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# A Modified Graphical Method to Target the Regeneration Stream Flow Rate for Water-Using Networks

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A few graphical methods in literature, sometimes, cannot give correct Regeneration Pinch and/or target of regeneration stream flow rate for water-using networks. By analysis, this paper points out that the reason for the above problem is that the streams of the processes, which reuse the outlet stream of the processes satisfied by freshwater only, are illustrated incorrectly. Based on the above analysis, a modified method is proposed. The procedure proposed in this article is as follows: (1) draw the Concentration-Cumulative Mass Load Curves (CCMLCs) for the processes which use freshwater only and that for other processes, respectively; (2) identify and remove the processes with high inlet concentrations and can reuse the outlet streams of the processes which are satisfied with freshwater only; (3) from the CCMLCs of the remaining processes with high-inlet concentrations, the target of regeneration stream flow rate and Regeneration Pinch can be obtained. This paper solves the problem of inconsistent results of some graphical methods and that of numerical methods in literature.

## 1. Introduction

Many methods have been proposed for design water-using networks involving regeneration, and most of them can be classified into Pinch Methods and Mathematical Programming Approaches. Wang and Smith (1994) presented a graphical method to design the water-using networks with regeneration. On the basis of Wang and Smith (1994), Kuo and Smith (1998) put forward a method to design water-using network involving regeneration reuse/recycling. Through analysis of water network with the regeneration process, Mann and Liu (1999) pointed out that for the water network system with regeneration unit, there exist not only existing Freshwater Pinch, but also Regeneration Pinch. Until very recently, graphical methods are still important tools for synthesis of water network (Zhang et al., 2015), design of hydrogen networks (Yang et al., 2014), planning and design of low carbon product (Mohd Nawi et al., 2014), and targeting and design of multiple utility systems (Wan Alwi et al., 2014).

## 2. Methodology

**Some problems existing in a few graphical methods in literature**

Some existing graphical methods cannot give correct results for the water network involving regeneration unit. An example will be analyzed to show the reason for this problem. The limiting data in Table 1 are taken from Feng et al. (2007), the regenerated concentration is 10 ppm, where M is the mass-load of the processes.

Now, we will use the method of Wang and Smith (1994) to solve this example. According to Wang and Smith (1994), Figure 1 can be obtained. From Figure 1, it can be seen that, the regeneration pinch is 100 ppm, the consumption of freshwater is 85 t/h, and the flow rate of the regenerated stream is 57.78 t/h. However, according to numerical methods, such as Liu et al. (2009) or other numerical methods, the Regeneration Pinch is 80 ppm, and the freshwater consumption and the flow rate of regenerated stream are 85 t/h and 55.71 t/h. The consumption of regenerated stream is less than that obtained by using the method of Wang and Smith (1994).

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*Table 1: Limiting data*

| Process | $C_{max,in}$ (ppm) | $C_{max,out}$ (ppm) | $F_{max}$ (t/h) | M (g/h) |
|---|---|---|---|---|
| 1 | 0 | 80 | 85 | 6,800 |
| 2 | 20 | 80 | 15 | 900 |
| 3 | 20 | 40 | 65 | 1,300 |
| 4 | 70 | 100 | 31.67 | 950 |
| 5 | 70 | 80 | 105 | 1,050 |
| 6 | 70 | 130 | 33.33 | 2,000 |

**Analysis**

Now, let us analyze the reason for the problem of the method of Wang and Smith (1994). First, we draw the concentration-cumulative mass load curves for the processes which use freshwater only (FOPs, Freshwater Only Processes) and the other process, respectively, as shown in Figure 2. Then, draw a horizontal line from the point of the outlet of FOPs (point A), and intersect non-FOPs at point K. Next，draw a parallel line of line OA from point K, and we obtain line KH. The processes, whose inlet concentrations are lower than the outlet concentration of FOPs, can reuse the outlet streams of FOP (represented by line OA) and need not to use regenerated streams. So, the outlet streams of FOP can satisfy the processes represented by curves KEF. If we satisfy the processes represented by curves KEF with regenerated stream, the amount of regenerated streams consumption will be increased (as shown in Figure 1). The reciprocal of the slope of the line representing regeneration stream in concentration-cumulative mass load curves is the consumption of regenerated stream. Therefore, increasing of consumption of regenerated stream can make the regeneration stream supply line slope decreased. This causes the incorrect results of Regeneration Pinch and/or regeneration stream target for some graphical methods in literature.

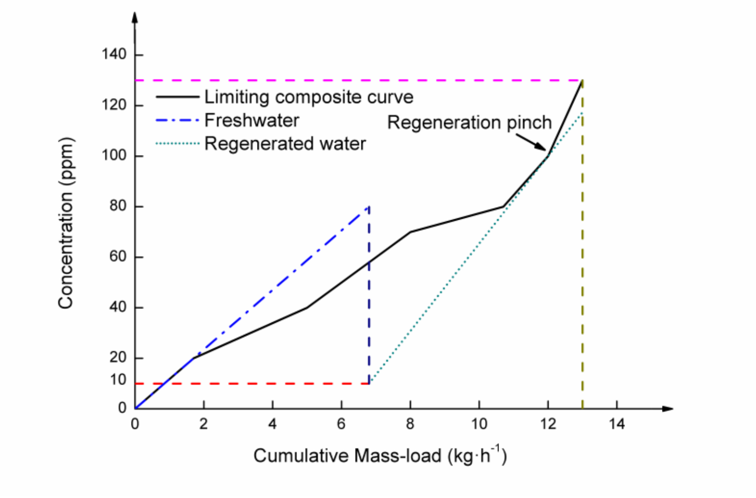


*Figure 1: The Concentration-cumulative mass load curves by the method of Wang and Smith (1994)*

**The new method**

Based on the above analysis, we will propose a modified graphical method to obtain the correct results. The core idea is to separate the processes which need not use regenerated stream with the processes which must use regenerated stream. In Figure 2, we move curve KEF to the top of curve OA. Then, we can obtain the concentration-cumulative mass load curves, as shown in Figure 3. Satisfying the processes represented by curves KEF with the outlet stream of FOP (process 1) can reduce the consumption of regenerated stream. From Figure 3, it can be seen that the Regeneration Pinch is 80 ppm, and the consumption of regenerated stream is 55.71 t/h. The results are same as that obtained by the numerical methods, such as Liu et al. (2009). Now, we will propose a modified graphical method as follows (see Figure 2):

1. Identifying FOPs and non-FOPs, and drawing the Concentration-cumulative mass load curves, respectively.
2. Drawing a horizontal line from the point of the outlet of FOPs (point A), and intersecting non-FOPs at point K.
3. Drawing a parallel line of line OA from point K. The processes which are above the parallel line can be satisfied with the outlet streams of the FOPs.

4. Moving the processes which can be satisfied with the outlet stream of FOPs to the upper part of the FOPs.
5. For the remaining non-FOPs processes, drawing a regenerated stream supply line from regenerated concentration point. Then, we can obtain the regeneration pinch and the target of regenerated stream flow rate.

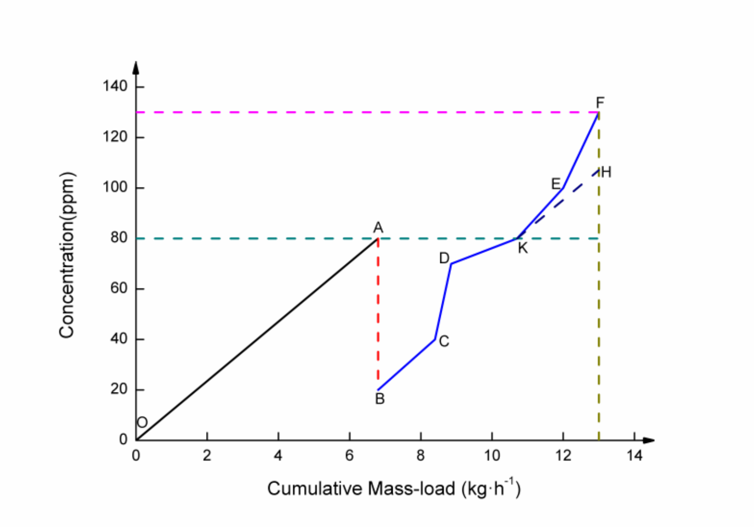


*Figure 2: The initial Concentration-cumulative mass load curves*

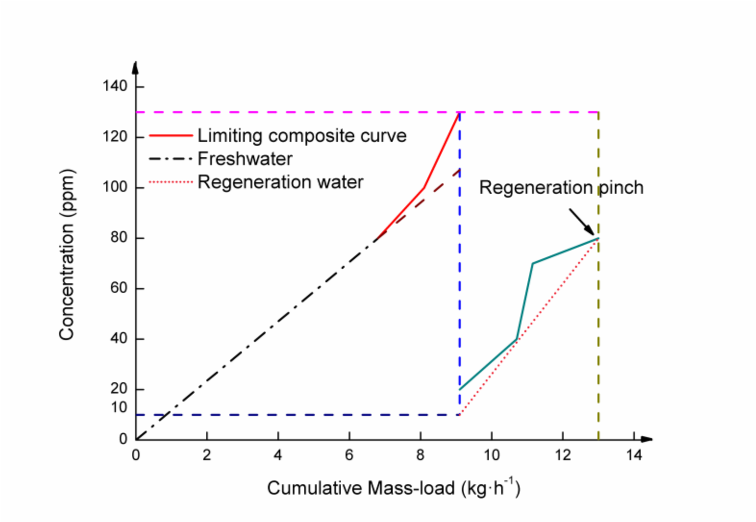


*Figure 3: The final Concentration-Cumulative Mass Load Curves*

## 3. Case study

This example is taken from Kuo and Smith (1998), with the data shown in Table 2. The regenerated concentration is 20 ppm. Now, the proposed method will be used to solve the example.

(1) Drawing the FOP (process 1) first, and then we can obtain the concentration-cumulative mass load curves for the non-FOPs, as shown in Figure 4.

(2) Drawing a horizontal line from point A, and intersecting the non-FOPs at point K. Drawing line KH which parallels to line OA from point K, and intersecting line CD at point F. Because curve KCF is located above line KH, the processes represented by curve KCF can be satisfied by the outlet streams of the FOPs. So, KCF can be moved to the top of curve(s) of the FOPs.

*Table 2: Limiting data for the case study example*

| Process | $C_{max,in}$ (ppm) | $C_{max,out}$ (ppm) | $F_{max}$ (t/h) | M (g/h) |
|---|---|---|---|---|
| 1 | 0 | 200 | 40 | 8,000 |
| 2 | 100 | 200 | 50 | 5,000 |
| 3 | 100 | 400 | 30 | 9,000 |
| 4 | 300 | 400 | 60 | 6,000 |
| 5 | 400 | 600 | 40 | 8,000 |

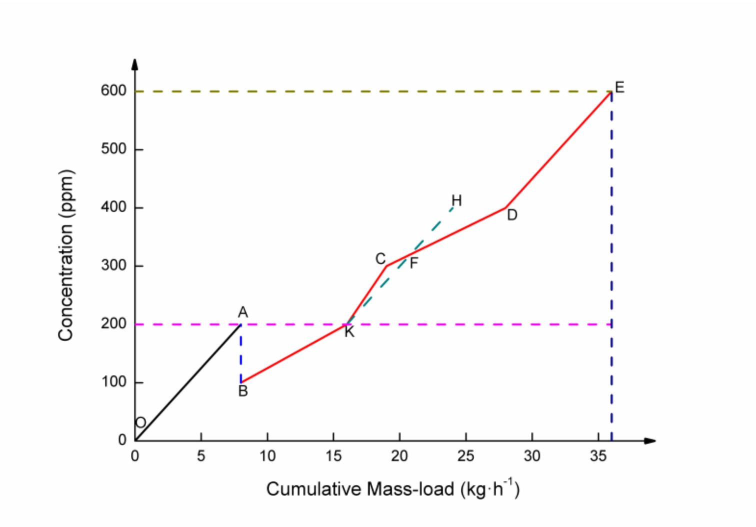


*Figure 4: The initial Concentration-Cumulative Mass Load Curves for the case study example*

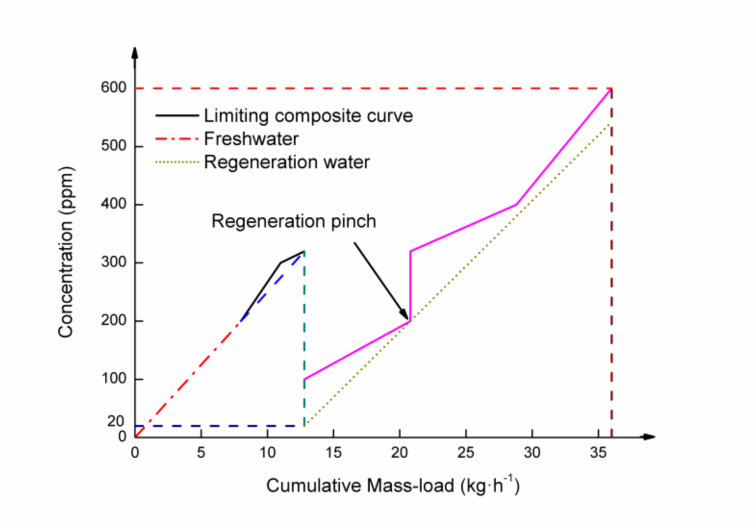


*Figure 5: The final Concentration-cumulative mass load curves for the case study example*

(3) From the Concentration-Cumulative Mass Load Curves shown in Figure 5. It can be seen that, the Regeneration Pinch is 200 ppm, and the consumption of freshwater is 40 t/h, and the flow rate of regenerated stream is 44.44 t/h.

Using the numerical method of Liu et al. (2009), and later Xu et al. (2013), it can be obtained that the Regeneration Pinch is 200 ppm. The flow rate of regenerated stream is 44.44 t/h, which are same as that obtained by the method proposed in this paper. The results are also the same with that obtained by the graphical method of Feng et al. (2007).

From Figure 6, which is obtained by using the method of Wang and Smith (1994), the regeneration pinch is 400 ppm, and the consumption of freshwater is 40 t/h, and the flow rate of regenerated stream is 52.63 t/h, which are not correct. By using software of Mann and Liu (1999), it can be obtained that Regeneration Pinch is 400 ppm, and the flow rate of regenerated stream is 66.67 t/h, which are not correct, either.

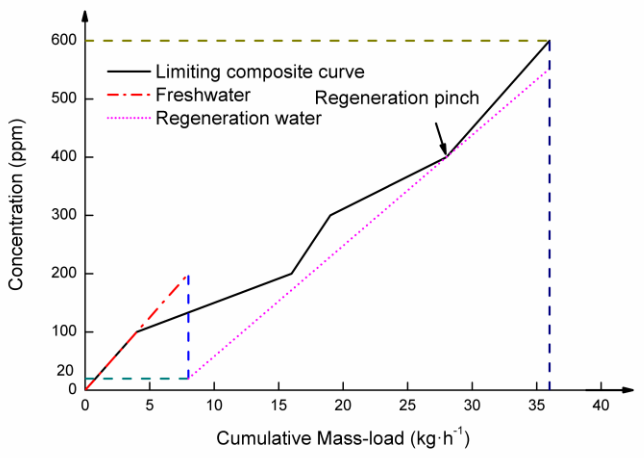


*Figure 6: The Concentration-Cumulative Mass Load Curves by the method of Wang and Smith for the case study example*

From this example, it can be seen that the results obtained by using the method proposed in this paper are the same as that obtained by using the numerical method of Liu et al. (2009), and later Xu et al. (2013), and that by using the graphical method of Feng et al. (2007). However, the authors claim that the results obtained by using the graphical method of Wang and Smith (1994) and software of Mann and Liu (1999) are not correct. The design obtained for the example is shown in Figure 7.

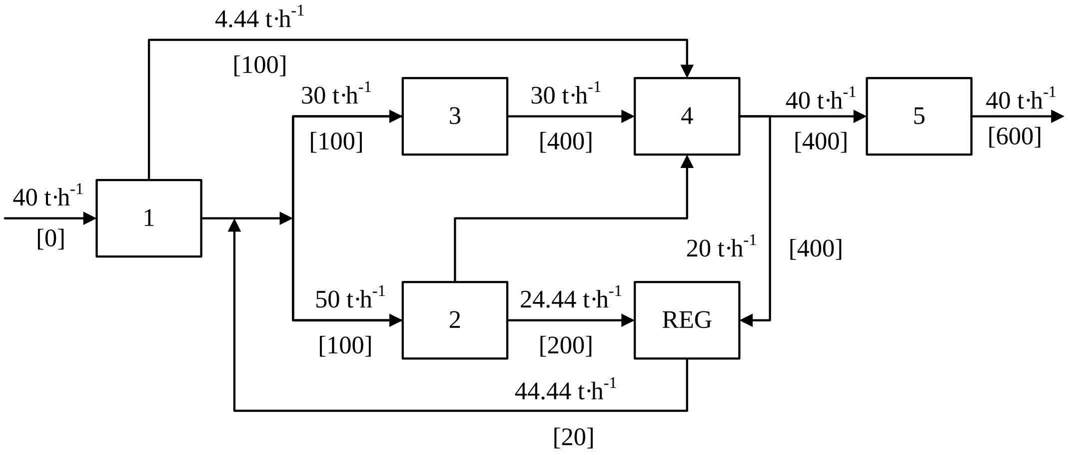


*Figure 7: The design for the example*

## 4. Conclusion

In this paper, by analysis, we point out the reason why some graphical methods in the literature cannot give the correct results for the Regeneration Pinch and the target of regenerated stream flow rate. Based on the above analysis, a modified graphical method is proposed to solve the problem of inconsistent results of some graphical methods in literature and that of numerical methods. In the proposed method, we move the processes which can reuse the outlet streams of the FOPs to the upper part of the FOPs, then, we can obtain the Regeneration Pinch and the target of regeneration stream flow rate in the remaining processes which reuse regenerated stream. The results show that the graphical method proposed in this paper can obtain the correct Regeneration Pinch and the target of regenerated stream flow rate.

**Notation**

| | | |
|---|---|---|
| $C_{max,in}$ | —— | the limiting data for inlet concentration, ppm |
| $C_{max,out}$ | —— | the limiting data for outlet concentration, ppm |
| $F_{max}$ | —— | the maximum flow rate of the processes, t/h |
| FOPs | —— | the processes which use freshwater only |
| M | —— | the mass load of the processes, g/h |

**Reference**

Feng X., Bai J., Zheng X.S., 2007, On the use of graphical method to determine the targets of single-contaminant regeneration recycling water systems, Chemical Engineering Science, 62, 2127-2138.

Kuo W.C.J., Smith R., 1998, Design of water-using systems involving regeneration, Trans IChemE (part B), 76, 94-114.

Liu Z.Y., Li Y.M., Zhang G.L., Yang Y.Z., 2009, Simultaneously designing and targeting for network s with multiple resources of different qualities. Chinese Journal of Chemical Engineering 17(3), 445– 453.

Mann J.G., Liu Y.A., 1999, Industrial Water Reuse and Wastewater Minimization, McGraw-Hill: New York.

Mohd Nawi W.N.R., Wan Alwi S.R., Manan Z.A., Klemeš J.J., 2014, A Graphical Approach for the Planning and Design of a Low Carbon Product. Chemical Engineering Transactions, 39, 205-210.

Wan Alwi S.R., Manan Z.A., Chezghani M., 2014, A Graphical Method for Simultaneous Targeting and Design of Multiple Utility Systems. Chemical Engineering Transactions, 39, 1045-1050.

Wang Y.P., Smith R., 1994, Wastewater minimization, Chemical Engineering Science, 49, 981-1006.

Xu D.L., Yang Y., Liu Z.Y., 2013, Predicting target values of the water-using networks involving regeneration recycling, Chemical Engineering Science, 104, 525-539.

Yang M., Feng X., Chu K.H., Liu G., 2014. Graphical method for identifying the optimal purification process of hydrogen systems. Energy, 73, 829-837.

Zhang Q, Yang M.B., Liu G.L., Feng X., 2015, Relative concentration based pinch analysis for targeting and design of hydrogen and water networks with single contaminant, Journal of Cleaner Production, doi:10.1016/j.jclepro.2015.06.019