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Water pinch analysis in oil refinery using regeneration reuse and recycling consideration

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ABSTRACT

The aim of this study was finding an appropriate way to minimize water utility in the petroleum refineries due to high rate of water consumption. For this purpose, Tehran oil refinery was well studied. In this research, three contaminants including suspended solid, hardness and COD were considered to analyze feasibilities of regeneration reuse and recycling for water and wastewater minimization in the water network. These contaminants once were analyzed two by two based on their mass transfer. As a result, in the targeting based on suspended solid and hardness, the amount of freshwater was reduced about 40%. This amount for suspended solid and COD was equal to 37% and for COD and hardness was 39%. In the next stage, three contaminants were analyzed simultaneously and the amount of freshwater was reduced to about 17.35%. Clearly, compared to triple contaminans consideration, water minimization through double contaminants was more considerable.

1. Introduction

Water is a key element for the normal functioning of the chemical and petrochemical industries. Nowadays, the crisis of water storage, discharging wastewater into the environment as well as expenditures of water supply and wastewater treatment are the main reasons for finding new methods to minimize freshwater utility in different industries [1–4]. Since water is intensively used in petrochemical and allied industries especially petroleum refineries, water pinch technique is introduced as an efficient method to minimize water and wastewater. Water pinch technology is a systematic technique for analyzing water networks and reducing expenditures related to different water using processes [5,6].

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. Nevertheless, if it includes mass transferring of two or more key contaminants, the problem will be solved as multiple contaminants [7]. Graphical methods, mathematical and computer based methods may be used for both cases. Each method has some advantages and disadvantages. Graphical methods are so practical to solve single contaminant problems. However, they are complicated and sometimes impossible for multiple contaminant problems. Mathematical methods are more exact but sometimes complicated especially in the case of multiple contaminants.

El-Halwagi and Srinivas [8] propounded the theory of mass exchange networks. This theory was based on a two-stage solution; first, Mixed Integer Nonlinear Programming and then Mixed Integer Linear Programming.

Wang and Smith [9] used a limiting composite curve to solve multiple contaminant problems. Kuo and Smith [10,11] applied a new method to reduce the complexity of the graphical method. This method was based on breaking the operations. Foo et al. [12] presented a two-stage procedure for the synthesis of a maximum water recovery (MWR) network for a batch process system, covering both mass transfer-based and non-mass transfer-based water using processes.

Gomes et al. [13] used a Water Source Diagram method based on the outlet flow-rate. Alva-Argaez et al. [14] introduced a systematic methodology that empowers conceptual engineering and water pinch with mathematical programming methods. The method focuses on petroleum refineries explaining trade-offs and savings between freshwater costs, wastewater treatment, piping costs and environmental constraints on the discharge.

Ulson de Souza et al. [15] investigated the implementation of the Water Source Diagram (WSD) in a petroleum refinery with six operations, which consume water. They observed that with the application of the WSD method the water consumption was substantially reduced.

Mohammadnejad et al. [16] studied the optimization of water and steam allocation network based on mathematical methods. Consequently, they developed an algorithm to simplify the relevant calculations and applied it for reforming the network in a petroleum refinery.

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Nomenclature

$C_{i,H,n}$	Concentration of H within operation i in interval boundary n
$C_{i,H,in}$	Inlet concentration of H in operation i
$C_{i,H,out}$	Outlet concentration of H in operation i
$C_{i,COD,n}$	Concentration of COD within operation i in interval boundary n
$C_{i,COD,in}$	Inlet concentration of COD in operation i
$C_{i,COD,out}$	Outlet concentration of COD in operation i
$C_{i,SS,n}$	Concentration of SS within operation i in interval boundary n
$C_{i,SS,in}$	Inlet concentration of SS in operation i
$C_{i,SS,out}$	Outlet concentration of SS in operation i
$f_{i,n}$	Required flow-rate
f_i	Inlet flow-rate
$T_{i,n}$	Outlet flow-rate
$q_{li,m\le n}$	Flow-rate from operation l within operation i with flow-rate q in previous interval boundary m
$F_{i,n}$	Required water for each operation in each interval boundary
$\overline{W}_{i,j,n}$	Average concentration of weighted flow-rate for current water sources
$W_{ij,n+1}$	Outlet concentration of any operation as inlet concentration of next operation

Table 1
Flow-rates and stream constraints for the optional water network.

No.	Flow-rate(m^3/h)	Stream constraints (ppm)
1	505	pH = 7/9, T.COND. = 360, TH = 150, COD = 0 M-ALK = 140, SiO2 = 9/3, SS = 1, TSS = 2/15, T.Fe < 0/05, Cl < 0/05
10	20	pH = 9/8, T.COND. = 90, TH = 0, T.Fe < 0/05, PO4 = 20, COD = 0
13	113	pH = 7/9, T.COND. = 360, TH = 150, M-ALK. = 140, SiO2 = 9/3, S.S = 1, T.SS = 2/15, T.Fe < 0/05, Cl < 0/05, COD = 0
15	37	PH = 7/1, T.COND. = 4350, TH = 1250, M-ALK. = 30, SiO2 = 48/9, S.S = 1, T.SS = 2/95, T.Fe = 0/35, Cl = 2/5
17	104	pH = 7/6, T.COND. = 1400, TH = 270, M-ALK. = 66, SiO2 = 9/87, S.S = 2, T.SS = 2/66, T.Fe < 0/05, Cl < 0/05
18	168	pH = 7/9, T.COND. = 360, TH = 150, M-ALK = 140, SiO2 = 9/3, SS = 1, TSS = 2/15, T.Fe < 0/05, Cl < 0/05, COD = 0
19	160	PH = 7/3, T.COND. = 930, TH = 241, M-ALK = 23, SS = 22, COD = 4
21	17	pH = 5/5, T.COND. = 850, TH = 12, M-Alk. = 44, SiO2 = 6/6, SS = 13, TSS = 24/3, Tfe = 0/83, Cl < 0/05, H2S = 3/4, NH3 = 46, COD = 10
22	59	pH = 5/5, T.COND. = 850, TH = 12, M-Alk. = 44, SiO2 = 6/6, SS = 13, TSS = 24/3, Tfe = 0/83, Cl < 0/05, H2S = 3/4, NH3 = 46, COD = 2
23	59	pH = 6.5, T.COND. = 1600, TH = 160, M-Alk. = 40, SiO2 = 1.4, SS = 20, TSS = 25, Tfe = 3.12, Cl < 0.05, COD = 5

In this research, three key contaminants including suspended solid (SS), hardness (H) and COD have been considered to analyze the feasibilities of regeneration reuse and regeneration recycling for water and wastewater minimization in the water network. Besides, this research is based on the work of Wang and Smith [9].

There are two targets for wastewater minimization by water pinch technology in this research:

1. Wastewater minimization considering double contaminant approach.
2. Wastewater minimization considering triple contaminant approach.

2. Materials and methods

This research has been performed for Tehran oil refinery from 2006 to 2009. The studied refinery comprises two refineries and some petroleum processing manufactories. The simplified flowchart of water and steam allocation network in the refinery has been showed by Fig. 1. Currently this refinery utilizes about 505 m^3/h water. As it is seen, water and steam allocation network in the refinery is well designed and the amount of water utility and wastewater generation are in an acceptable level while wastewater is reused or regenerated.

Table 1 illustrates flow-rate and stream constraints in the water network. Based on these constraints, the limiting water flow-rates are determined for the optional operations. The water flow-rate is needed to achieve the mass transfer of contaminants required for water minimization. Contaminant selection depends on the industry and its water requirements. In addition, it is very important to select processes, which have high rate of water consumption.

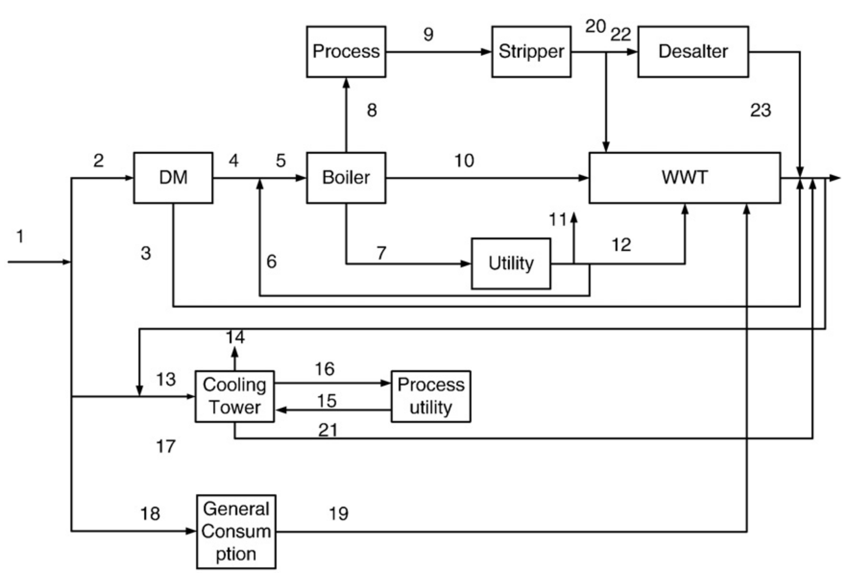

Fig. 1. Flowchart of water and steam allocation network in the refinery.