Studies on Design For Maximum Water Reuse For Single Contaminants

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***Abstract*:** Water is being used in most process industries, agriculture and for a wide range of applications. To fulfil this demand the sources of clean water are limited and decreasing in many areas due to droughts, changes in climatic conditions. Increasingly society no longer has the luxury of using water only once. However, the adaption of water minimization techniques can effectively reduce overall fresh water demand in water using processes and subsequently reduce the amount of effluent generated. The aim of this study is finding an appropriate way to minimize water utility due to high rate of water consumption and wastewater generation. In this study, different design methods for maximum water reuse are considered for single contaminants. An open source software designed by Liu Resereach Group was also demonstrated to be used for networking water operations.

Keywords: *Single contaminant, Water networking, Open source software*

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1. Introduction

Due to the wide use of water and increase in population, per capita demand of water is increasing. Freshwater resources are limited and declining. Also it is very expensive and sometimes difficult to purify wastewater to get desired purity. In these circumstances it is very difficult to precisely assess the quantity of clean water demanded by the public. As about 35% out of the total consumption of water is being used in industries, if some level of inlet contamination is allowed, then, in principle, water can be reused between operations. This concept of maximum water reuse can provide a combined solution to these problems by supplying the water to fulfill per capita demand, saving cost.

In present work, emphasis is given on minimizing fresh water supply by maximizing reuse of water. To illustrate how the overall minimum water consumption can be targeted when allowing reuse, single contaminant is considered for present study. The single contaminant might be a specific component (e.g. phenol, acetone, starch, etc.) or an aggregate property (e.g. total organic material, total suspended solids, total dissolved solids, COD). Later the approach can be extended to systems where limiting concentrations for multiple contaminants are specified. Maximization of water reuse of can be achieved by two ways. (1) Minimizing the flow rates to individual operations, (2) Reapplication of the stream between operations[1].

To achieve maximization water reuse Pinch Technology is used. Water pinch technology is a systematic technique for analyzing water networks and reducing expenditures related to different water using processes. Most of the methods used in water pinch analysis are based on the mass exchange of one or several contaminants. If the mass exchange is based on mass transferring of one contaminant, the problem will be solved as a single contaminant[2]. To illustrate use of this method specific example is taken for discussion.

2. Definitions and Methods

2.1 Definitions

Water Reuse: Water reuse is the use of treated wastewater for beneficial use, such as industrial operations and agricultural irrigation[3].

Reclaimed water: Reclaimed water is defined to mean water, which as a result of treatment of wastewater, is suitable for a direct beneficial use or a controlled use that would not otherwise occur[3].

Limiting concentrations: This specifies the maximum inlet and outlet concentrations for a single contaminant[1].

Limiting water flow-rate: This is the flow rate required if the specified mass of contaminant is picked up by the water between the maximum inlet and outlet concentrations. If an operation has a maximum inlet contaminant concentration greater than zero and it is fed by water with zero concentration, then for the specified mass load, a lower flow rate than the limiting water flow rate could be used[1].

Limiting Composite Curve: To determine the maximum potential for reuse, process streams or operations are plotted on axes of concentration versus mass load. As the concentrations are maximum inlet and outlet concentrations i.e. limiting concentrations, the curve is termed as a limiting composite curve of the water streams[1].

3. Results and Discussion

Consider problem given in table 1 for a process involving four operations. The objectives are to –

a. Target the minimum water consumption for the system through maximum reuse:

b. Design a network for the target water consumption:

Table 1: Limiting data for four operations:[1]

Operation No.	Contaminant mass (g/h)	Cin (ppm)	Cout (ppm)	Limiting Water Flow rate (t/h)
1	2000	0	100	20
2	5000	50	100	100
3	30000	50	800	40
4	4000	400	800	10

As the concentration of contaminant is so small, there is virtually no difference between the concentrations based on the mass flow rate of water and the mass flow rate of the mixture. So the concentration of contaminant can be specified on the basis of the mass flow rate of water rather than the mass flow rate of the mixture.

(1)

Where, C = Concentration of contaminant (ppm)

m_c = mass flow rate of contaminant (g/h)

m_w = mass flow rate of water (t/h)

It is convenient to define the water flow rate in terms of metric tons per hour (or t/day), mass flow rate of contaminant in terms of gram per hour (or g/day), hence the concentration in terms of parts per million (ppm).

The relationship between mass pickup of contaminant, mass flow rate of water and concentration change is given by:

(2)

Where, Δm_c = mass pickup of contaminant (g/h)

m_w = flow rate of water (t/h)

ΔC = concentration change (ppm)

The minimum flow rates with freshwater feed for streams calculated from equation (2):

$m_{w1} = (2000) / (100-0) = 20$ t/h

$m_{w2} = (5000) / (100-0) = 50$ t/h

$m_{w3} = (30000) / (800-0) = 37.5$ t/h

$m_{w4} = (4000) / (800-0) = 5$ t/h

Therefore, Total flow rate of freshwater = (20 + 50 + 37.5 + 5) = 112.5 t/h

3.1 Construction of the Limiting Composite Curve

1. Plot the four operations on axes of concentration versus mass load.
2. To construct the limiting composite curve, the diagram is divided into concentration intervals.
3. Then the mass load within each concentration interval combined to obtain the limiting composite curve. This represents a quantitative profile of the single-stream equivalent to the four separate streams. It is a combined boundary between feasible and infeasible concentrations.
4. To target for the minimum water flow rate, a steepest line drawn starting from zero (or initial) concentration within the feasible region, called as a water supply line which represent the minimum water supply.
5. The point where the steepest slope corresponds with the water supply line touching the limiting composite curve termed as the pinch point. It implies that the water concentration goes to its maximum value at pinch point. This could

correspond with minimum mass exchange driving force, maximum solubility limit, minimum flow rate of the system, and so on.

6. In this limiting composite curve there are two design regions: above the pinch and below the pinch. Below the pinch the full amount of the target minimum flow rate is needed. Above the pinch the process could operate with a lower flow rate than the target. (Figure 4)
7. The minimum flow rate required above the pinch is determined by a simple mass balance equation (2).

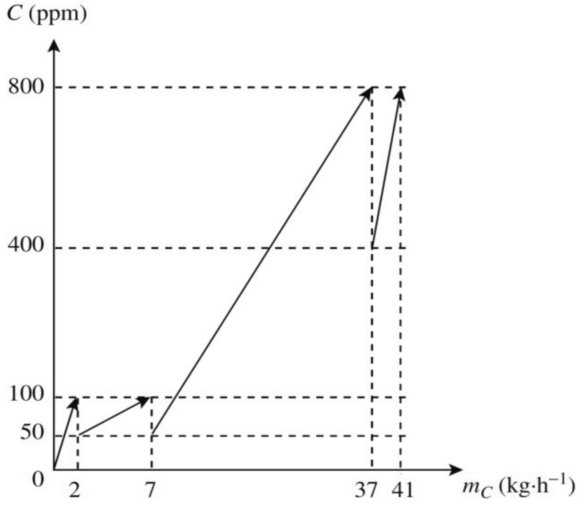

Figure 1: Limiting water data for the four operations

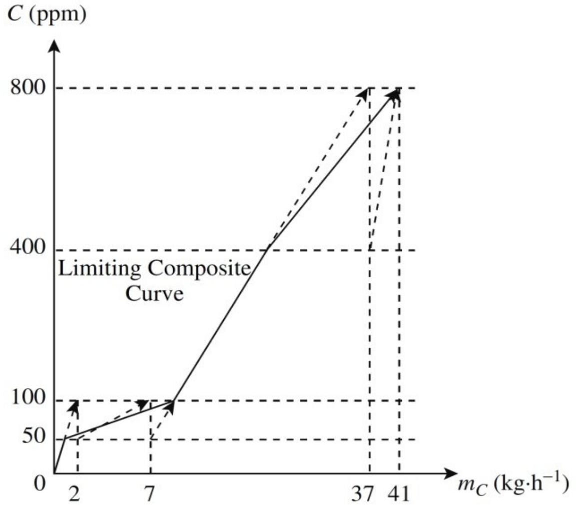

Figure 2: The Limiting Composite Curve

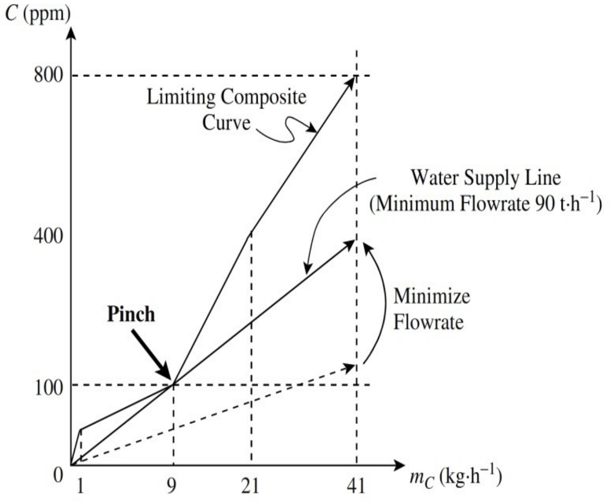

Figure 3: Targeting minimum water flow rate for a single contaminant

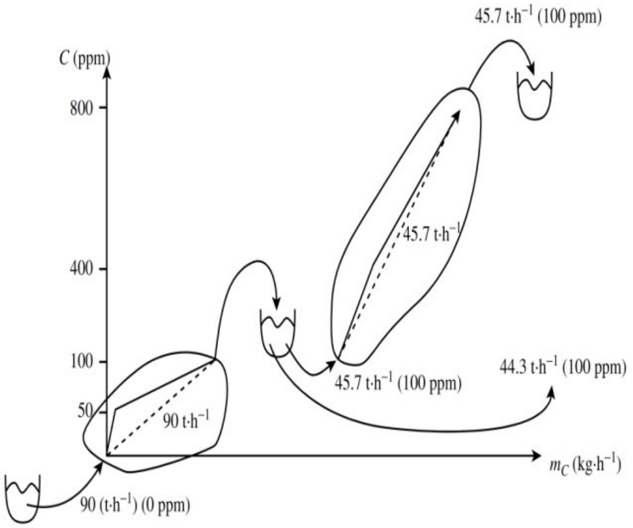

Figure 4: Basis of design strategy

3.2 Design Grid for the Water System

1. The design grid starts by setting up three *water mains*, corresponding with freshwater concentration, pinch concentration and the maximum concentration (Figure 5).
2. The flow rate required by each water main is shown at the top of the main and the wastewater generated by the main at the bottom.
3. Streams representing the individual operation requirements are superimposed on the water mains.
4. Operation 1 starts with fresh water at the inlet and terminates with 100 ppm at the outlet and is therefore shown between the freshwater main and the pinch concentration water main.
5. Operation 2 starts at 50 ppm and terminates at 100 ppm and is therefore shown between the freshwater and pinch concentration mains.

6. Operation 3 is broken into two parts as it features both below and above-pinch concentrations.
7. Operation 4 starts at 400 ppm and ends at 800 ppm and therefore features between the pinch concentration and final concentration mains.
8. The operations are then connected to the appropriate water mains, as shown in Figure 6.
9. The freshwater flow rates calculated from mass balance equation (2).
10. There is a problem created by Operation 3, in that, below the pinch it receives a flow rate of 20 t/h of freshwater, but at the pinch it receives a flow rate of 40 t/h of water at 100 ppm. This change in flow rate in the middle of Operation 3 would be impractical for most operations. It could be practical if Operation 3 involved, for example, an operation with multiple stages of washing.
11. To correct the change in flow rate for Operation 3, consider Figure 6. A mass balance around Part 1 in Figure 6 gives:

$$m_{W1}\,(C_{PINCH} - C_0) = m_{W2}\,(C_{PINCH} - C_{in,max}) \tag{3}$$

$$C_{in} = [(m_{W2} - m_{W1})\,C_{PINCH} + m_{W1}\,C_0\,]\,/\,m_{W2}$$

$$C_{in} = [m_{W2}\,C_{PINCH} - m_{W1}\,(C_{PINCH} - C_0)]\,/\,m_{W2} \tag{4}$$

Substituting equation (3) in equation (4),

$$C_{in} = [m_{W2}\,C_{PINCH} - m_{W2}\,(C_{PINCH} - C_{in,max}\,)]\,/\,m_{W2}$$

$$C_{in} = C_{in,max} \tag{5}$$

This implies that, if the mixing junction is moved from the middle of the operation to the beginning of the operation, then there is a constant flow rate throughout the operation corresponding with an inlet concentration after mixing of the maximum inlet concentration. Thus the change in flow rate for Operation 3 that previously occurred at the pinch concentration water mains is now added at that concentration to the inlet of Operation 3. The design now features a constant flow rate in all of the operations and achieves the target minimum flow rate of 90 t/h.

12. The arrangement shown in Figure 7 involves reuse of water from Operations 1 and 2 into Operations 3 and 4 via a water main at the pinch concentration of 100 ppm.

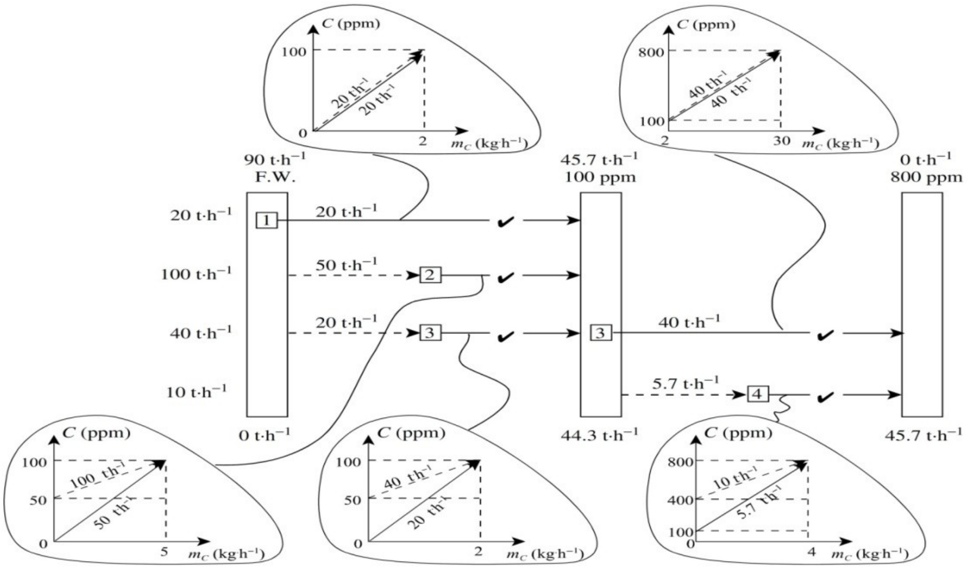

Figure 5: Streams connected with the water mains

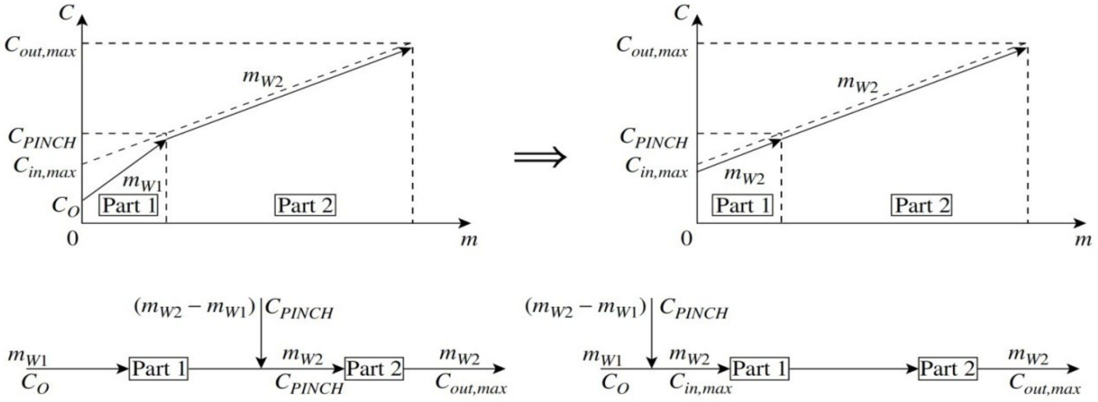

Figure 6: An operation involving a change in flow rate

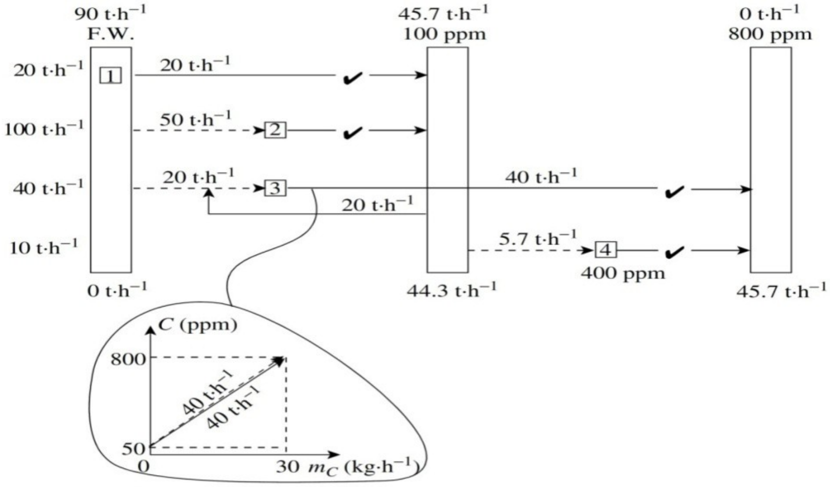

Figure 7: Correcting the change in flow rate in the design grid

3.3 Water Network Diagram without the Intermediate Water Mains:

An alternative way to arrange the design is to make the connections directly, rather than through an intermediate water main. If the intermediate water main is removed, then there are basically two sources of water from Operations 1 and 2 at 100 ppm and two sinks for water for Operations 3 and 4 at 100 ppm, as illustrated in Figures 8, 9, 10. Figure 8 shows a direct connection from Operation 1 to Operation 3 and another from Operation 2 to Operation 4 with 44.3 t/h going to wastewater from Operation 2. The arrangement shown in Figure 8 is the only one possible arrangement of connections between the sources and the sinks. Figure 9 shows this arrangement in the grid diagram, and Figure 10 shows the final design as a conventional flowsheet.

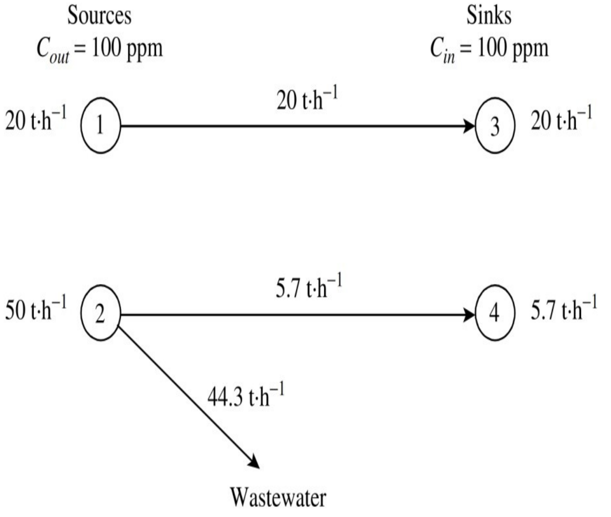

Figure 8: Removing the intermediate water main allows the connections to be made directly

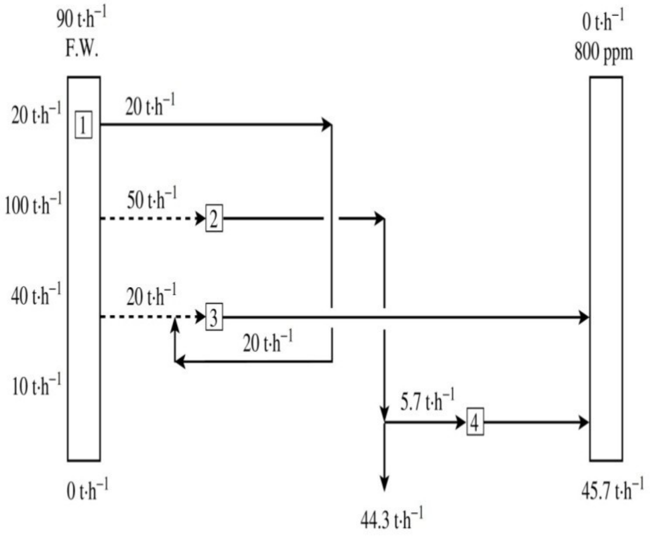

Figure 9: Water network without the intermediate water main

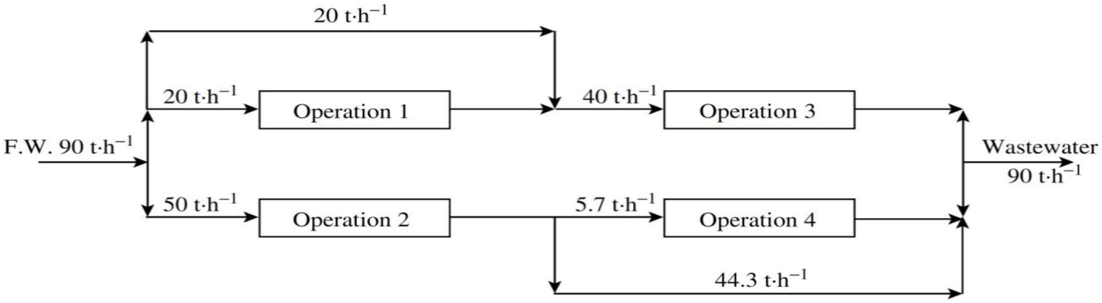

Figure 10: Final flowsheet for the water network

So from principle mass balance principles, fresh water requirement is 112.5 t/h and by applying pinch technology fresh water requirement reduces to 90 t/h without affecting process.

4. Conclusions

Pinch technology for water management can be handy tool for minimizing fresh water requirement without affecting process requirement and product quality. It also provides advantage of treating less water as there is lower requirement of fresh water. Application of Pinch Technology With the help of open source software can reduce efforts and increase accuracy to manifolds.

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