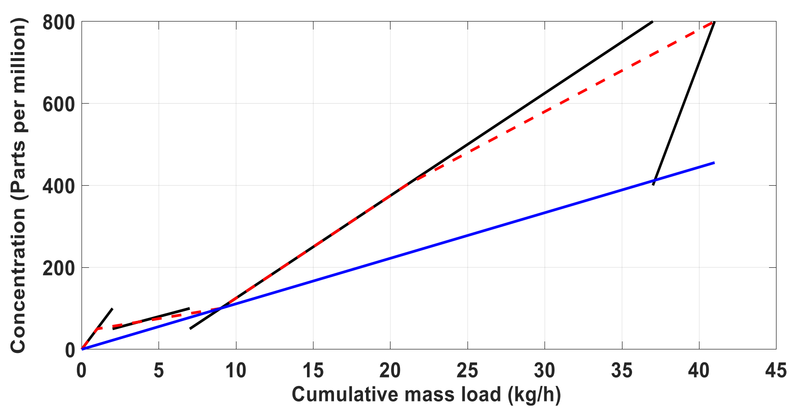
1) In raw water, pollutant concentration is zero in the beginning (it means that the line should cross from the origin of coordinate system).




**(a)**




**(b)**




**(c)**

**Figure 1.** Step by step diagram of restriction curve and water supply line with Wang and smith's data

2) Raw water supply line without water reuse is drawn by connecting the origin of coordinate system to maximum output concentration. This line can be located higher than the combined concentration curve. However, raw water supply line should be placed lower than the combined concentration curve due to effective forces and pollutant mass exchange. Therefore, water supply

line can be drawn by rotating this line around coordinate origin and in the direction of reducing slope up to the point that this line becomes contacts the combined curve.

3) Contact point of the combined concentration curve with water supply line is referred to as raw water pinch point. Systems with higher than pinch concentrations do not need raw water. According to relation (1), minimum flow intensity of raw water pinch is:

$$f_{min}\left(\frac{ton}{hr}\right) = \frac{\Delta m_{pinch}(\frac{kg}{hr})}{C^*_{pinch}\ (ppm)} 10^3 \quad (1)$$

Where, $C^*_{pinch}$ is pollutant concentration in the center of pinch cross section;

$\Delta m_{pinch}$ is exchanged mass load of the pollutant in the edge of pinch cross section

This methodology is taken from Wang and Smith's methods. The difference is that MATLAB is used in this study in order to increase the accuracy of graphical drawings in pinch [point analysis and minimization of water consumption of modeling network. In this section, MATLAB programming version 7.7 is used for estimation of pinch point in pinch analysis part and discharge (debit) value in optimal mode.

In the presented program, at first, input data are given to the program which includes flow intensity, input concentration, and output concentration. For this end, flow intensity should be in Tone/hour unit, and concentrations should be in parts per million unit. Then, mass load of each cross section (kg/h) and cumulative mass load are estimated by the relations presented in references (Wang and Smith, 1994, 1995; Shafikhani, 2016). Finally, a diagram is drawn by the software. In this diagram, horizontal axis stands for cumulative load, and vertical axis stands for concentration. Moreover, all the operations are based on cumulative mass load and concentration range. Then, the existent concentrations are defined as a vector in which all the concentrations are ordered in an ascending trend and are representative of repetitive concentrations. After drawing the concentration vector, concentration difference values are indicated by $\Delta C$ in each range. Then mass load and cumulative mass load of each concentration range are estimated. Eventually, pinch point can be estimated, water supply line can be drawn, and values of concentration and mass load in pinch point can be printed by the software.

*Verification*

For verification of the results of presented algorithm, some of the technical results in literature review are used. The data are given to the algorithm as a sample and its responses are compared with the previous results of literature review in order to verify the written program.

*Data of Kuo and Smith article*

In this sample, the data of Kuo and Smith article (Table 1) are used.

**Table 1**. The analyzed data in Kuo and smith article (Kuo & Smith, 1998)

| Number of operation | Mass load (Kg/h) | Input concentration (Parts per million) | Output concentration (Parts per million) | Flow intensity (Tone/kg) |
|---|---|---|---|---|
| 1 | 4 | 0 | 100 | 40 |
| 2 | 5 | 50 | 100 | 100 |
| 3 | 7 | 50 | 400 | 20 |
| 4 | 16 | 200 | 600 | 40 |

Figure 2 indicates a schematic of concentration changes and water supply lines which are resulted from this paper (Kuo & Smith, 1998). Figure 3 indicates a schematic resulted from the written program. According to Figure 4, the results of this paper for water supply line and the written algorithm are totally overlapped.

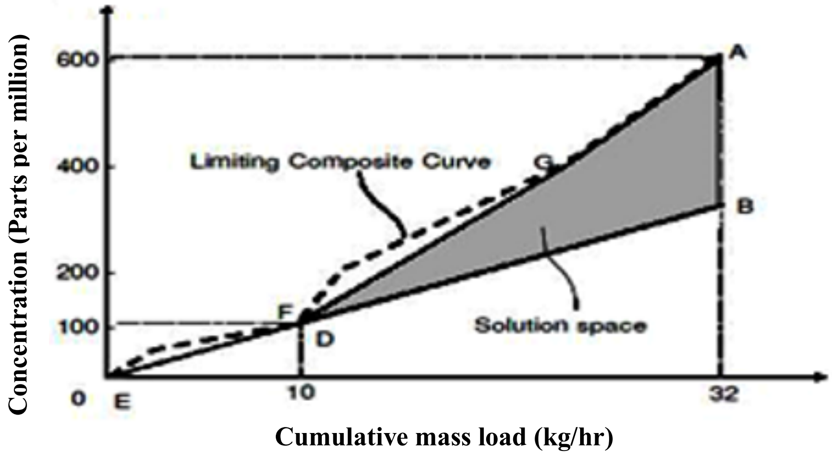



**Figure 2.** Cumulative mass load versus concentration resulted from Kuo and smith (1998)

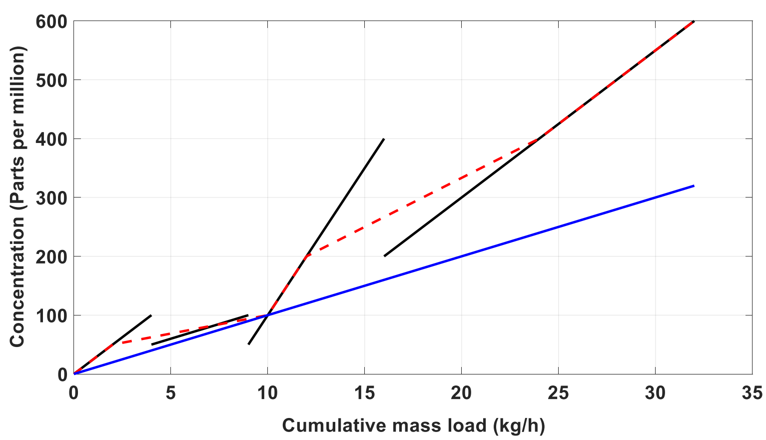



**Figure 3.** The resulted curve from Kuo and Smith data using the analyzed algorithm

*Data of Mohammadnejad research*

In this sample, the data of Mohammadnejad research on water pinch technology are used (Table 2). These data are extracted from Tehran refinery (Mohammadnejad 2010). The resulted curve from these data is indicated in Figure 5. The resulted curve from the written algorithm is indicated in Figure 6.

**Table 2.** Data of Mohammadnejad research (Mohammadnejad, 2010; Mehrdadi et al. 2009).

| Number of operation | Input concentration (Parts per million) | Output concentration (Parts per million) | Flow intensity (Tone/kg) |
|---|---|---|---|
| 1 | 1 | 2 | 37 |
| 2 | 13 | 20 | 59 |
| 3 | 1 | 22 | 160 |

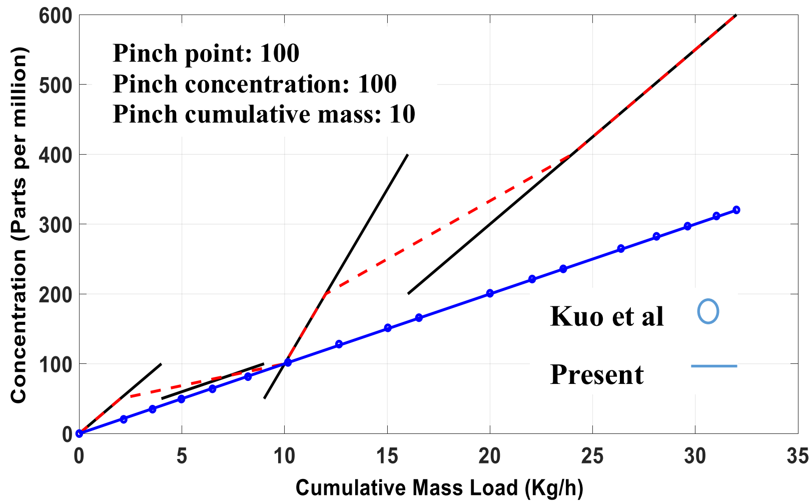



**Figure 4.** Comparison of Kuo and smith results with the written program

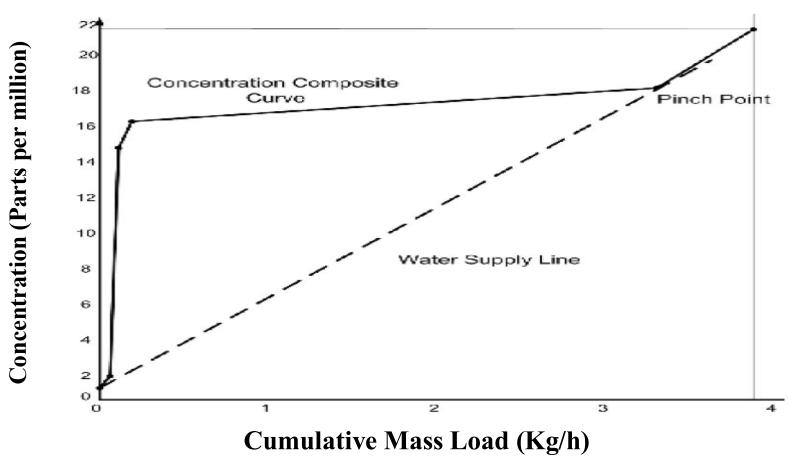



**Figure 5**. The resulted curve from Mohammadnejad's data (Mohammadnejad 2010).

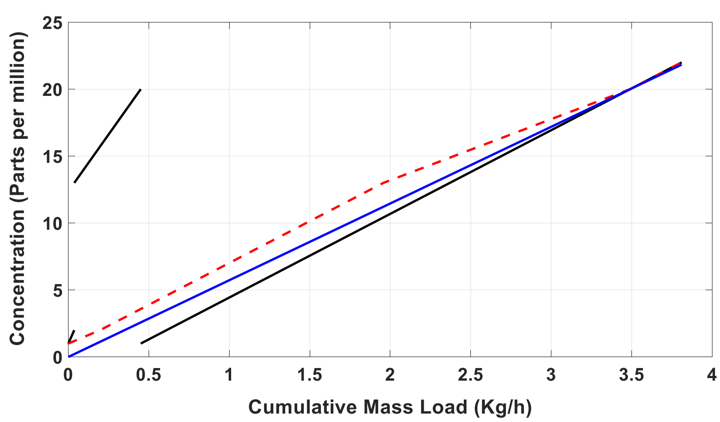



**Figure6**. The resulted curve from Mohammadnejad's data using the analyzed algorithm

According to Figure 7, water supply line, algorithm, and curve are totally overlapped.

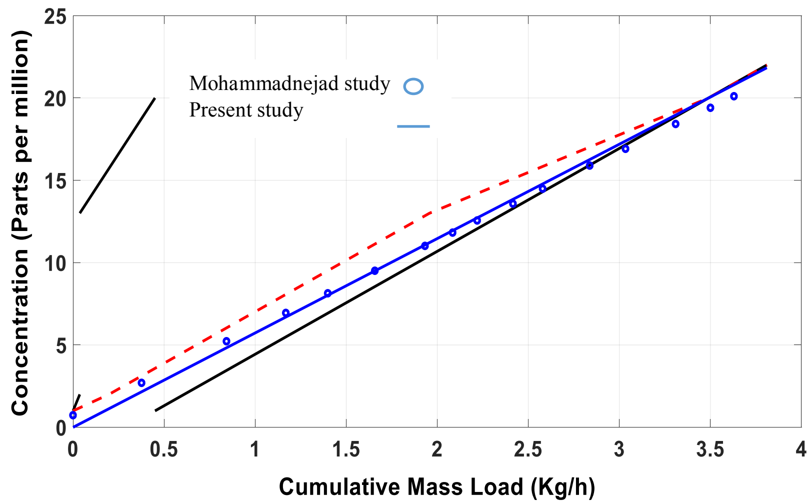



**Figure 7**. Resulted curve from the analyzed algorithm

### 2.3. Case Study: Shahid Tondgooyan Oil Refining Co., Tehran

A cooling tower, from Shahid Tondgooyan oil refining Co., with five flows, including discharges (debits) and different pollutant concentrations, is analyzed. The objective is to estimate the value of optimal discharge based on pinch point and the written program. The resulted data are presented in Table 3.

**Table 3.** Restriction data of cooling tower for dissolved solid pollutants (Shafikhani, 2016)

| Number of operation | Input flow intensity ($m^3$/h) | Output flow intensity ($m^3$/h) | Input concentration (Parts per million) | Output concentration (Parts per million) |
|---|---|---|---|---|
| 1 | 20 | 20 | 1300 | 1349 |
| 2 | 25 | 25 | 1488 | 1542 |
| 3 | 30 | 30 | 1670 | 1710 |
| 4 | 37 | 37 | 1600 | 1710 |
| 5 | 42 | 42 | 1750 | 1800 |

According to the results of analyzed algorithm, the following conclusions are taken from dissolved solid pollutants:

Figure 8 indicates numerical value, concentration, and cumulative mass load of pinch point. The numerical value of pinch point stands for the optimal amount of consumed raw water. By comparing the values, it can be inferred that discharge value in normal pinch point is 5.3889, and pinch point of consumed potable water is 5.8497. Therefore, it is observed that water consumption has reduced up to 8.5%. According to three input concentration, output concentration, and flow intensity variables, the effects of change in each factor on pinch point are analyzed. For this end, ten operations with different pollutants are assumed. The results are indicated in Figure 9.

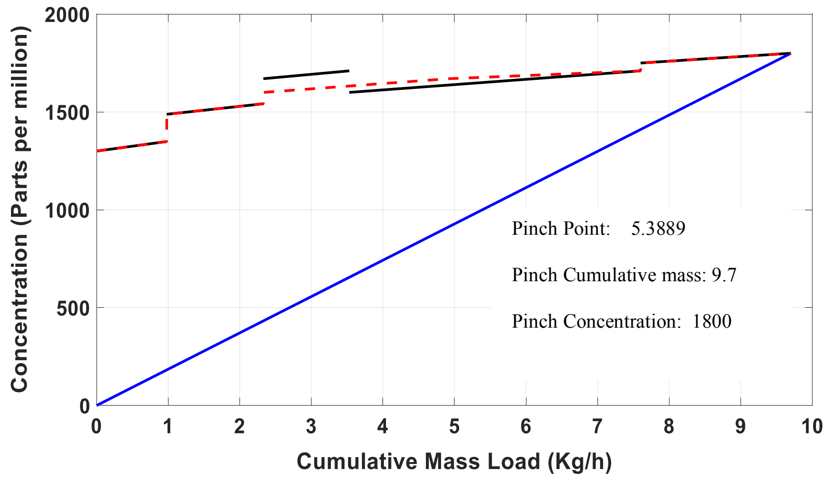



**Figure 8**. Water supply line for dissolved solid pollutants in cooling tower (shafikhani, 2016)

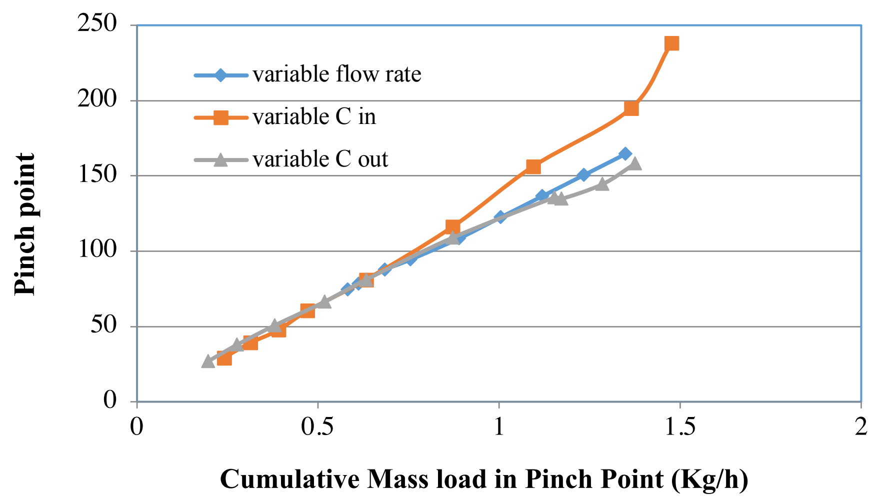



**Figure 9.** Comparative Diagram for three different changes

In this analysis, three different modes are analyzed. First mode includes flow intensity of the variable, constant input and output concentrations. Second mode includes input concentration of the variable, flow intensity, and constant output concentration. And the third mode includes output concentration of the variable, flow intensity, and constant input concentration. According to Figure 9, by assuming that cumulative mass load is constant, input concentration and input flow intensity changes are more effective on pinch point, and output concentration has lower effects on pinch point.

## Conclusion

In this paper, an algorithm is used for minimization of water consumption based on water pinch method. In this regard, the existing data in other published papers were applied in prepared algorithm as input data. Then, after comparing the results, it was seen that the agreement was favorite. Technical literature review mostly contains graphical methods for pinch analysis. The mentioned methods has some issues in solving the problems based on pinch approach including the complexity of graphical drawings and limitation of its input operations, which these items lead to range reduction. However, the presented algorithm makes it possible to use infinite number of operations in pinch analysis and development. According to the reports of refinery regarding dissolved solid pollutants as input operation, water consumption has reduced up to 8.5% in comparison with non-renewable raw water. By using an assumed pollutant with ten operations and changing one variable without changing the others, it can be said that output concentration changes have more effects on pinch point in comparison with input concentration and flow intensity. It should be noted that change range is considered to be so extensive in this study. The presented algorithm provides the opportunity for more accurate drawings and calculations in minimum time. By applying this algorithm in pinch combination and update sections, a model can be presented and used for reducing water consumption of the whole network.

## References

Alva-Argeaz, A.A., Antonis, C., Kokossis, Smith, R. (2006). The design of water-using systems in petroleum using a water-pinch decomposition, Chemical Engineering Science, 128, 33-46.

Akeem, A. O., Paiko, I. I., Sule, U. D., & Jipo, N. A. (2017). Application of Composition Interval Diagram for Cost Minimization in Mass Exchanger Networks. International Journal of Scientific Engineering and Technology, 6(8), 318-323.

Balla, W. H., Rabah, A. A., & Abdallah, B. K. (2017). Pinch Analysis of Sugarcane Refinery Water Integration. Sugar Tech, 1-13.

Castro, P., Matos, H., Fernandez. C., Pedro N. C. (1999). Improvements for Mass-Exchange Networks Design, Chemical Engineering Science, 54, 1649-1665.

Dhole, V. R., Ramchandi, N., Tanish .R. A., Wasileswski, M. (1996). Make your Process Water Pay for Itself, Chemical Engineering Science, 103(1), 100-103.

El-Halwaji, M .M. (2017). Sustainable Design through Process Integration, (Butterworth-Heinemann).

El-Halwaji, M .M. (2016). Sustainability in the Design, Synthesis and Analysis of Chemical Engineering Processes, (Oxford, Butterworth-Heinemann).

El-Halwaji, M .M. (2006). Process Integration, Elsevier, 7, 183–230.

El-Halwaji, M . M., Gabriel, F. and Harell, D.(2003). Rigorous graphical targeting for resource conservation via material recycle/reuse networks, Ind.Eng.Chem. Res, 42, 4319–4328.

El- halwagi, M. M., Manousiouthakis, V. (1990). Mass exchanger networks with single component target, Chemical Engineering Science, 45(9), 2813-2825.

Gomes, J., Queiroz, F., Pessoa, L. P. (2006). Design Procedure for Water/Wastewater Minimization: Single Contaminant, Journal of Cleaner Production, 15(5), 474-485.

Halale, N. (2002). A New Graphical Targeting Method for Water Minimization, Advances in Environmental Research, 6 (3), 377-390.

Hansen, É., Rodrigues, M. A. S., Aragao, M. E., & de Aquim, P. M. (2018). Water and wastewater minimization in a petrochemical industry through mathematical programming. Journal of Cleaner Production, 172, 1814-1822.

Kuo, W.-C. J., Smith, R. (1998). Designing for the interactions between Water-use and effluent treatment, Trans I. Chem, Vol 76, Part A.

Linnhoff, B. and Eastwood, A. R. (1997). Overall site optimisation by Pinch Technology. Chemical Engineering Research and Design, 75(Supplement), 138-144.

Linnhoff, B., Townsend, D. W., Boland, D., Hewitt, G. F., Thomas, B. E. A., Guy, A. R.and Marshall, R. H.(1982). A User Guide on Process Integration for the Efficient Use of Energy, The Institution of Chemical Engineers, Rugby, UK.

Manan, G., Liu Y. A. (1999). Industrial Water Reuse and Wastewater Minimization, USA: McGraw Hill.

Manan, Z. A., Wan Alwi, S. R., Z. Ujang. (2006). Water Pinch Analysis for an Urban System: A Case Study on The Sultan Ismail Mosque at The University Teknologi Malaysia (UTM), Desalination, 194 (1-3), 52-68.

Mehrdadi, N., Nabi Bidhendi, Gh., Mohammadnejad, Sh. (2009). An Overview on Different Water Pinch Methods for Industrial Water and Wastewater Minimization, Envirenmental Sciences, 6, No.4, 29-42.

Mughees, W. and Al-Ahmad, M. (2015), Application of water pinch technology in minimization of water consumption at a refinery, Computers & Chemical Engineering, 73, 34-42.

Mohammadnejad, Sh. (2010). Water and Wastewater Minimization in Tehran Oil Refinery using Water Pinch Analysis, Dissertation, Tehran University.

Nabi Bidhendi, Gh, Mehrdadi, N., Mohammadnejad, Sh. (2010). Water and Wastewater Minimization in Tehran Oil Refinery using Water Pinch Analysis, Environ Monit Assess, 4(4), 583-594.

Olesen, S. G., Polley, G. T. (1997). A Simple Methodology for the Design of Water Networks Handling Single Contaminants, Trans. I. Chem, 75, 420-426.

Paudel, E., Van der Sman, R. G., Westerik, N., Ashutosh, A., Dewi, B. P., & Boom, R. M. (2017). More efficient mushroom canning through pinch and exergy analysis. Journal of Food Engineering, 195, 105-113.

Priya, K. G.S. and Bandyopadhyay, S. (2017), Multiple objectives Pinch Analysis, Resources, Conservation and Recycling, 119, 128-141.

Sardiñas, G. O. L., Bastida, E. J. L., Gárciga, J. P., & Mira, L. D. (2017). Water pinch technology application to minimize sulphurous wastewater in an oil refinery. Centro Azucar, 44(1), 1-10.

Shafikhani, A., (2016), Pinch technology for optimizing water consumption (case study: Shahid Tondgoyan oil refinery). Dissertation, Alborz Tehran University campus.

Shahruddin, M. Z., Rahimi, A. N., Zubir, M. A., Islam Zahran, M.F., Ibrahim, K. A. and Abd Hamid, M. K. (2017). Energy Integrated Distillation Column Sequence by Driving Force Method and Pinch Analysis for Five Components Distillation, Energy Procedia, 142, 4085-4091.

Sorin, M., Bedard, S. (1999). The Global Pinch Point in Water Reuse Networks, Process Safety and Environmental Protection, 77 (5), 305-308.

Sun, L. and Luo, X. (2011). Synthesis of multipass heat exchanger networks based on pinch technology, Computers & Chemical Engineering. , 35(7), 1257-1264.

Tan, Y.L., Foo, D.C.Y., Tan, R.R., Ng, D.K.S. (2007). Approximate Graphical Targeting for Water Network with Two Contaminants, Paper presented in 10th Conference on Process Integration, Modelling & Optimisation for Energy Saving & Pollution Reduction, Italy.

Tan, Y. T., Manan, Z. A., Yee, F. C. (2007). Retrofit of Water Network with Regeneration Using Water Pinch Analysis, Process Safety and Environmental Protection, 85 (4), 305-317.

Wang Y. P., Smith, R. (1995), Wastewater minimization with flowchart constraints Tran, Chemical Engineering Science, 73(A), 889-904.

Wang, Y. P. and Smith, R. (1994). Design of distributed effluent treatment systems, Chemical Engineering Science, 49(18), 3127-3145.

Winterbone, D. E. and Turan, A. (2015). Advanced Thermodynamics for Engineers. (Butterworth-Heinemann, edition 2).

Yesaswini, G., & Saravanathamizhan, R. (2018). Wastewater Minimization of Starch Industry using Water Pinch Analysis and Comparison with Water Design Software.