AquaSPICE

Advancing Sustainability of Process Industries through Digital and Circular Water Use Innovations

Water Integration

Design of a Minimum Capacity Wastewater Treatment System

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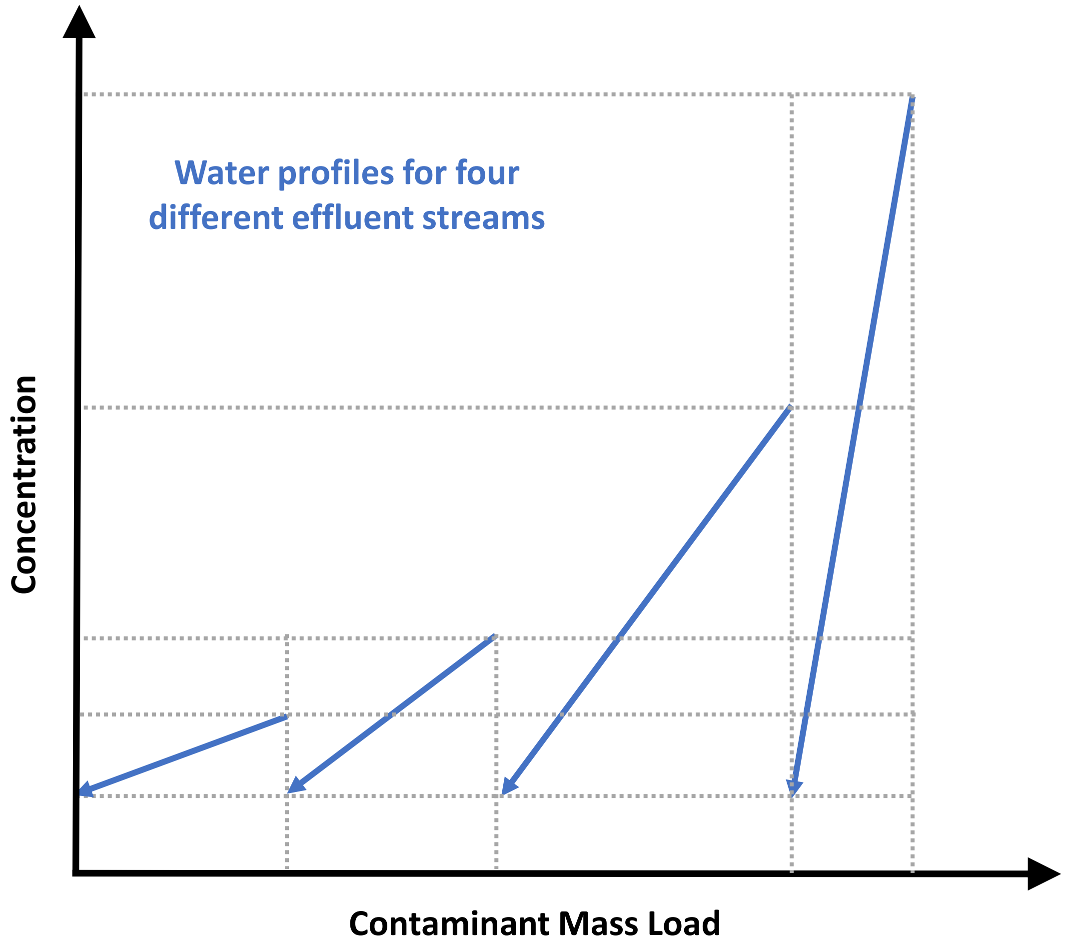
Minimum Wastewater Treatment Flowrate

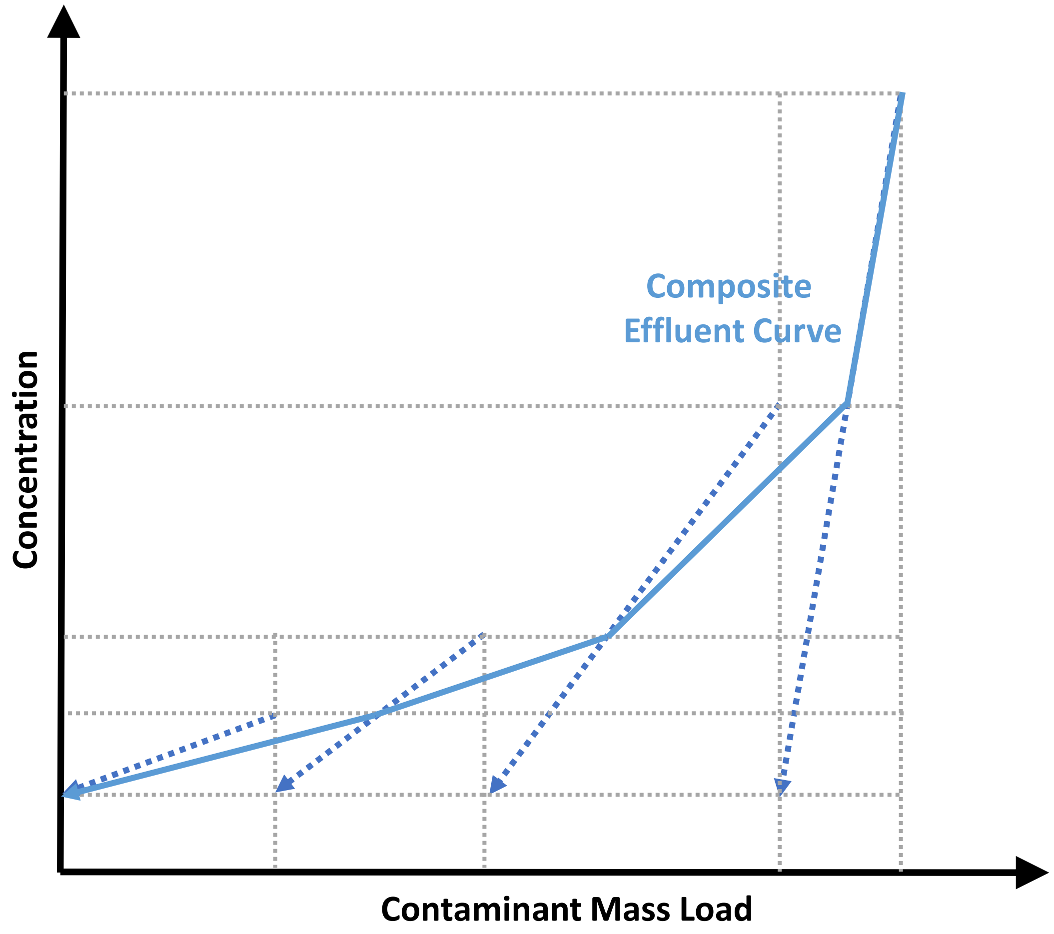
- Easiest solutions?
  - Mix all wastewater streams together and treat them
    - Increase in the operational cost by combining streams that require different treatment because:
      - Capital cost for each treatment process is related to the total wastewater flowrate
      - O&M cost for each treatment process increases with decreasing concentration of the contaminant
  - Treat each wastewater stream separately
    - Miss opportunities of combined treatment with two or more streams with similar load

Composite Effluent Curve



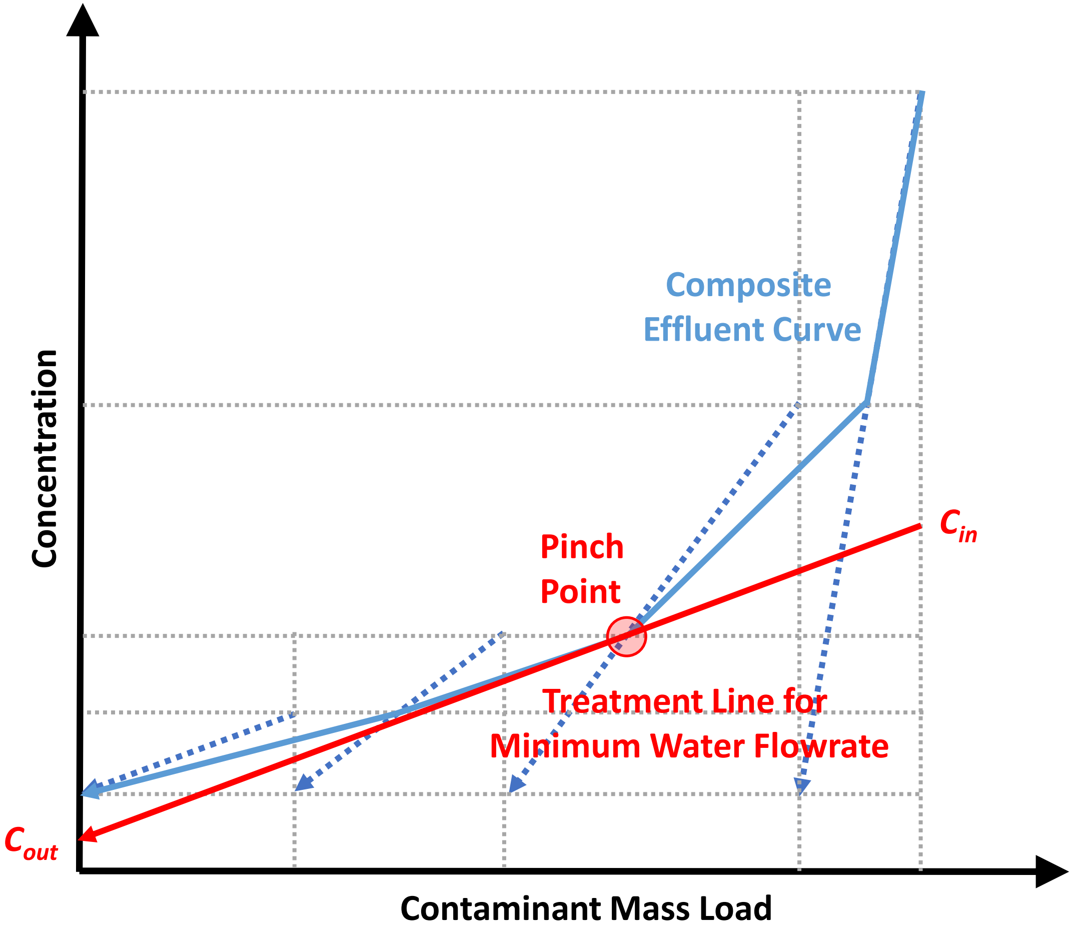
- When combining different effluent streams for various operations in the same chart, the output will be the composite effluent curve of the water streams

Composite Effluent Curve



- The drawing of the composite effluent curve is analogous to the limiting composite curve
- The y-axis is divided into the corresponding concentration intervals and the contaminant loads in each interval are combined to create the composite curve.

Minimum Water Flowrate



- The treatment line with the minimum flowrate corresponds to the line with the steepest slope that passes from the pinch point and:
  - either ends up at the minimum acceptable outlet concentration
  - or corresponds to a specific desired contaminant removal ratio

Removal Ratio

- The removal ratio of a certain contaminant can be defined as:
  - $R = \frac{\text{Mass of contaminant removal}}{\text{Inlet Mass of Contaminant}} = \frac{m_{w,in}C_{in} - m_{w,out}C_{out}}{m_{w,in}C_{in}}$
- It can be assumed that the change in the flowrate through the treatment process is minimal, so:
  - $R = \frac{C_{in} - C_{out}}{C_{in}}$

Let’s try an example

- An industrial unit has 3 effluent streams which require treatment, and their specifications are presented below.
  - Draw the composite effluent curve
  - Determine the minimum treatment flowrate, when the outlet concentration is fixed and equal to 5 ppm
  - Repeat the previous calculation when the removal ratio is set to 95%
- Assume that the environmental discharge limit is 20 ppm.

No	Inlet Concentration (ppm)	Water Flowrate (t/h)
1	250	20
2	100	100
3	40	40

Step 1. Calculate the contaminant mass load

- Assuming that the maximum environmental discharge limit is 20 ppm.

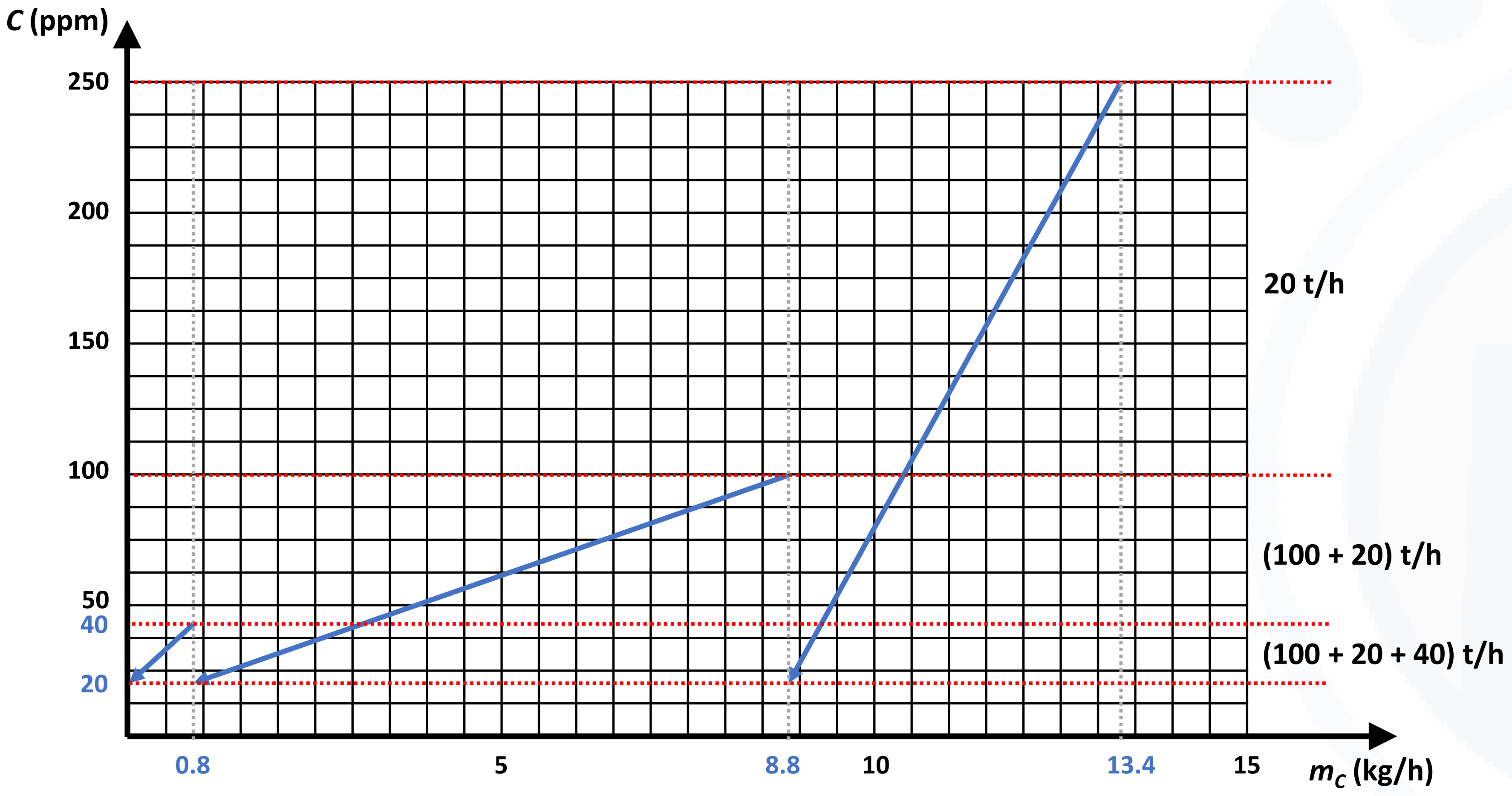
No	Inlet Concentration (ppm)	Maximum Discharge Limit (ppm)	Water Flowrate (t/h)	Contaminant Mass (g/h)
1	250	20	20	4600
2	100	20	100	8000
3	40	20	40	800

$$\Delta m_{C1} = mW_1 \times \Delta C_1 = 20 \times (250 - 20) = 4600 \text{ g/h}$$

$$\Delta m_{C2} = mW_2 \times \Delta C_2 = 100 \times (100 - 20) = 8000 \text{ g/h}$$

$$\Delta m_{C3} = mW_3 \times \Delta C_3 = 40 \times (40 - 20) = 800 \text{ g/h}$$

Step 2. Draw the wastewater profiles



Step 3. Calculate the concentration intervals

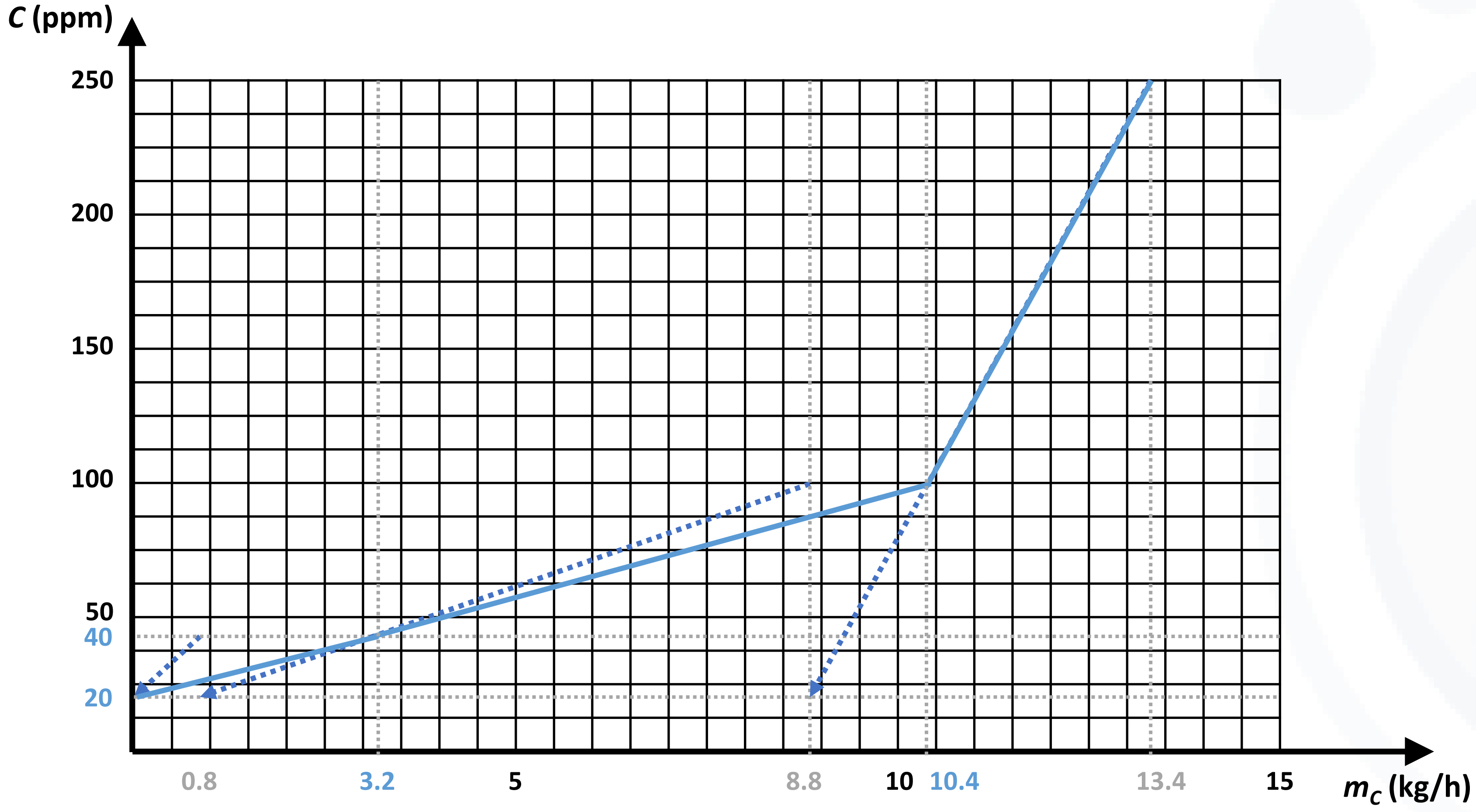
No	Inlet Concentration (ppm)	Maximum Discharge Limit (ppm)	Water Flowrate (t/h)	Contaminant Mass (g/h)
I	250	100	20	3000
II	100	40	20 + 100	7200
III	40	20	20 +100 +40	3200

$$\Delta m_{CI} = m_{WI} \times \Delta C_I = 20 \times (250 - 100) = 3000 \text{ g/h}$$

$$\Delta m_{CII} = m_{WII} \times \Delta C_{II} = 120 \times (100 - 40) = 7200 \text{ g/h}$$

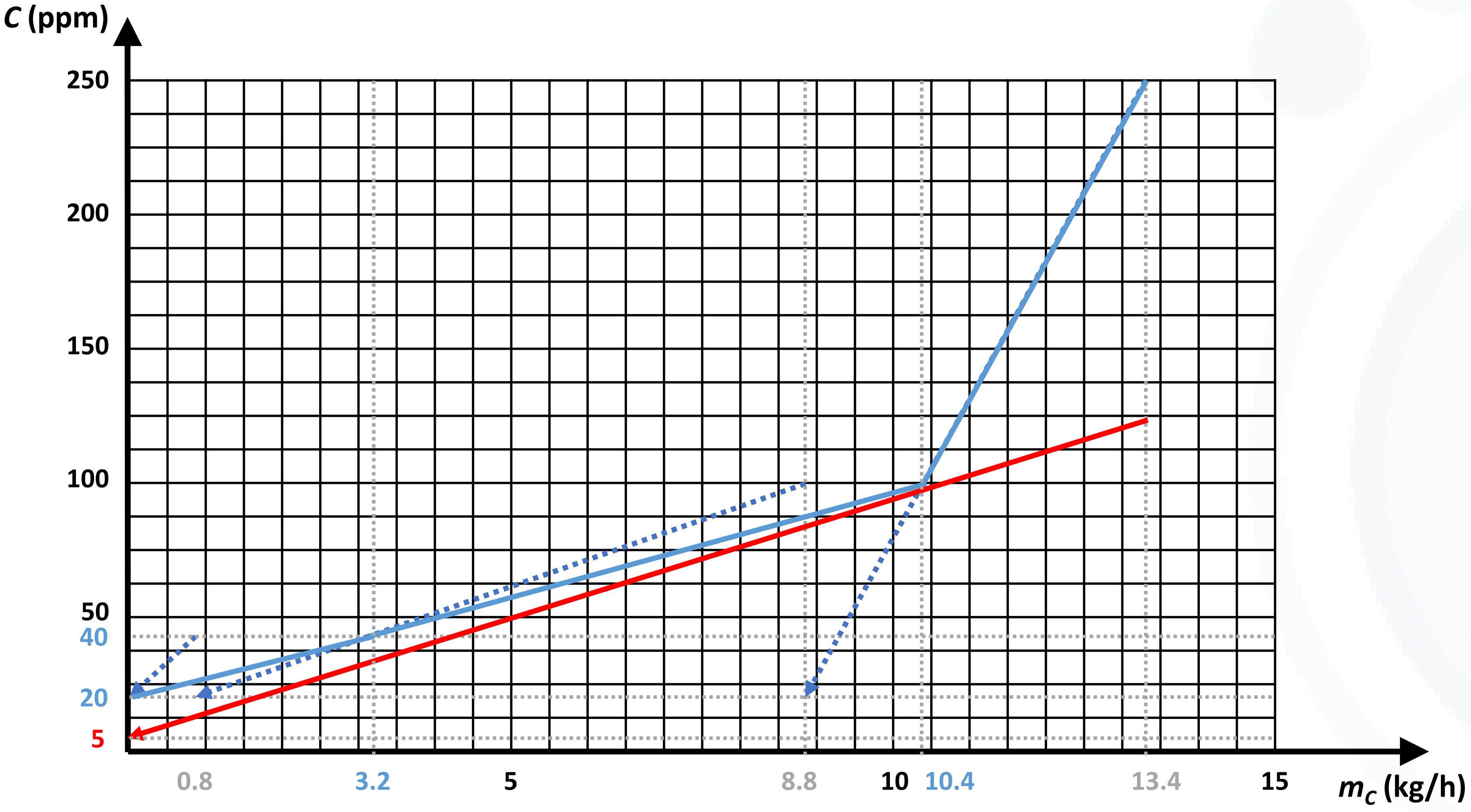
$$\Delta m_{CIII} = m_{WIII} \times \Delta C_{III} = 160 \times (40 - 20) = 3200 \text{ g/h}$$

Step 4. Composite Effluent Curve



Step 5. Minimum Flowrate Line

Assuming a fixed outlet concentration of 5 ppm.



Step 6. Calculate minimum flowrate and savings

- Calculate the minimum flowrate
  - From the pinch point

$$m_{w,min} = \frac{\Delta m_{C,pinch}}{\Delta C_{pinch}} = \frac{10400}{100 - 5} = 109.5 \text{ t/h}$$

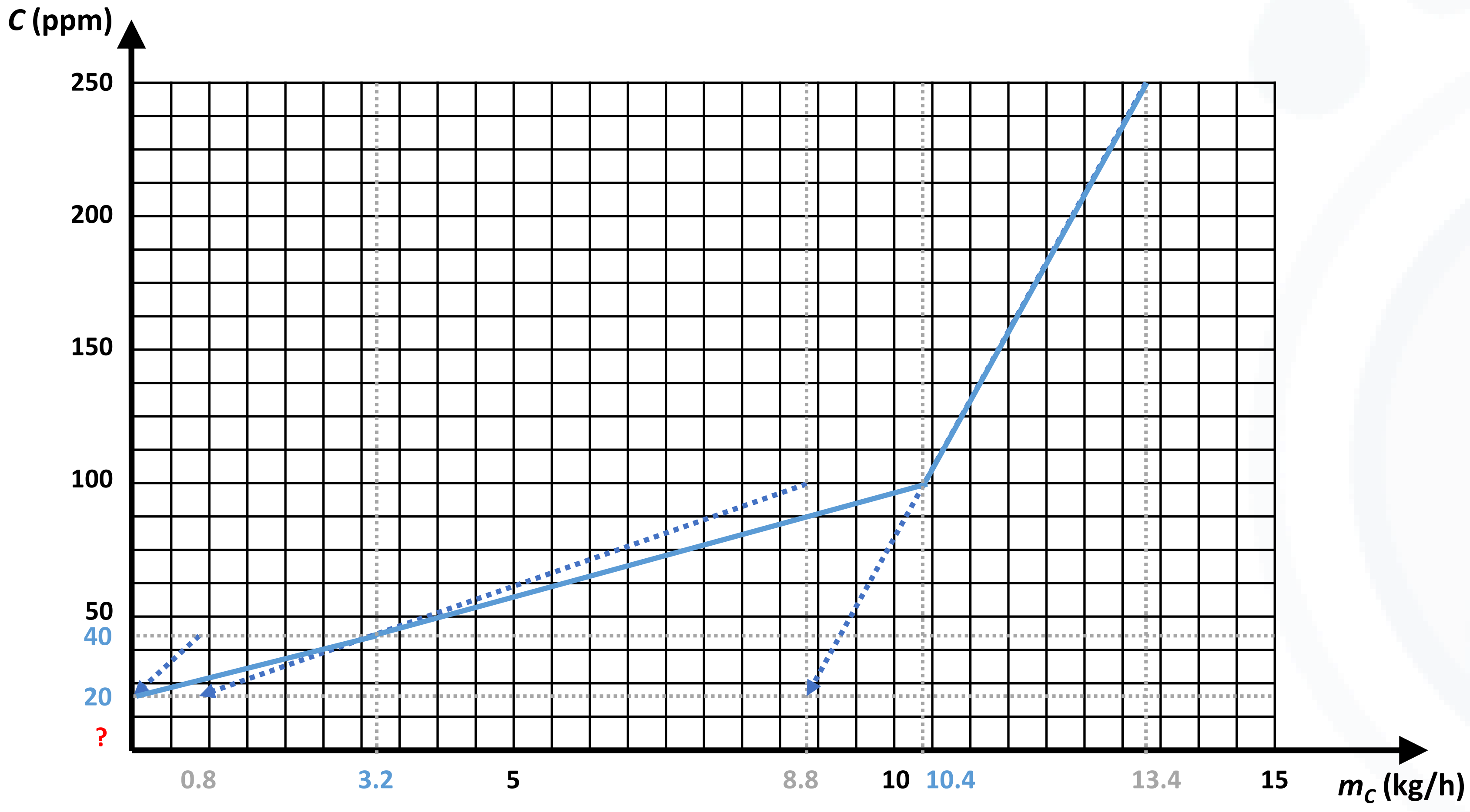
- Calculate the water savings
  - If effluents from all processes were treated separately

$$m_{w,sep} = 100 + 20 + 40 = 160 \text{ t/h}$$

- Water Savings = 160 – 109.5 = 50.5 t/h

Step 5. Minimum Flowrate Line

Assuming a fixed removal ratio of 95%



Step 5. Minimum Flowrate Line

Calculate the outlet concentration

- If the outlet concentration is determined using a fixed removal ratio of 95%, then:

$$R = \frac{C_{in} - C_{out}}{C_{in}} = 0.95 \Rightarrow C_{out} = \frac{C_{in}}{20} = 0.05C_{in}$$

- Total Mass Balance:

$$\Delta m_{Ctotal} = mW_{min} \times \Delta C_{total} \Rightarrow 13400 = m_{Wmin} \times (C_{in} - C_{out})$$

- Mass Balance Below Pinch:

$$\Delta m_{CBP} = mW_{min} \times \Delta C_{BP} \Rightarrow 10400 = m_{Wmin} \times (100 - C_{out})$$

Step 5. Minimum Flowrate Line

Calculate the outlet concentration

- By dividing the two mass balances and replacing $C_{out} = 0.05C_{in}$:

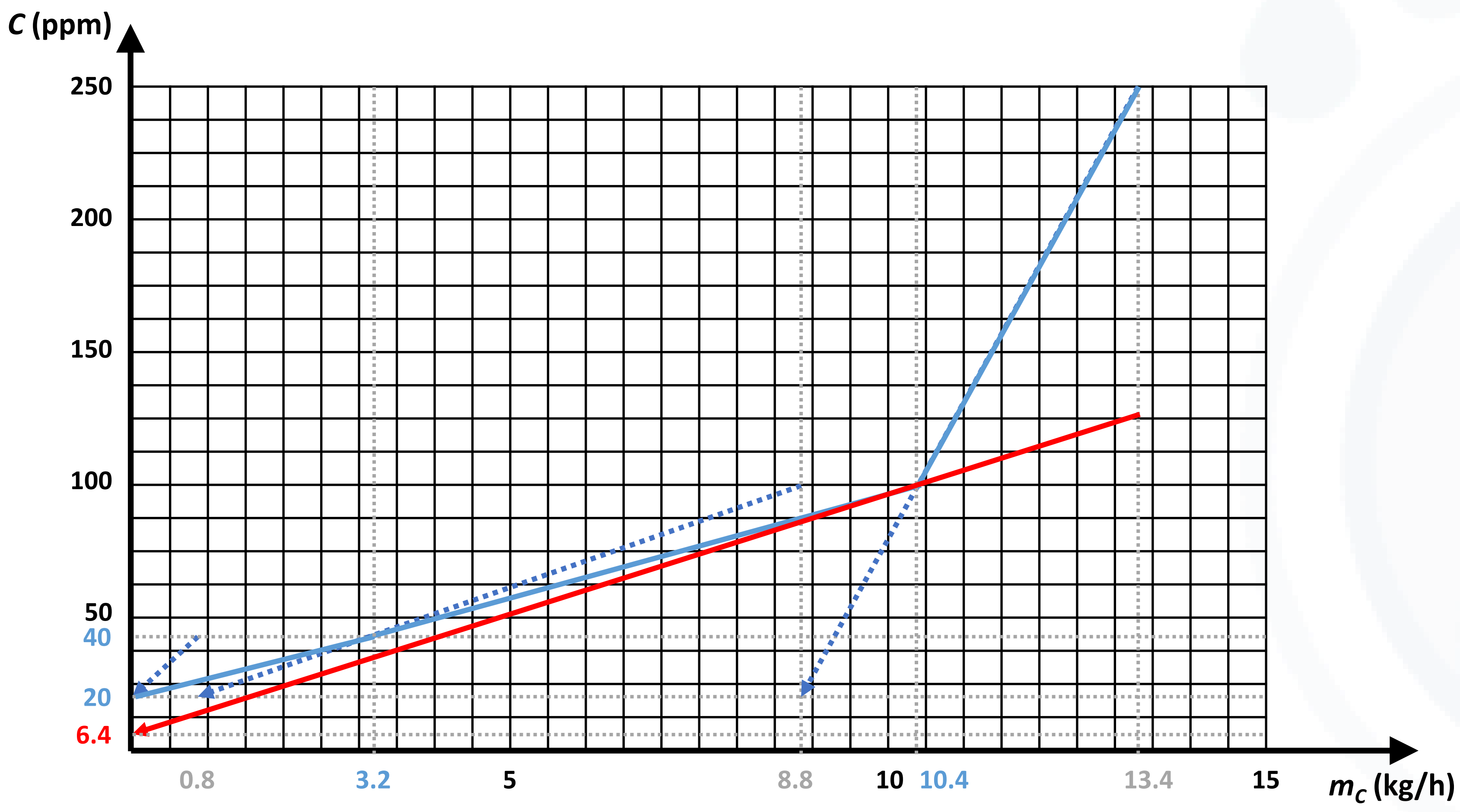
$$\frac{13400}{10400} = \frac{(C_{in} - C_{out})}{(100 - C_{out})} \Rightarrow C_{in} = 127ppm$$

- The outlet concentration will thus be:

$$C_{out} = 0.05C_{in} = 6.36\ ppm$$

Step 5. Minimum Flowrate Line

Assuming a fixed removal ratio of 95%



Step 6. Calculate minimum flowrate and savings

- The minimum flowrate in this case will be:

$$m_{w,min} = \frac{\Delta m_{C,pinch}}{\Delta C_{pinch}} = \frac{10400}{100 - 6.36} = 111 \text{ t/h}$$

- Water Savings: 160 – 111 = 49 t/h

Designing a Minimum Flowrate WWT Network

- The three main design principles for a wastewater treatment network are the following:
  - If the inlet concentration of a stream is lower than the pinch concentration, then this stream does not need to be treated
  - If the inlet concentration of a stream is higher than the pinch concentration, then all this stream must be fully treated
  - If the inlet concentration of a stream is equal to the pinch concentration, then this stream must be partially treated

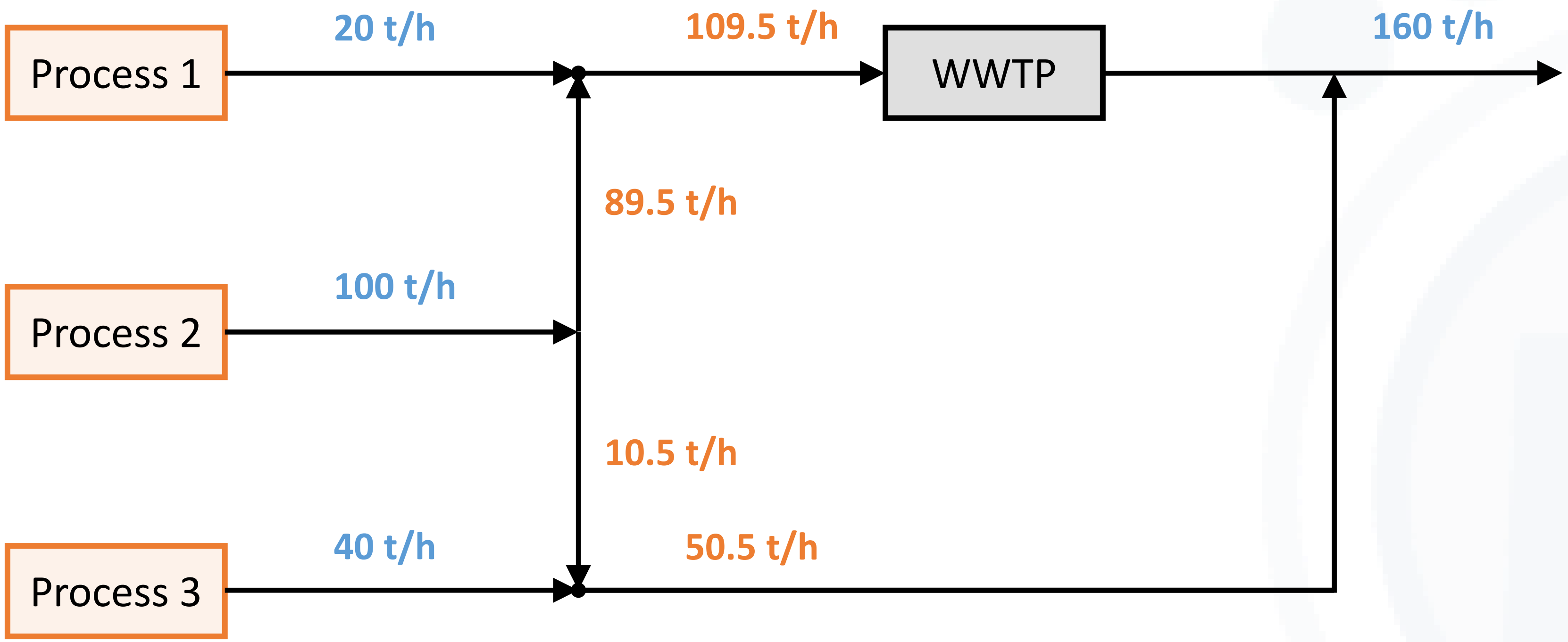
Following on from the previous example

Assuming a fixed outlet concentration of 5 ppm

No	Inlet Concentration (ppm)	Maximum Discharge Limit (ppm)	Water Flowrate (t/h)	Contaminant Mass (g/h)
1	250	20	20	4600
2	100	20	100	8000
3	40	20	40	800

- One process with inlet concentration below pinch (3)
  - Not treated
- One process with inlet concentration above pinch (1)
  - Treated
- One process with inlet concentration equal to the pinch (2)
  - Partially treated

Designing the Network



Real Life Design

- When the stream concentration is equal to the pinch concentration, is might be that:
  - It is not feasible to split the effluent stream of a process
  - It is too expensive to split the effluent stream
  - Regulatory authorities might not accept the partial treatment of a given effluent stream
- In practice, when designing a wastewater treatment network, the streams which are at the pinch are fully treated
  - In big networks, with more than 20 effluent streams, the impact of that decision can be considered negligible

Real Life Complications

- Some effluents might already be below the environmental discharge limit
  - A new effective environmental limit can be defined in this case
- More than one processes might be required to remove contaminants over different concentration ranges
  - Separate composite curve for each treatment range

References

- Alwi, S, Varbanov, P.S., Manan, Z.A. & Klemes, J.J. (2014). *Process integration and intensification: saving energy and resources*, De Gruyter.
- Smith, R. (2016), *Chemical process design and integration,* 2nd Ed. Wiley Blackwell, Chichester, West Sussex.