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Minimizing Fresh and Wastewater Using Water Pinch Technique in Petrochemical Industries

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Abstract**—**This research involves the design and analysis of pinch-based water/wastewater networks to minimize water utility in the petrochemical and petroleum industries. A study has been done on Tehran Oil Refinery to analyze feasibilities of regeneration, reuse and recycling of water network. COD is considered as a single key contaminant. Amount of freshwater was reduced about 149m^3/h (43.8%) regarding COD. Re-design (or retrofitting) of water allocation in the networks was undertaken. The results were analyzed through graphical method and mathematical programming technique which clearly demonstrated that amount of required water would be determined by mass transfer of COD.

Keywords**—**Minimization, Water Pinch, Water Management, Pollution Prevention.

I. Introduction

EXCESSIVE usage of industrial water affected it's future availability. Reduction of water consumption has received attention of many researchers. El-Halwagi and Manousiouthakis suggested a technique to produce a mass exchange networks [1].

Many industries are saving their economy by practicing on this waste recovery applications. Pinch Analysis was proposed many years early [2]. After some time a graphical method was offered to determine the freshwater target. This proposed method got the attention of many researchers [3] later on many industrial practices proved the success of this technology. Sorin and Be´dard presented the evolutionary table method to estimate the freshwater target [4]. Proposed graphic method "the water surplus diagram" was to target the fresh water [5]. Even though his method created the right pinch points, it was tedious. Manan et al. after some time proposed a non-iterative numerical method, water cascade analysis, [6] to target the freshwater. He addressed that their method can provide important insights on pinch-causing stream and water allocation but cannot be achieved by using the graphical technique of the water surplus diagram of Hallale [5]. Graphical method was proposed to determine the targets of the freshwater and wastewater. This method can also be used to find various pinch points [7]. Another scientist proposed a graphical method to calculate the freshwater targets based on the cumulative flow-rate/contaminant-load curves [8]. Most of the researchers determined the pinch point and the targets of freshwater at the same time. Hence, all the streams should be observed in detail either graphically or mathematically in target calculation. In fact, if the insights of the pinch analysis are incorporated, the pinch point can be determined before target calculation. This can reduce the objective calculation struggle.

In the case of recycle/reuse arrangements, Gabriel and El-Halwagi described a simplified formation that eliminates the mixing of different streams to avoid bilinear terms and to yield a convex problem formulation [9]. This approach avoids the bilinear terms of the mass balances, it simplifies the problem and do not pay attention to the configurations of potential interest. The model was stretched to be based on different properties instead of dealing only with the compositions [10]. Scientists addressed the problem of global optimization of recycle and reuse networks based on properties using NLP and MINLP formulations [11], [12].

In this paper, an approach has been adopted to determine the minimum fresh water, maximum recycle/reuse and minimum waste water. COD is selected as a single contaminant for the study. Pinch technique graphical method has been used to carry out the required objective and also mathematical programming has been developed to verify the results. Results from mathematical programming have showed the allocation of best possible network of source stream(s) to the demand stream(s) also. The results of this work are more precise than the referred previous work discussed in the literature.

II. Methodology & Case Study

The selected process/unit is firstly divided into sinks and sources streams. Sinks streams are categorized as inlet streams of the selected unit/process and the outlet streams are considered as sources. However, freshwater and waste water is also placed under sources category as some of the waste streams cannot be used/reused as sources to the unit.

Target for fresh water is determined by considering all the sinks and sources in the process. The sinks and sources are arranged in ascending order of their maximum property loads as property loads are analogous to mass loads [13]. El-Halwagi and Prakash have shown that the ascending arrangement of sources and sinks, respectively, provide a simplified target and design arrangement [7], [8]. The maximum property load of a sink is calculated by (1).

$$M_j^{Sink,\max} = G_j * z_j^{\max} \qquad (1)$$

where G_j is flow rate, $M_j^{Sink,\,max}$ is admissible maximum load,

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z_j^{max} is maximum property value for sink stream.

Similarly, the source maximum property is calculated by (2). Where W_i is the flow rate, $M_i^{Source,max}$ is admissible maximum load, y_i^{max} is maximum property value for source stream.

$$M_i^{Source,\max} = W_i * y_i^{\max} \qquad (2)$$

After calculating the loads of each sink and source stream, sink and source composite curves are created, respectively, using superposition.

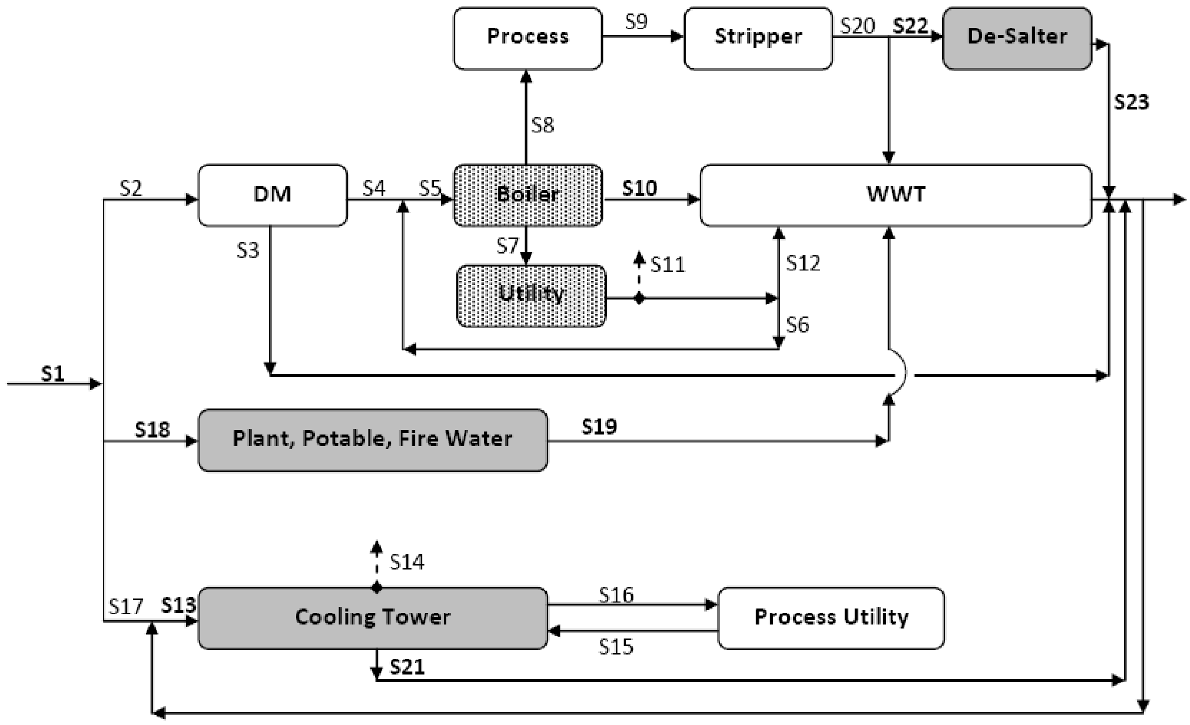

Fig. 1 Water Streams Flow-Sheet in Refinery

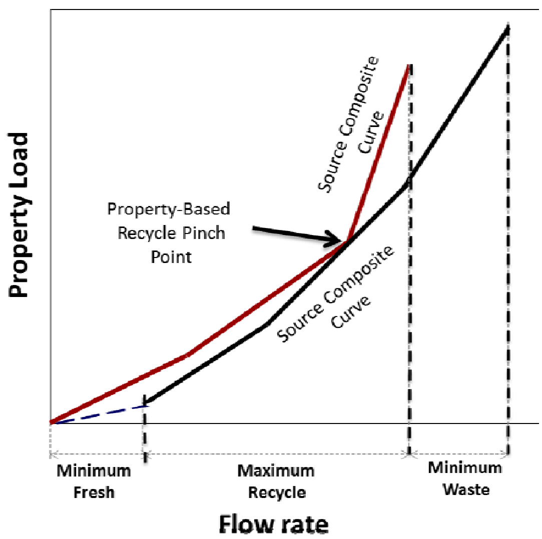

Fig. 2 Property-Based Material Recycle Pinch Diagram

Required fresh water demand is calculated by sliding source composite curve on the fresh line depicting on the x-axis while keeping it below sink composite curve. Source composite curve is pushed until it touches the sink composite curve to a certain point. This point of interaction is named as *Property-Based Recycle Pinch Point* and can be seen in Fig. 2.

Kazantzi and El-Halwagi has provided some design rules for constructing the pinch diagram for minimum usage of fresh water, maximum use of recycled waste water and minimum waste water [13] and these are;

- *Property load should not be passed through Pinch Point i.e. the two composites should touch*
- *Fresh water should not be used in any sink unit above the Pinch Point*
- *Below the Pinch Point, waste should not be discharged from sources*

The procedure identifies the targets for fresh, recycle/reuse and waste without going in to detailed network design.

In this research, the case study is performed on Tehran oil Refinery [14]. Fig. 1 shows the overall simplified flow sheet of the process in the refinery. Tables I, II and IV list the data for the under study case. Based on these values, optimized water network is determined. Water flow rate is needed to achieve mass transfer of contaminants required for water optimization. However, contaminant selection is dependent on the industry requirements [14]. The overall process is utilizing 505m^3/h water and allocation of water streams is well designed including reuse of wastewater. Table II shows three sinks (cooling tower, de-salter and plant, potable, fire water) which uses water about 340m^3/h and COD is selected as a single contaminant case study. Table IV shows two sources (boiler blow down and outlet utility).

TABLE I
STREAM FLOW RATES AND CONSTRAINTS

Stream Number	Flow Rate of Streams m^3/h	Stream Constraints ppm
S1	505.0	COD = 0.0
S10	20.0	COD = 0.0
S13	113.0	COD = 0.0
S18	168.0	COD = 0.0
S19	160.0	COD = 0.4
S21	17.0	COD = 10.0
S22	59.0	COD = 2.0
S23	59.0	COD = 5.0

III. RESULTS AND DISCUSSION

A. Graphical Method

To minimize the fresh water and wastewater through Pinch Technique using graphical method, load (*M*) of each sink is calculated using (1). The calculated maximum property loads for the sinks are listed in Table II. The sinks are arranged in ascending order of their increasing load. Next step is to develop the Sink Composite Curve as shown in Fig. 3 using data in Table III which list the sinks data in ascending order in term of their cumulative loads including flow rates. Similarly, the loads of sources are calculated Table IV and placed in ascending order of their increasing property loads as shown in Table V. Fig. 4 represents the Source Composite Curve based on the cumulative source loads data in Table V.

TABLE II
SINKS DATA

Sinks	Flow Rate *G* m^3/h	COD*in* *Z* (ppm)	Maximum Load (m^3/h)
Cooling Tower	37.0	1.0	0.000037
De-Salter	59.0	2.0	0.000118
Plant, Potable, Fire Water	160.0	3.0	0.00048

TABLE III
CUMULATIVE SINKS DATA FOR SINK COMPOSITE CURVE

Sinks	Flow Rate (*G* m^3/h)	Cumulative Load (m^3/h)
Cooling Tower	37.0	0.000037
De-Salter	59.0	0.000155
Plant, Potable, Fire Water	160.0	0.000635

TABLE IV
SOURCE DATA

Sources	Flow Rate *W* m^3/h	COD*out* *y* (ppm)	Maximum Load (m^3/h)
Boiler Blow down	20.0	4.0	0.00008
Outlet Utility	45.0	2.0	0.00009
Fresh Water	-	0.0	-

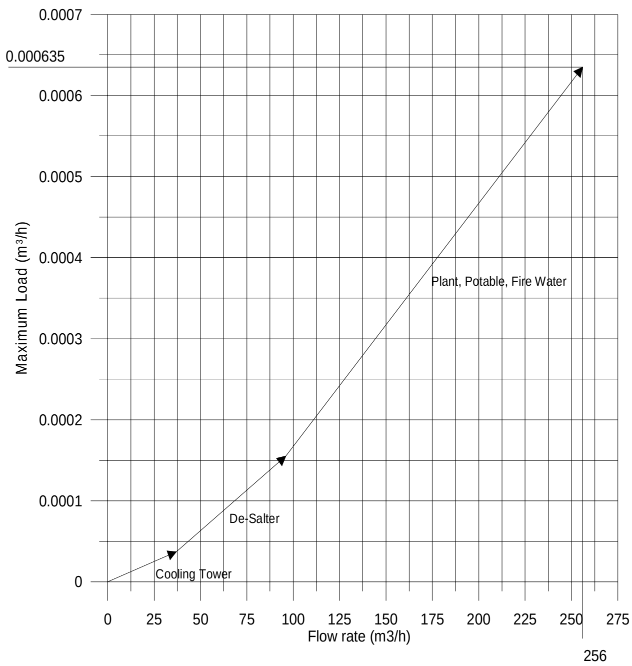

Fig. 3 Sink Composite Curve

TABLE V
CUMULATIVE SOURCE DATA FOR SOURCE COMPOSITE CURVE

Sources	Flow Rate *W* m^3/h	Cumulative Load (m^3/h)
Boiler Blow down	20.0	0.00008
Outlet Utility	65.0	0.00017

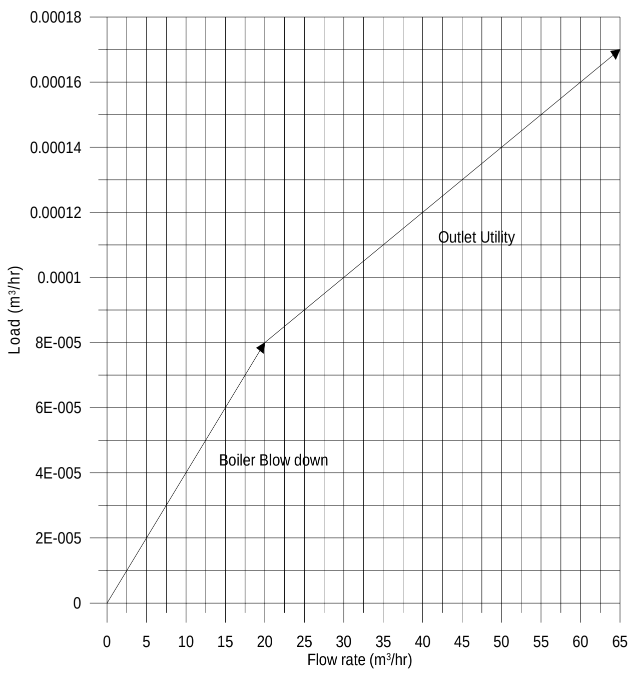

Fig. 4 Source Composite Curve

In Fig. 5, the sink composite cure and source curves are drawn on the same scale to determine the *Pinch Point*.

In this graphical method, the horizontal and vertical axis represents the flow rate and load, respectively. The source composite curve is dragged to the left until it touches to one of the point to sink composite curve while keeping in mind that source composite curve should not cross the sink composite curve as previously mentioned in the designing rules.

This method is much easy and effective for calculating the fresh water requirements and to check the maximum recycle. In fig. 5, the sink line on the left is out of the reach of source composite curve show that 38.5m^3/h amount of fresh water is necessary for sinks in addition to another water demand of 152.5m^3/h shown on the right side. By adding these quantities, the total fresh water demand is 191.0m^3/h that is needed for the sinks. As it is seen that the amount of fresh water is reduced from 340.0m^3/h to 191.0m^3/h, which shows a reduction of 149.0m^3/h and about 43.8% fresh water reduction in terms of single contaminant COD.

B. Mathematical Modeling

Mahmoud M. El-Halwagi [15] has developed a mathematical tool of optimization and to provide a systematic solution of problems. An optimization formulation provides a solution in the area of minimization or maximization of an objective constraint. Mathematical programming deals with the formulation, solution, and analysis of optimization problems or mathematical programs. If the objective functions as well as the constraints are linear then it is called as linear program (LP); otherwise, it is will be a nonlinear program (NLP).

The sinks and sources are selected as constraints to formulate an optimization model. Sets formulation model has been established [15] based on (1) and (2) that accurately describes the amount of the objective fresh water demand using mathematical relationships. LINGO is one of the optimization tools that provide the solution for linear, nonlinear, and mixed integer linear and nonlinear programs. Using sets formulation optimization also evaluates and identifies one of the best possible solution and water distribution network.

A set is a collection of objects and is typically denoted by upper-case letters A, B, X, Y, and so on. The LINGO coding program is developed based on sets formulation using (1) and (2). The coding developed is;

```
!LINGO INPUT SETS FORMULATION CODE;

min=Fresh;
SETS:
SOURCES /1..2/: W, Y, Waste;
SINKS /1..3/: G, Zmax, Z, F;
FLOW_CONNECTIONS (SOURCES, SINKS): Split;
ENDSETS
DATA:
W=20 45;
Y=0.000004 0.000002;
G=37 59 160;
Zmax=0.000001 0.000002 0.000003;
ENDDATA
Fresh=@SUM(SINKS(j): F(j));
XF=0;
@FOR (SOURCES(i):
 @SUM(SINKS(j): Split(i,j))+Waste(i)=W(i));
@FOR (SINKS(j):
 @SUM(SOURCES(i): Split(i,j))+F(j)=G(j));
@FOR (SINKS(j):
 @SUM(SOURCES(i): Split(i,j)*Y(i))+F(j)*XF=G(j)*Z(j));
@FOR (SINKS(j): Z(j)<=Zmax(j));
Waste_Total=@SUM(SOURCES(i):Waste(i));
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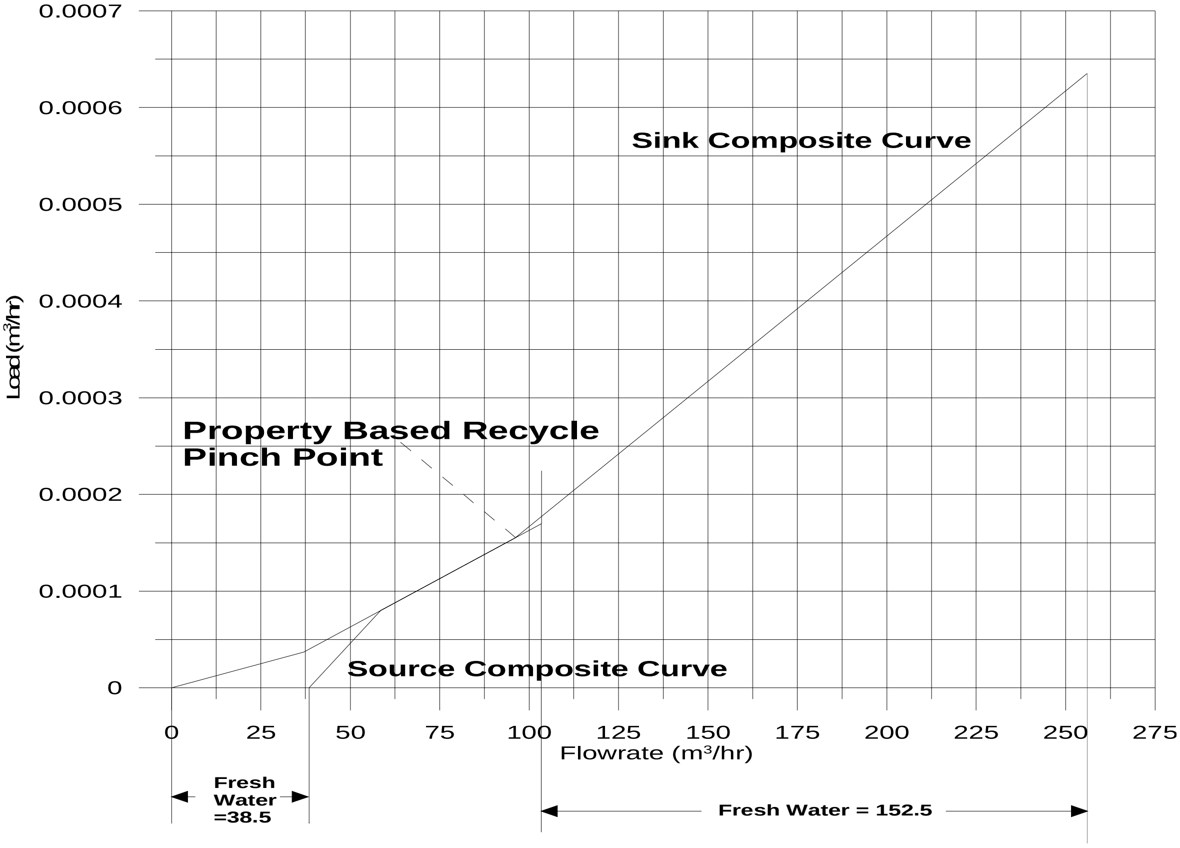

Fig. 5 Final Property Based Recycle Pinch Diagram

TABLE VI
LINGO OUT PUT RESULTS

Variable	Value
Fresh	191.000
Xf	0.000
WASTE_TOTAL	0.000
W(1)	59.000
Y(1)	0.000
G(1)	37.000
G(2)	59.000
G(3)	160.000
ZMAX(1)	0.1000000E-05
ZMAX(2)	0.2000000E-05
ZMAX(3)	0.3000000E-05

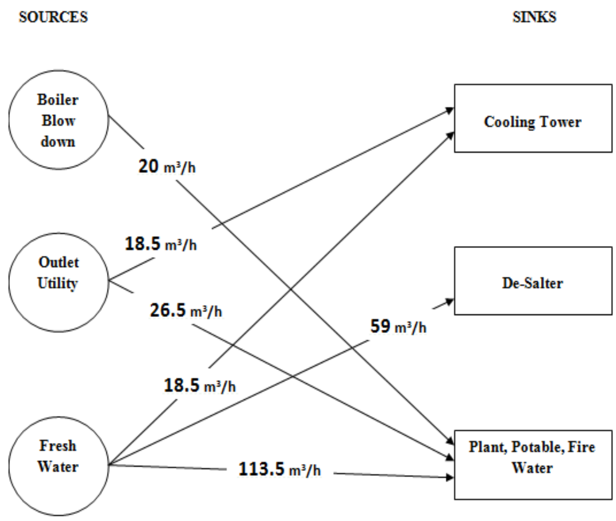

Fig. 6 Source-Sink Water Network Distribution

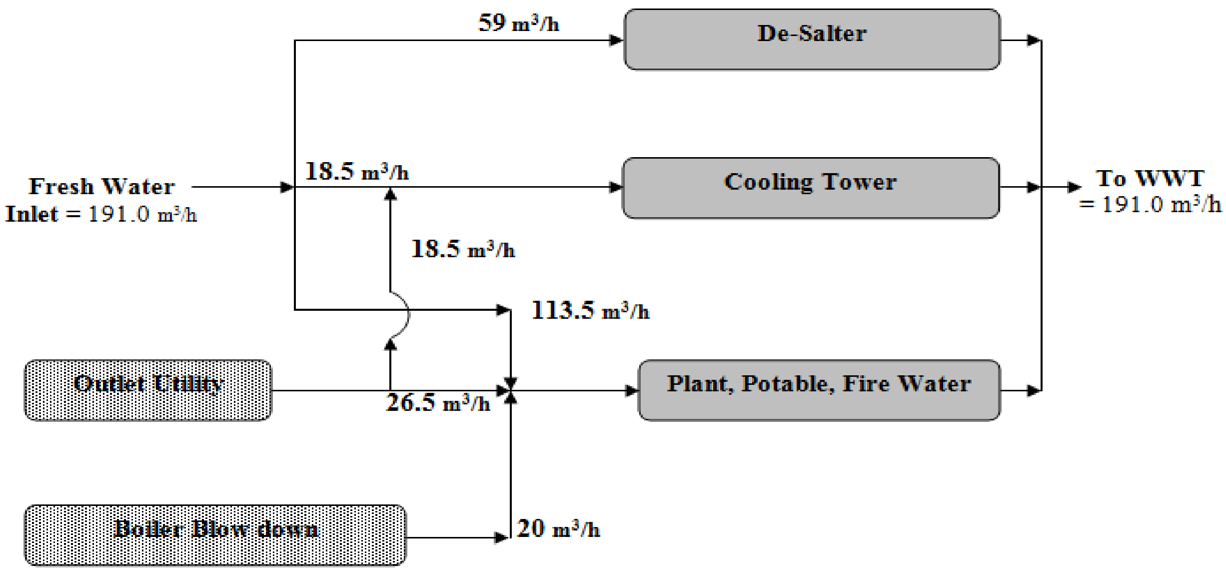

Fig. 7 Final Flow Sheet Regarding COD Case

LINGO Output Results are shown in Table VI.

The results from LINGO have verified that the amount of fresh water required is 191.0m^3/h with a reduction of 149.0m^3/h of fresh water. The program provides a best possible distribution of water streams to the sinks also. The proposed water network design from Sources to Sinks distribution is represented in Fig. 6. The final flow-sheet of the Tehran Oil Refinery with 43.8% fresh water reduction is shown in Fig. 7.

IV. Conclusion

This study was based on single contaminant approach and COD was selected for consideration. This work has been performed by a new technique comparison to the studies performed earlier. This technique has shown a very good percentage reduction of 43.8.0% of fresh water in three processes. Analyzing the results from mathematical programming proved the exact requirement of fresh water. In addition to LINGO programming, the best possible water networking was suggested based on COD contaminant. Besides to this, double contaminant can be more precise to reduce the water loss.

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References

[1] M. M. El-Halwagi, V. Manousiouthakis, “Synthesis of mass exchange networks” AIChE J., Vol. 35, pp. 1233–1244, 1989.
[2] B. Linnhoff, D. W. Townsend, D. Boland, G. F. Hewitt, B. E. A. Thomas, A. R. Guy, and R. H. Marshall, “A User Guide on Process Integration for the Efficient Use of Energy (The Institution of Chemical Engineers, Rugby, UK). 1982.
[3] Y. P. Wang, and R. Smith, “Wastewater minimization” Chem. Eng. Sci., Vol. 49, pp. 981–1006, 1994.
[4] M. Sorin, and S, Be´dard, “The global pinch point in water reuse Networks” Transactions of IChemE Part B, Vol. 77, pp. 305–308, 1999.
[5] N. Hallale, “A new graphical targeting method for water minimization” Adv. Environ. Res., Vol. 6 pp. 377–390, 2002.
[6] Z. A. Manan, Y. L. Tan, and C. Y. Foo, “Targeting the minimum water flow rate using water cascade analysis technique” AIChE J.,Vol 50, pp. 3169–3183, 2004.
[7] M. M. El-Halwagi, F. Gabriel, and D. Harell, “Rigorous graphical targeting for resource conservation via material recycle/reuse networks” Ind Eng Chem Res., Vol. 42, pp. 4319–4328, 2003.
[8] R. Prakash, and U. Shenoy, “Targeting and design of water networks for fixed flowrate and fixed contaminant load operations” Chem Eng Sci., Vol. 60, pp. 255–268, 2005.
[9] F. B. Gabriel, M. M. El-Halwagi, “Simultaneous synthesis of waste interception and material reuse networks: problem reformulation for global optimization” Environ. Prog. Vol. 24(2), pp. 171–180, 2005.
[10] J. M. Ponce-Ortega, M. M. El-Halwagi, A. Jime´nez-Gutie´rrez, “Global optimization of property-based recycle and reuse networks including environmental constraints” Comput. Chem. Eng., Vol. 34(3), pp. 318–330, 2010.
[11] J. M. Ponce-Ortega, A. C. Hortua, M. M. El-Halwagi, A. Jime´nez-Gutie´rrez, “A property-based optimization of direct recycle networks and wastewater treatment processes” AIChE J., Vol. 55(9), pp. 2329–2344, 2009.
[12] F. Na´poles-Rivera, J. M. Ponce-Ortega, M. M. El-Halwagi, A. Jime´nez- Gutie´rrez, “Global optimization of mass and property integration networks with in-plant property interceptors” Chem. Eng. Sci., Vol. 65(15), pp. 4363–4377, Apr. 2010.
[13] V. Kazantzi, M. M. El-Halwagi, “Targeting material reuse via property integration” Chem. Eng. Prog., Vol. 101 (8), pp. 28–37, 2005.
[14] Gh. R. Nabi Bidhendi, N. Mehradadi, and S. Mohammadnejad, “Water and wastewater minimization in Tehran Oil Refinery using water pinch analysis” Int. J. Environ. Res., Vol. 4(4), pp. 583-594, June. 2010.

[15] M. M. El-Halwaji, “Sustainable Design through Process Integration” B. H. Elsevier, 2012, pp. 287-298.