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Design of Wastewater Treatment Network for Multiple Contaminate with Single internal Water Main

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Abstract- Industries witnessed a great development in the previous period, which led to a significant and increasing consumption of water, which the industry cannot do without in many industrial processes. In this topic, we will apply a methodology for multiple-contaminant water networks with single internal water main.

Keywords- internal Water Main, Wastewater, Water Resources

I. INTRODUCTION

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IN THE PRESENT WORK

Internal water main a process tank it is placed in a specific context of unit process to receive and collect contaminated water at different concentrations of unit processes. The pollutants that come from the processes entering the tank become less in concentration, the water is then pushed from the tank to other unit processes, through this method, the consumption of fresh water consumed and the polluted water discharged is reduced.

BASIC CONCEPTS

In this process, a water reservoir is added to receive the contaminated water from the process units that have a little pollutant concentration, and then this water is poured into other processes with a higher pollutant concentration

II. REVIEW CONCENTRATION POTENTIAL OF SOURCE (CPS)

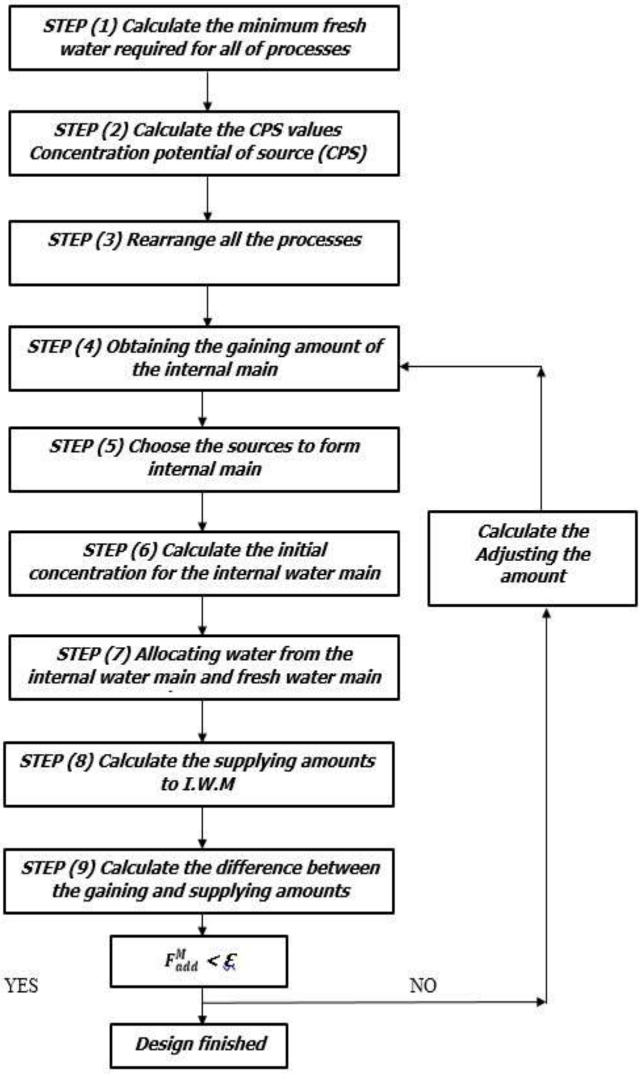


Figure 1. Design single internal water main.

Step (1). Calculate the Minimum Fresh Water Required for All of Processes

$$F_j^{F\,w,min} = Max_K^{NC} = \left|\frac{M_{j,k}}{C_{j,K}^{Out,max}}\right| \quad (1)$$

$$C_{j,K} = \frac{M_{J,K}}{F_j^{F\,w,min}} \quad (2)$$

Where:

$F_j^{F\,w,min}$: The water flow rate required by stream j when only fresh water used.

$M_{j,k}$: The mass load of contaminate k in stream j.

$C_{j,K}^{Out,max}$: The limiting outlet concentration of cont. k in stream j.

$C_{j,K}$: The outlet concentration of cont. k in stream j.

Step (2). Calculate the CPS Values

Concentration Potential of Source (CPS)

$$CPS_{(SL)} = \frac{1}{\sum_{J=1,K=1.2...NC}^{ND} Min\left(\frac{C_{Dj,k}^{lim}}{C_{Sj,k}}\right)} \quad (3)$$

Where:

$C_{Dj,k}^{lim}$: limiting concentration of cont. K in demand Dj

$C_{Sj,k}$: Concentration of cont. K in source Sj

NC: no. of contaminant, ND: no of demand stream

Step (3). Rearrange all the Processes

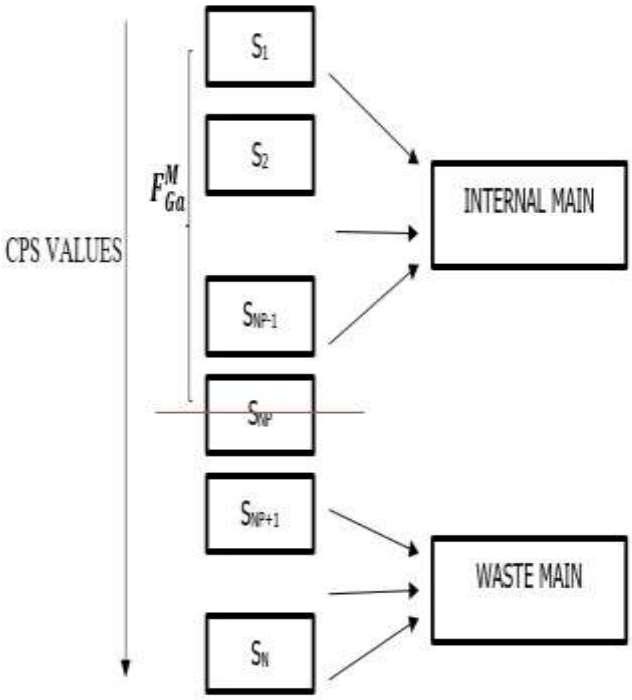


Figure 2. The arrangement for the sources of the internal main.

Step (4). Obtaining the Gaining Amount of the Internal Main

$\boldsymbol{F_{Ga}^{M}} = \boldsymbol{\alpha}$ F total fresh water (4)

Where:

F_{Ga}^{M} : is the gaining amount of the internal main,

α: is a factor and assumed to be taken as 65%

F total: is the total freshwater amount in the conventional network obtained.

Step (5). Choose the Sources to Form Internal Main

$F_{Ga}^{M} = \sum_{j=1}^{NP-1} F_j^{F_{w,min}} + \beta\, F_{NP}^{F_{w,min}}$ (5)

Where:

NP: no. of water sources allocated to the internal main

β: factor % of stream S_{NP} to be allocated to I.M.

Step (6). Calculate the Initial Concentration for the Internal Water Main

$C_K^M = \frac{\sum_{j=1}^{NP-1} M_{j,k} + \beta M_{NP,K}}{F_{Ga}^{M}}$ (6)

Where:

$M_{NP,K}$: Mass load of contaminate K in stream NP.

The initial structure of the internal water main can be obtained, as shown in Figure3.

Streams S_1 to S_{NP-1} and part of S_{NP} are allocated to the internal water main.

Streams S_{NP+1} to S_N will use the water of the internal water main and freshwater, and discharge wastewater to the waste main.

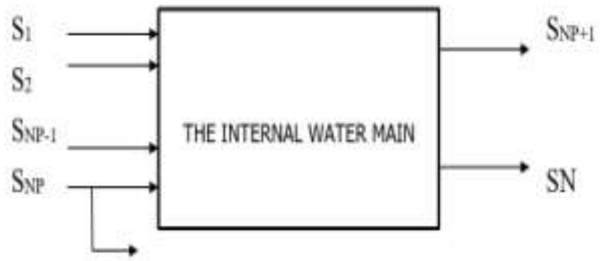


Figure 3. *The initial network design.*

Step (7). Allocating Water from the Internal Water Main and Fresh Water Main to the Processes

$$F_{m,j} = Max_{K=1}^{NC}\left[\frac{M_{j,k}}{C_{j,k}^{out,max} - C_K^M}\right] \quad (7)$$

Where:

$F_{m,j}$: The allocating amount of water from the internal main to process j

II) When at least one of the inlet concentrations of the demand is lower than the corresponding concentration of the internal water main, freshwater will be required.

The allocating amounts of the internal main and freshwater can be calculated by Equation (8), (9) and (10) respectively.

$$F_{m.j} = Min_{K=1}^{NC}\frac{F_j^{max}\ C_{j,k}^{in,max}}{C_K^M} \quad (8)$$

$$F_{f,j} = F_j^{max} - F_{m,j} \quad (9)$$

$$F_j^{max} = max_{k=1}^{NC}\left[\frac{M_{j,k}}{C_{j,k}^{out,max} - C_{j,k}^{in,max}}\right] (10)$$

Where:

$C_{j,k}^{in,max}$: The limiting inlet of contaminate k in stream j.

F_j^{max} : The limiting flow rate of stream j.

$F_{f,j}$: is the fresh water amount required by stream j to meet the conc. Limit.

Step (8). Calculate the supplying Amounts to I.W.M

$$F_{SU}^M = \sum_{j=NP+1}^{M} F_{m,j} \quad (11)$$

Step (9). Calculate the Difference between the Gaining and Supplying Amounts

$$F_{add}^M = F_{Ga}^M - F_{SU}^M \quad (12)$$

If the absolute value of F_{add}^M is in allowable range (which is taken as 0.1 t h^{-1} in this thesis), the design is finished; otherwise, the amount of the internal water main should be adjusted.

Step(10). Adjusting the Amount and the Concentrations of the Internal Main

$\Delta Fp = \frac{F^{M}_{add,i}}{F^{M'}}$ (13)

Where:

ΔFp: the adjusted amount

$F^{M'}$: The impact factor of adjusted stream

$F^{M}_{add,i}$: The difference between the gaining & supplying amounts of the internal water main in iteration i

$F^{M'} = \frac{dF^{M}_{add,i}}{dFp}$(14)

Where:

$dF^{M}_{add,i}$: The differential of internal water main in iteration i

dFp : The differential of adjusted stream.

The gaining amounts of the internal water main in iteration i recalculated by equation (15).

$F^{M}_{Ga,i+1} = F^{M}_{Ga,i} + \Delta Fp$ (15)

Examples for Water Networks with Single Internal Mains

Example (1):

Table 1. Limiting process data for example1 including 3 processes and 3 contaminants.

Process	F_{ma} (T/H)	Contaminant	$Cin_{,max}$ (ppm)	$C\ out_{,max}$ (ppm)	M (gh-1)
1	45	A	0	15	675
		B	0	400	18000
		C	0	35	1575
2	34	A	20	120	3400
		B	300	12500	414800
		C	45	180	4590
3	56	A	120	220	5600
		B	20	45	1400
		C	200	9500	520800

∴ Cp_3 = (102.15 , 25.54 , 9500.18)

Fresh water → *106.7 T/H*

Step (1) Calculate the minimum fresh water required for all of processes

First We Will Calculate minimum required freshwater amounts for each unit process, which can be calculated using Eq. (1), the outlet concentrations when only fresh water used can be calculated with Eq. (2).

$\boldsymbol{F_1 = max\ of \left|\frac{M}{Cout}\right|}$

$$= max\begin{cases}\frac{675}{15} = 45\\ \frac{18000}{400} = 45\\ \frac{1575}{35} = 45\end{cases}$$

∴ F_1 = 45 T/H

For Process(2)

$$F_2 = max\begin{cases}\frac{3400}{120} = 28.33\\ \frac{414800}{12500} = 33.184\\ \frac{4590}{180} = 25.5\end{cases}$$

$$Cp_2 = \frac{M}{Fmax} = \begin{cases}\frac{3400}{33.184} = 102.46\\ \frac{414800}{33.184} = 12500\\ \frac{4590}{33.184} = 138.32\end{cases}$$

∴ Cp2 = (102.46 , 12500, 138.32)

For Process(3)

$$F_3 = max\begin{cases}\frac{5600}{220} = 25.45\\ \frac{1400}{45} = 31.11\\ \frac{520800}{9500} = 54.82\end{cases}$$

$$Cp_3 = \frac{M}{Fmax} = \begin{cases}\frac{5600}{54.82} = 102.15\\ \frac{1400}{54.82} = 25.54\\ \frac{520800}{54.82} = 9500.18\end{cases}$$

STEP (2) Calculate the CPS values

For Process(1)

For Process(1)	*C in demand*
C outsource cps_1 *(15 , 400 , 35)*	*D2 (20 , 300 , 45)* *D3(120 , 20 , 200)* *D5(50, 400 , 60)*

$$\text{Sum of min} = \frac{1}{D2\left(\frac{20}{15},\frac{300}{400},\frac{45}{35}\right)+D3\left(\frac{120}{15},\frac{20}{400},\frac{200}{35}\right)+D5\left(\frac{50}{15},\frac{400}{400},\frac{60}{35}\right)}$$

∴ cps1 = .398

For Process(2)

For Process(2)	*C in demand*

C outsource cps2 (102.46 , 12500 , 138.32)	D3(120 , 20 ,200)

Sum of min = $\frac{1}{D3\left(\frac{120}{102.46},\frac{20}{12500},\frac{200}{138.32}\right)}$

∴ cps $_2$ = 212

STEP (3) Rearrange all the processes

Source	S1	S3	S2
CPS	.32	.34	1.61

Arrangement of CPS values for example 1

STEP (4) Obtaining the gaining amount of the internal main

The gaining amount of the internal water main it's the amount of minimum contaminant concentration which will form the internal main can be calculated by Eq. (4)

F_G^M *= .65*106.7 = 69 T/H*

STEP (5) Choose the source t form internal water main

S1 will form internal water main

∴ F_G^M *= 45 T/H*

STEP (6) Calculate the initial concentration for the internal water main

According to the mass balance of the contaminants, the initial concentrations of the internal water main can be estimated as in equation (6)

$$C_{K1}^M = \frac{675}{45} = 15$$

$$C_{K2}^M = \frac{18000}{45} = 400$$

$$C_{K3}^M = \frac{1575}{45} = 35$$

$C_K^M = (15, 400, 35)$

Step (7). Allocating water from the internal water main and fresh water to the processes

For Process(3)

$C_{in} < C_K^M$

F_1 = min of $\left|\frac{F*Cin}{C_K^M}\right|$

$$= max \begin{bmatrix} \frac{56*120}{15} = 448 \\ \frac{56*20}{400} = 2.8 \\ \frac{56*200}{35} = 320 \end{bmatrix}$$

∴ Fm_3 =min=2.8 T/H

For Process(3

F_1 = min of $\left|\frac{F*Cin}{C_K^M}\right|$

$$= max \begin{bmatrix} \frac{34*20}{15} = \mathbf{45} \\ \frac{34*300}{400} = \mathbf{25.5} \\ \frac{34*45}{35} = \mathbf{43} \end{bmatrix}$$

∴ Fm_2 =min=25.5 T/H

STEP (8) Calculate the supplying amounts to I.W.M

$F_{sup}^{m} = \mathbf{25.5 + 2.8}$=28.3 T/H

STEP (9) Calculate the difference between the gaining and supplying amounts

$F_{add}^{m} = F_{Ga}^{M} - F_{sup}^{m}$

=45-28.3= 16.7

That means the surplus water amount of I.W.M

STEP (10). Adjusting the amount and the concentrations of the internal main

B =$\frac{16.7}{45}$= .37

C_K^M = ($\mathbf{14.955}$, 398.8, 34.895)

Fm_2 =min=25.5 T/H

Fm_3 =min=2.8 T/H

$$F_{add}^{m} = F_{Ga}^{M} - F_{sup}^{m}$$

$F_{add}^{m} = \mathbf{16.7 - 28.3}$= **-11.6**

That means the amount of I.W.M. is insufficient.

df =$\frac{11.6}{45}$= .258

B = .63

$$F_{Ga}^{M} = .63 * 45 = 28.35$$

C_K^M = ($\mathbf{14.955}$ **, 398.8, 34.895)**

Fm_2 =min=25.5 T/H

Fm_3 =min=2.8 T/H

$$F_{add}^{m} = F_{Ga}^{M} - F_{sup}^{m}$$

$$F_{add}^{m} = 28.35 - 28.3 = .05$$

$$\therefore F_{add}^{m} = .05 < \varepsilon$$

∴ Design is finished as shown in figure

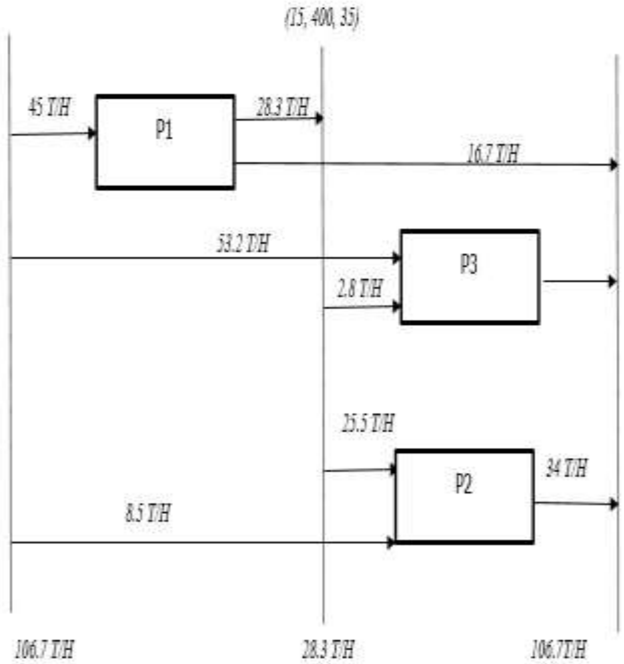


Figure 4. Solution of the problem of Table 1.

The final network design with single internal water mains for example 1.

We use an example (1) including 3 processes and 3 contaminants.to show this by considering the limiting data for a water-using network taken from Wang et al. Fresh water 106.7 T/H. Finally we can summarize a result from example (1) Fresh water is 106.7 T/H when solve by using single internal water main design procedure. This method is not very effective in small process plant.

. Examples for Water Networks with Single Internal Mains

Example (2):

Table 2. *Limiting data for example2 including 4 processes and 3 contaminants.*

Process	F_{max} (T/H)	Contaminant	$C_{in,max}$ (ppm)	$C_{out,max}$ (ppm)
1	45	A	0	15
		B	0	400
		C	0	35
Single internal water main	28.3	A	15	15
		B	400	400
		C	35	35
2	34	A	15	120
		B	400	12500
		C	35	180
3	56	A	15	220
		B	400	45
		C	35	9500

∴ *Design is finished as shown in figure*

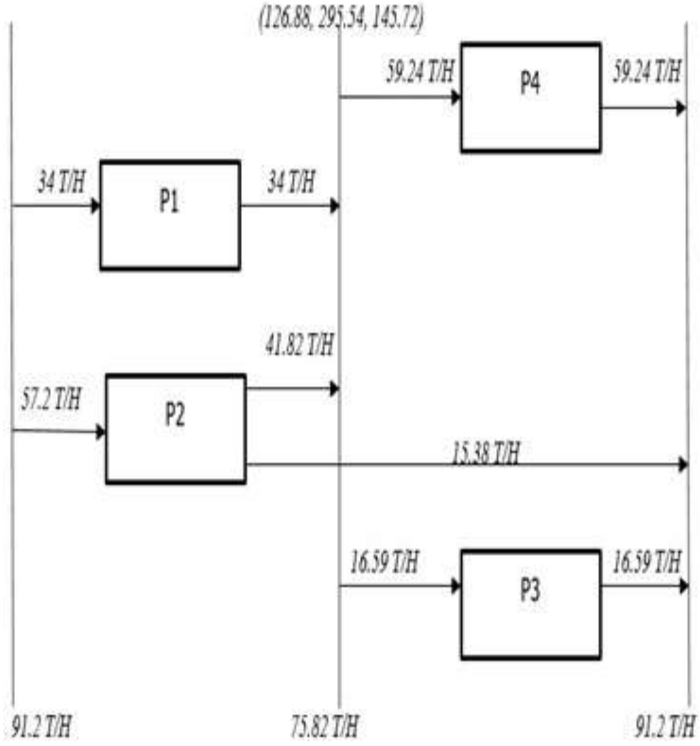


Figure 5. *Solution of the problem of Table 2.*

The final network design with single internal water mains for example 2.

We use an example (2) including 4 processes and 3 contaminants.to show this by considering the limiting data for a water-using network taken from Wang et al. Fresh water 92.33 T/H .Finally we can summarize a result from example (2) Fresh water is 91.20 T/H when solve by using single internal water main design procedure. This method is not very effective in small process plant.

Examples for Water Networks with Single Internal Mains

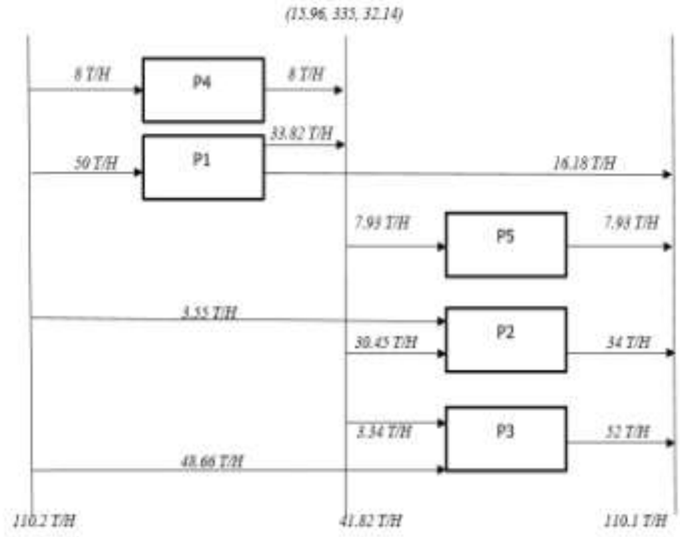
Example (3):

Table 3. *Limiting data for example 3 including 5 processes and 3 contaminants*

Process	F_{max} (T/H)	Contaminant	$Cin_{,max}$ (ppm)	C $out_{,max}$ (ppm)	M (gh-1)
1	50	A	0	15	750
		B	0	400	20000
		C	0	35	1750
2	34	A	20	120	3400
		B	300	12500	414800
		C	45	180	4590
3	56	A	120	220	5600
		B	20	45	1400
		C	200	9500	520800
4	8	A	0	20	160
		B	0	60	480
		C	0	20	160
5	8	A	50	150	800
		B	400	8000	60800
		C	60	120	480

Fresh water: 112.9 T/H

∴ *Design is finished as shown in figure*



We use an example (3) including 5 processes and 3 contaminants.to show this by considering the limiting data for a water-using network taken from Wang et al. Fresh water 112.9 T/H

Finally we can summarize a result from example (3) Fresh water is 110.2 T/H when solve by using single internal water main design procedure.

Previous Work Example for Water Networks with Single Internal

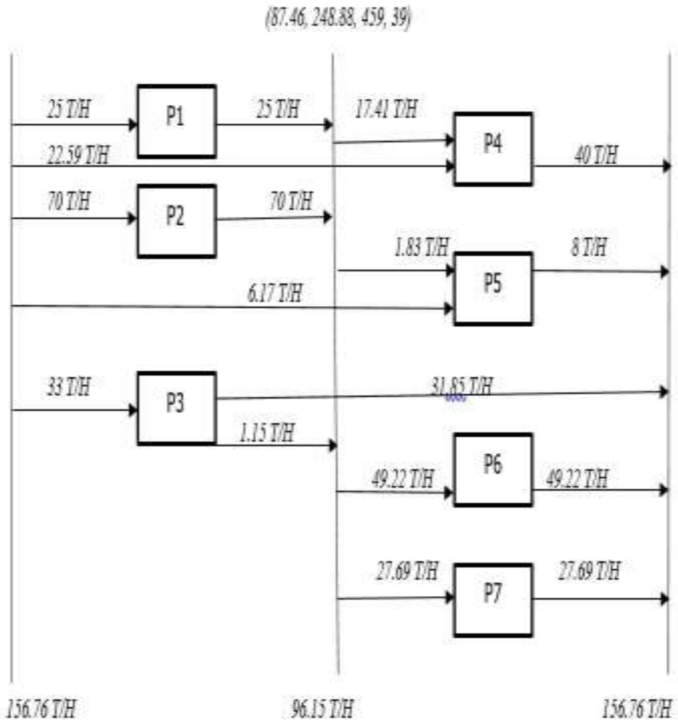
Table 4. Limiting process data of example 4. From Developing network without I.W.M obtained

by using concentration Potential method. Shown in Figure 7.

Process	F_{max} (T/H)	Contaminant	C in_{max} (ppm)	$Cout_{max}$ (ppm)	M(gh-1)
1	25	A	0	50	1250
		B	0	100	2500
		C	0	50	1250
2	70	A	0	100	7000
		B	0	300	21000
		C	0	600	42000
3	35	A	20	150	4550
		B	50	400	12250
		C	50	800	26250
4	40	A	50	600	22000
		B	110	450	13600
		C	200	700	20000
5	8	A	20	500	3840
		B	100	650	4400
		C	200	400	1600
6	50	A	500	1100	30000
		B	300	3500	160000
		C	600	2500	95000
7	30	A	150	900	22500
		B	700	4500	114000
		C	800	3000	66000

We get the fresh water consumption = 160.4 t/h.

∴ *Design is finished as shown in figure*



Design is finished as shown in figure (7) with The total Freshwater consumption is 156.76 ton/hr Comparing with previous results we found that the freshwater consumption and connection number obtained by Wang et al. (2003) are 160.4 t/h and 156.76 which are obtained by using single internal water main.

III. RESULT AND DISCUSSION

- The design methodology of water network with internal water mains for wastewater regeneration is quite different from that for simple reuse. With water regeneration, the locations of all processes have been determined when regeneration concentrations are calculated. The design methodology illustrated in the following:
- (1) The figure shows that the vertical lines represent the external or internal water pipes and the fresh water is the vertical line in the far left and the last vertical line is the wastewater
- (2) The box in the figure is a unit of operations, and the units that have the lowest pollutant concentration should be on the left and the units with a higher pollutant concentration are on the right
- (3) The arrows in the figure are the water flowing in and out of this unit of each unit. It is noted that all the arrows are directed from right to left.

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