Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345 (Online)
An Open Access, Online International Journal Available at www.cibtech.org/sp.ed/jls/2016/01/jls.htm
2016 Vol. 6 (S1), pp. 334-343/Khakpour et al.
Research Article

DEVELOPMENT OF LINEAR MODEL TO MINIMIZE WATER CONSUMPTION AND WASTEWATER PRODUCTION OF COPPER PROCESSING BASED ON TDS, TSS AND TURBIDITY PARAMETERS

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ABSTRACT
Wastewater from copper process industries in terms of volume of production, environmental pollution and the cost of treatment and disposal is important. In addition to the economic benefits, the recovery of the wastewater reduces the pollutant load in the environment. So the necessity of reviewing of various methods to reduce water consumption and wastewater production can be apprehended. This study has investigated the minimization of water consumption and wastewater in Khatoon Abad copper mine. The conventional method of reducing water consumption and a new technology by the name of water pinch for this purpose has been explained. In this research, water pinch technology has been examined for the three pollutant indices (TSS, TDS and turbidity) in three commonly used units in Khatoon Abad copper complex. For TSS, TDS and turbidity as pollutant indices, totally 614, 525 and 451 cubic meters per day of raw water consumption equivalent to 40.96, 35 and 30 percent can be saved, respectively.

Keywords: *Minimization, Water Pinch, Mass Transfer Networks, Water Reuse, Khatoon Abad Copper Complex*

INTRODUCTION
The water quota of the industrial sector is about 1 percent of total water consumption in Iran and slightly more than one billion cubic meters per year (Wan-Alwi *et al.*, 2007). The water consumption in the industry has a very different spectrum because of variation in the nature of the industry, type of processing, age of technology, production capacity, supplies electricity and steam, wastewater treatment, water reuse and wastewater rate, the industrial automation, navigation skills, equipment and facilities, the beliefs and dominance of executives on the factors affecting water usage and the area where each industrial unit has been established (Mann and Liu, 1999). Accordingly, technical and information empowerments of engineers and managers in the field of minimization of water consumption and decrease wastewater production can have a suitable and probably an effective role in fixing problem of water stress for the industry, or at least mitigating it (Brouckaert and Buckley, 2003). In recent years, the incidence of serious restrictions on access to safe water supplies across Iran causes several implications for the industrial sector. For example, the constant increase in prices of raw water along with the announcement of restrictions on the possibility of not being able to supply water to the industry in the coming years, setting standards on wastewater discharge and obtaining progressive fines for non-compliance, introducing the industrial unit as polluting industry and obtaining separate fines to the amount of 1 percent can be noted. This concept gradually points the industrialists at sustainable water supply and the necessity of principled management (Sorin and Bedard, 1999).
The above concerns gradually reveal the importance of sustainable water supply for managers of industries and in these conditions, minimization of water consumption is of particular importance because of limited access to new sources (Manan *et al.*, 2006). The researchers used various techniques that include graphical methods, numerical and mathematical programming (Polley and Polley, 2000). The base of most of graphical and numerical methods is the pollutant mass transfer. While mass transfer

doesn't take place in many water consumption operations (Savelski and Bagejewicz, 2000). Recently used water pinch technology is an effective method to minimize wastewater that considers three water consumption reduction approach combined or single (Hallale, 2002). The concept of water pinch technology is the integration of mass transfer in operations that consume water because the technology is used in the same network (Foo *et al.*, 2003).
In this paper, the water consumption reduction and then the validation of calculation based on comparing the results with the Wang Smith basic model has been presented. Finally, based on the results, the proposed simplified model to minimize the water that industries consume is presented.

MATERIALS AND METHODS

The Study Area

Khatoon Abad copper smelter factory has been constructed in 30 kilometers east of Shahr E Babak, 80 kilometers to Meidook copper mine and 200 kilometers west of Kerman province with an area of 60517 square meters (total area of 100 ha). Different units of the factory are stockpiling, blending, flash furnaces, dryers, electric furnace, converter, anode furnace and casting unit. Total water consumption of Khatoon Abad copper complex is from wells and equals to 3102.5 cubic meters per day. The most consumption of raw water is in unit 82, unit 21 and blow down boiler that equal 758, 611 and 482 cubic meters per day, respectively. In fact, most of the water used in Khatoon Abad copper complex is consumption of cooling units in different sectors. Finally, the produced wastewater is transferred by two distinct paths to the WW (Wastewater) pond and DW (Drain Water) pond. WW pond is an evaporation pond of which outflow is not used and the outflow of DW pond is used for irrigation of landscape.
According to investigations, the largest volume of wastewater inflow to DW pond is from unit 82, unit 21 and blow down boiler and the largest volume of wastewater inflow to WW pond is from unit 79. About 70 percent of DW pond wastewater inflow is from unit 82; unit 21 and blow down boiler, so investigating these three units almost reflect the characteristics of the DW pond wastewater.

Methodology

The water pinch model, an appropriate method for operation of industrial water consumption, is showing is presenting operation as mass transferor from the polluted process stream to water stream. The pollutants could be suspended solids, chemical oxygen demand or similar parameters of which concentrations restrict the reuse of effluent water in the operations (Hallale and Fraser, 1998). In order to study the minimization of water consumption by using the water pinch method, parameters are selected which are considered single (Tan *et al.*, 2002).

Figure 1: A View of Mass Transferor

In the single pollutant method, the high affecting pollutant should be chosen first. The choice depends on the type of pollutant and the type of requirements of the industry. Then the selection of process that should be analyzed is important (El-Halwagi and Manousiouthakis, 1989).
To achieve this, unit operations 21, 82 and cooling water and circulation boiler as well as three pollutants (total suspended solids, total dissolved solids and turbidity) were selected as the basis of calculations according to the information received from Khatoon Abad copper complex.

RESULTS AND DISCUSSION

Calculations to minimize water consumption and wastewater production were performed for single pollutant by reforming Wang and Smith's conceptual-drawing method (Dunn and Bush, 2001). The results of the minimization of water consumption based on water pinch method according to single pollutants are given below.

TSS Index

The first step in calculations of pinch method is the calculation of transitional pollutant mass load. Pollutant load that transfers from process to water must be calculated. Water plays the role of mass transferor (Juliana *et al.*, 2007).

$$f_{i,k}^{tot}(m^3/day) = \frac{\Delta m_{i,k}(kg/day)}{\left[C_{k+1}^{*} - C_{i,k}^{w}\right](ppm)} \times 10^3 \tag{1}$$

$$\Delta m_{i,tot}(kg/day) = f_i(m^3/day) \times \left[C_{i,out}^{lim} - C_{i,i}^{lim}\right]/10^3 \tag{2}$$

In this formula, i is the number of unit operations; k is the concentration level; $\Delta m_{i,tot}$ is The mass load of pollutant in each operation; $m_{i,k}$ is the mass load of pollutant in each concentration section; C_{in}^{lim} concentration Entry into operation; C_{out}^{lim} Output concentration of operations; f_i^{lim} operation`s inflow; $f_{i,k}^{tot}$ is discharge from operation in each concentration section; $C_{i,k}^{w}$ concentration In each section of operation; $\left[C_{k+1}^{*} - C_{i,k}^{w}\right]$ is the difference between pollutant concentration in upper section and operation inflow concentration.

$$\Delta m_{82tot}(kg/day) = 758(m^3/day) \times [25 - 20]/10^3 = 3.79$$
$$\Delta m_{CWP,tot}(kg/day) = 130(m^3/day) \times [8 - 3]/10^3 = 0.65$$
$$\Delta m_{21atot}(kg/day) = 395(m^3/day) \times [24 - 20]/10^3 = 1.6$$

Table 1: Summary of Limiting Data for the Calculation of TSS Parameter

Process i	**(m³/day)**f_i^{lim}	**(kg/day)**Δm_i	**(ppm)**C_{out}^{lim}	**(ppm)**C_{in}^{lim}
CWP	130	0.65	8	3
21a	395	1.6	24	20
21b	216	-	-	20
82	758	3.8	25	20

Note: there is water lost in operation 21. The operation is divided into two parts, the part without water lost (a) and the part with water lost (b). The part b is not considered in calculations and just its required flow rate (part of the water that is lost in the operation) is shown in chart.

Calculations of Transitional Pollutant Mass Load in each Section

The difference between each concentration and the next concentration is called section. There is 4 sections in the analysis. The Operation 82 has continued at two sections. The operation CPW and 21a are located only in one section. So there is no necessity for calculation of operation CWP and 21a.

Calculations of transitional pollutant mass load in each concentration $m_{i,k}$ section:

$$m_{i,k}(kg/day) = \Delta m_{i,tot}(kg/day)\left[\frac{C_{k+1}^{*} - C_{k}^{*}}{C_{i,out}^{Lim} - C_{i,in}^{Lim}}\right] \tag{3}$$

$C_{k+1}^{*} - C_{k}^{*}$: The difference between upper section and lower section

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$$m_{82,3}(kg/day) = 3.8(kg/day)\left[\frac{24-20}{25-20}\right] = 3.04$$

$$m_{82,4}(kg/day) = 3.8(kg/day)\left[\frac{25-24}{25-20}\right] = 0.76$$

Calculation of Required Flow Rate for Transferring Mass Load in each Concentration Section

Calculation of required flow rate in each section:

$$f_{cwp,1}^{tot}(m^3/day) = \frac{0.65(kg/day)}{[8-0](ppm)} \times 10^3 = 92.85$$

$$f_{21a,3}^{tot}(m^3/day) = \frac{1.6(kg/day)}{[24-8](ppm)} \times 10^3 = 100$$

$$f_{82,3}^{tot}(m^3/day) = \frac{3.04(kg/day)}{[24-1](ppm)} \times 10^3 = 132$$

$$f_{82,4}^{tot}(m^3/day) = \frac{0.76(kg/day)}{[25-24](ppm)} \times 10^3 = 760$$

The required water is equal to 760 cubic meters per day. There are 132 cubic meters from operation 82 in last section and 100 cubic meters from operation 21a in last section. Totally the outflow of last section equals to 132 cubic meters, so the shortage that equals to 437 cubic meters should be supplied from wells. Figure 2. represents the diagram of minimizing water consumption calculation based on total suspended solids. Figure 3. represents the diagram of final results using the pinch method for total suspended solids.

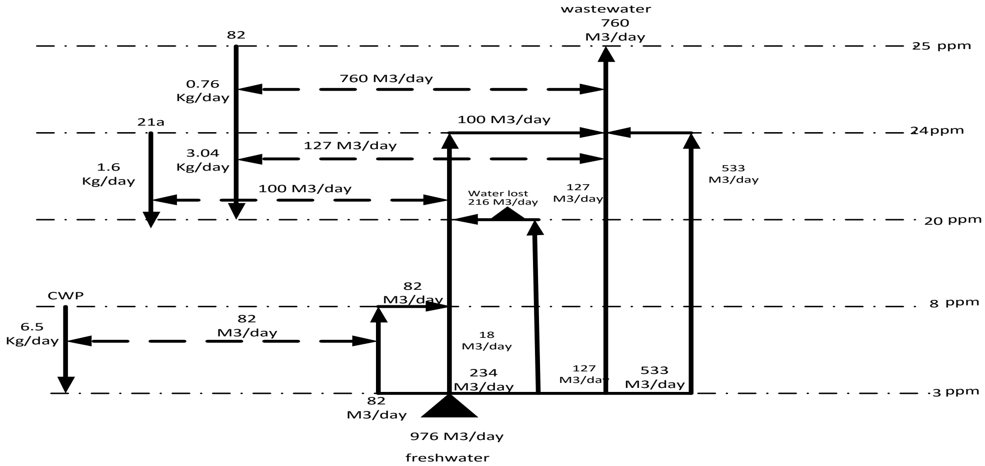

Figure 2: Calculation Diagram of Water Consumption Minimization Based on Pollutant TSS

Calculation of the total water consumption of operations:
Before running the water pinch: 758 + 130 + 395 + 216 = 1499 m^3/day
After running the water pinch: 92.85 + 223.15 + 132 + 437 = 885 mm^3/day
Percentage of water consumption reduction in the calculation of TSS:

$$\frac{1499-885}{1499} \times 100 = 40.96\%$$

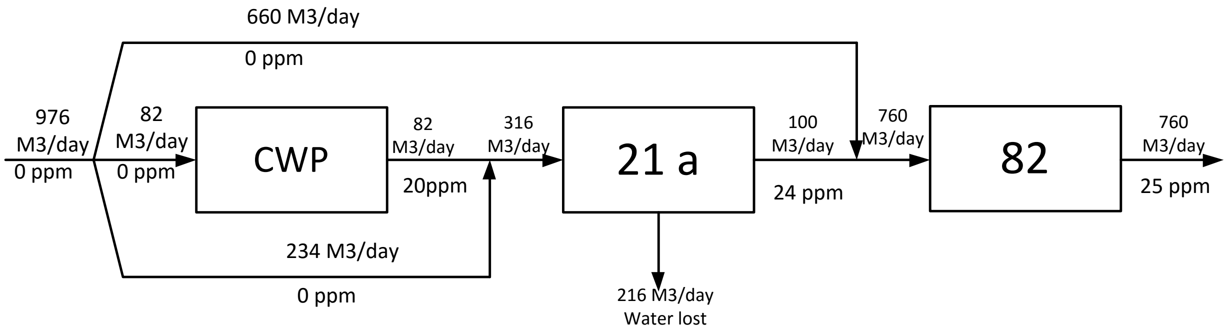

Figure 3: Diagram of the Final Results Using the Pinch Method for TSS

TDS Index

The first step in calculations of pinch method is the calculation of transitional pollutant mass load. Pollutant load that transfers from process to water must be calculated. Water plays the role of mass transferor.

$$\Delta m_{CWP,tot}(kg/day) = 130(m^3/day) \times [400 - 300]/10^3 = 13$$
$$\Delta m_{21a,tot}(kg/day) = 395(m^3/day) \times [447 - 350]/10^3 = 38.3$$
$$\Delta m_{82,tot}(kg/day) = 758(m^3/day) \times [731 - 600]/10^3 = 99.3$$

Table 2: Summary of Limiting Data for the Calculation of TSS Parameter

Process i	(m^3/day)f_i^{lim}	(kg/day)Δm_i	(ppm)C_{out}^{lim}	(ppm)C_{in}^{lim}
CWP	130	13	400	300
21a	395	38.3	447	350
21b	216	-	-	350
82	758	99.3	731	600

Note: there is water lost in operation 21. The operation is divided into two parts, the part without water lost (a) and the part with water lost (b). The part b is not considered in calculations and just its required flow rate (part of the water that is lost in the operation) is shown in chart.

Calculations of Transitional Pollutant Mass Load in each Concentration $m_{i,k}$ Section

$$m_{cwp,1}(kg/day) = 13(kg/day)\left[\frac{350-300}{400-300}\right] = 6.5$$
$$m_{cwp,2}(kg/day) = 13(kg/day)\left[\frac{400-350}{400-300}\right] = 6.5$$
$$m_{21a,2}(kg/day) = 38.3(kg/day)\left[\frac{400-350}{447-350}\right] = 20$$
$$m_{21a,3}(kg/day) = 38.3(kg/day)\left[\frac{447-400}{447-350}\right] = 18.3$$

Calculation of Required Flow Rate for Transferring Mass Load in each Concentration Section

$$f_{cwp,1}^{tot}(m^3/day) = \frac{6.5(kg/day)}{[350-290](ppm)} \times 10^3 = 108$$

$$f^{tot}_{cwp,2}(m^3/day) = \frac{6.5(kg/day)}{[400-350](ppm)} \times 10^3 = 130$$

$$f^{tot}_{21a,2}(m^3/day) = \frac{20(kg/day)}{[400-290](ppm)} \times 10^3 = 182$$

$$f^{tot}_{21a,3}(m^3/day) = \frac{18.3(kg/day)}{[447-400](ppm)} \times 10^3 = 389$$

$$f^{tot}_{82,5}(m^3/day) = \frac{99.3(kg/day)}{[731-600](ppm)} \times 10^3 = 758$$

Figure 4 represents the diagram of minimizing water consumption calculation based on total dissolved solids. Figure 5 represents the diagram of final results using the pinch method for TDS.

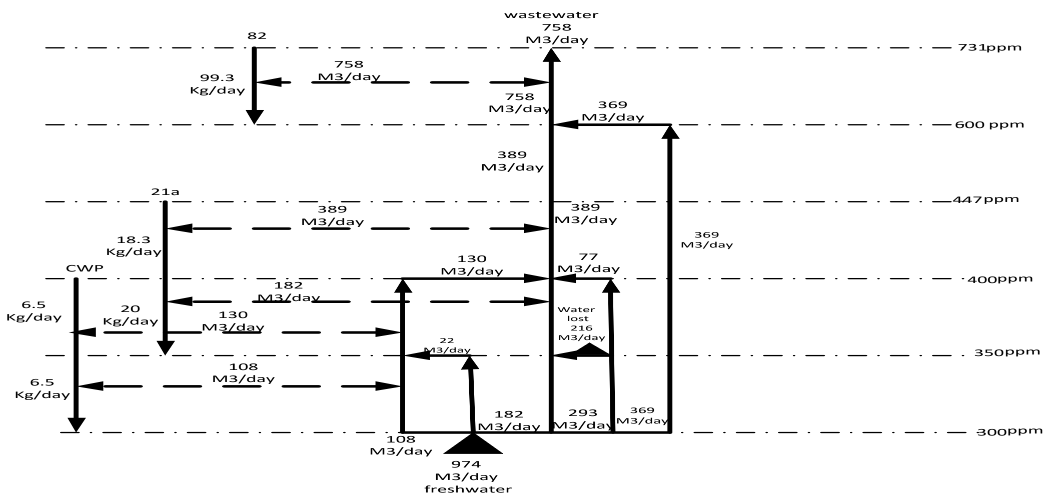

Figure 4: Calculation Diagram of Water Consumption Minimization Based on Pollutant TDS

Calculation of the total water consumption of operations
Before running the water pinch: 758 + 130 + 395 + 216 = 1499 m^3/day
After running the water pinch: 108 + 22 + 182 + 77 + 216 + 369 = 974 m^3/day
Percentage of water consumption reduction in the calculation of TDS:

$$\frac{1499-974}{1499} \times 100 = 35\%$$

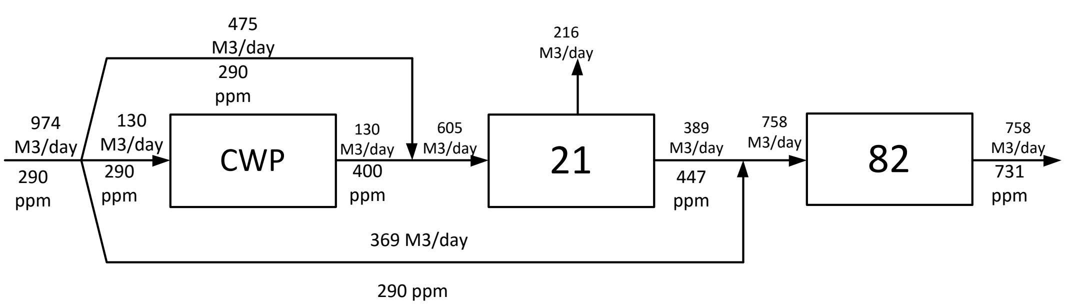

Figure 5: Diagram of the Final Results Using the Pinch Method for TDS

Turbidity Index

The first step in calculations of pinch method is the calculation of transitional pollutant mass load. Pollutant load that transfers from process to water must be calculated. Water plays the role of mass transferor.

$$\Delta m_{21a,tot}(kg/day) = 395(m^3/day) \times [3-1]/10^3 = 0.79$$

$$\Delta m_{CWP,tot}(kg/day) = 130(m^3/day) \times [5-3]/10^3 = 0.26$$

$$\Delta m_{82,tot}(kg/day) = 758(m^3/day) \times [4-2]/10^3 = 1.57$$

Table 3: Summary of Limiting Data for the Calculation of TSS Parameter

Process i	**(m³/day)f_i^{lim}**	**(kg/day)Δm_i**	**(ppm)C_{out}^{lim}**	**(ppm)C_{in}^{lim}**
21a	395	0.79	3	1
21b	216	-	-	1
82	758	1.57	4	2
CWP	130	0.26	5	3

Note: there is water lost in operation 21. The operation is divided into two parts, the part without water lost (a) and the part with water lost (b). The part b is not considered in calculations and just its required flow rate (part of the water that is lost in the operation) is shown in chart.

Calculations of Transitional Pollutant Mass Load in each Concentration $m_{i,k}$ Section

$$m_{21a,1}(kg/day) = 0.79(kg/day)\left[\frac{2-1}{3-1}\right] = 0.395$$

$$m_{21a,2}(kg/day) = 0.79(kg/day)\left[\frac{3-2}{3-1}\right] = 0.395$$

$$m_{82,2}(kg/day) = 1.57(kg/day)\left[\frac{3-2}{4-2}\right] = 0785$$

$$m_{82,3}(kg/day) = 1.57(kg/day)\left[\frac{4-3}{4-2}\right] = 0.785$$

$$m_{cwp,3}(kg/day) = 0.26(kg/day)\left[\frac{4-3}{5-3}\right] = 0.13$$

$$m_{cwp,4}(kg/day) = 0.26(kg/day)\left[\frac{5-4}{5-3}\right] = 0.13$$

Calculation of Required Flow Rate for Transferring Mass Load in each Concentration Section

$$f_{cwp,3}^{tot}(m^3/day) = \frac{0.13(kg/day)}{[4-1](ppm)} \times 10^3 = 44$$

$$f_{cwp,4}^{tot}(m^3/day) = \frac{0.13(kg/day)}{[5-4](ppm)} \times 10^3 = 130$$

$$f_{21a,1}^{tot}(m^3/day) = \frac{0.395(kg/day)}{[2-1](ppm)} \times 10^3 = 395$$

$$f^{tot}_{21a,2}(m^3/day) = \frac{0.395(kg/day)}{[3-2](ppm)} \times 10^3 = 395$$

$$f^{tot}_{82,2}(m^3/day) = \frac{0.758(kg/day)}{[3-1](ppm)} \times 10^3 = 393$$

$$f^{tot}_{82,3}(m^3/day) = \frac{0.758(kg/day)}{[4-3](ppm)} \times 10^3 = 758$$

Figure 6 represents the diagram of minimizing water consumption calculation based on turbidity. Figure 7 represents the diagram of final results using the pinch method for turbidity.

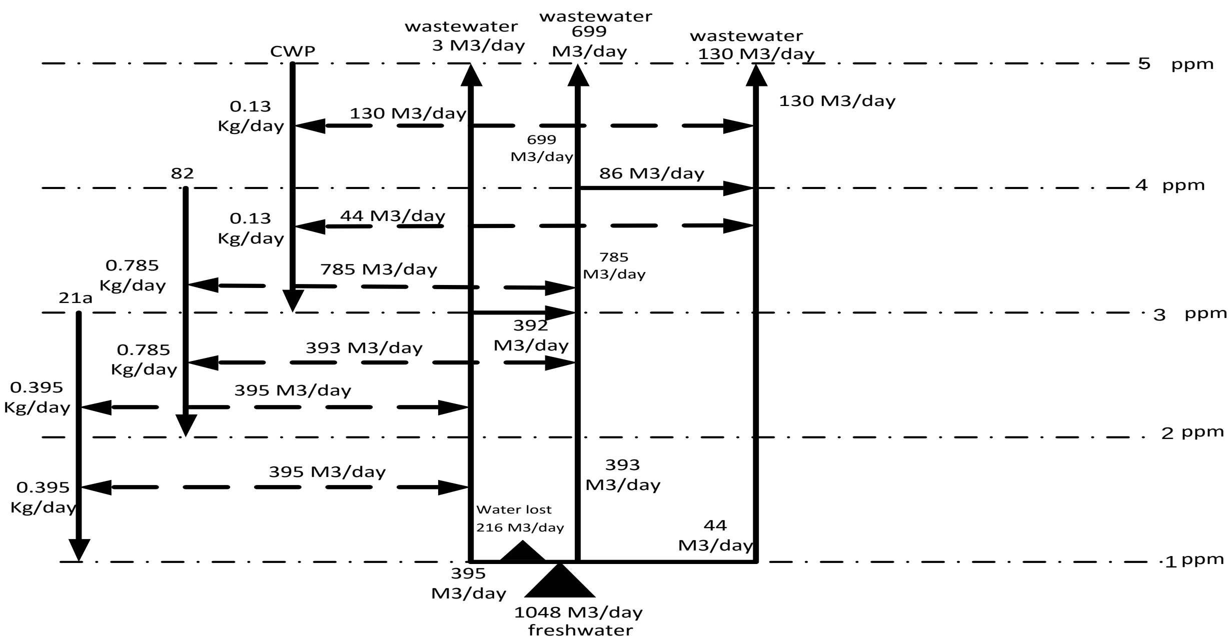

Figure 6: Calculation Diagram of Water Consumption Minimization Based on Pollutant of Turbidity

Calculation of the total water consumption of operations
Before running the water pinch: 758 + 130 + 395 + 216 = 1499 m^3/day
After running the water pinch: 395 + 216 + 393 + 44 = 1048 m^3/day
Percentage of water consumption reduction in the calculation of turbidity:

$$\frac{1499-1048}{1499} \times 100 = 30\%$$

Khajian minimized the water consumption network at north branch of Tehran Refinery by considering boilers, cooling towers and public consumption as a major operation which consume water, wastewater treatment system as water suppliers and SS as the main pollutant. According to calculation the water consumption has been decreased from 505 m^3/hr to 320 m^3/hr (36.6% decrement) (Khajian and Shayegan, 2008). Manan in the Mosque of Sultan Ismail of University of Teknologi Malaysia used the method and reduced 65.1% of raw water usage and 51.5% of wastewater production (Manan *et al.*, 2006). Ujang in order to minimize wastewater of old textile factories used WPA method that showed the operating costs of reuse and reconstruction-reuse has been reduced 16% and 50%, respectively (Ujang *et al.*, 2002).

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Khezri showed that using WPA model in water management of aluminum industry reduced wastewater production from 7.6% of raw water to 4.14% (Khezri *et al.,* 2010).

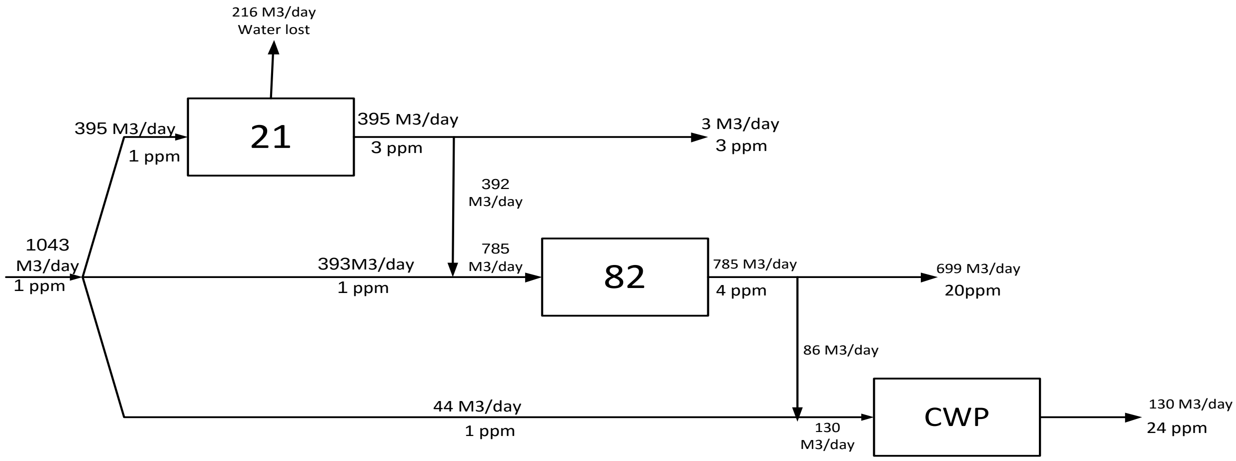

Figure 7: Diagram of the Final Results Using the Pinch Method for Turbidity

Conclusion

In this study, due to a serious shortage of water resources in Iran, finding an appropriate way to minimize water consumption and wastewater production was considered so that it can be used as a model in industries that consume water. By reviewing methods of water consumption minimization, the conceptual drawing method has been used because of various reasons, especially appropriate flexibility in design, possibility of realistic commenting of plant engineering team based on actual data of operational and executive privileges and restrictions on the plant, as well as ability to understand the calculation process and rational technical proposals by designers for minimization. Studying design principles of the method showed that it is possible to use some other technologies in the procedure (Khajian and Shayegan, 2008; Wang and Smith, 1994).

In the next step, Khatoon Abad copper smelter complex, as one of the largest consumer of water in Iran has been selected and three priority operations to minimize water consumption has been considered. After choosing three pollutants to determine the best options in single-pollutant minimization as well as new innovations, with considering boundary contaminants, the first screening of designs was carried out.

The following table summarizes the results of the pinch model that minimized water consumption in this research.

Table 4: Percentage of Water Consumption Reduction According to Assessed Indices

Pollutant	**TSS**	**TDS**	**Turbidity**
Percentage of Water Consumption Reduction	40	35	30

Reduction of water consumption is clear according to the above table. In this research, water pinch technology has been examined for the three pollutant indices (TSS, TDS and turbidity) in three commonly used units in Khatoon Abad copper complex. In the first case, TSS has been considered as single index and totally 614 cubic meters per day equivalent to 40.96 percent has been saved. In the second case, TDS has been considered as single index and totally 525 cubic meters per day equivalent to 35 percent has been saved. In the third case, turbidity has been considered as single index and totally 451 cubic meters per day equivalent to 30 percent has been saved. In this study, a suitable model for the minimization of water consumption and wastewater production in process industries were developed. This model has been prepared in such a way that can be used in all industries that consume water and even engineers who are unfamiliar with conceptual - drawing method of water consumption minimization could easily solve their complex problems about water consumption minimization of their industrial units. The proposed model that considers a single pollutant could be as a guide to the industrial experts. The importance of this case study is that it is complicated given that the overwhelming industries have less components and administrative problems than the case study.

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