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Research Paper

Water and Wastewater Industry and Energy Management

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Abstract

In this paper**,** simultaneous management of energy and water systems in single contaminant state was considered in two different conditions: (i) systems with only fresh water usage and (ii) systems with maximum reuse of water. In first mode, situations of individual stream, isothermal stream and non-isothermal stream mixing were investigated. Graphical and conceptual techniques for minimizing the targets have been used. As a case study, the water minimization along with energy-efficient in gas refinery was considered. Fresh water consumption of the refinery is 34 kg/s. Using non-isothermal mixing, number of streams and heat exchangers were decreased, but energy targets were increased. Fresh water consumption of final water network was reduced to 21 kg/s because the Cooling tower as a major water-using operation unit didn't use fresh water anymore and a single contaminant approach was considered too. The new water network has 1399.2 kW hot utility duty and 962.2 kW cold utility duty.

Keywords*:* Gas refinery; HEN Network; Water and Wastewater Minimization; WAN Networks

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1. Introduction

Over the last two decades, attitudes toward the environment have changed dramatically. Water is a key element for the normal functioning of the chemical and petrochemical industry. Steam stripping, liquid-liquid extraction and washing operations are among the many processes present in refineries and chemical plants where water is intensively utilized. In refineries, steam is used in atmospheric and vacuum crude fractionation, as well as in coking, hydro cracking, FCC, visbreaking, sweetening, hydrotreating, alkylation, ether synthesis, etc. In addition, water is used in desalters to remove primarily the salted water droplets that the crude contains. In refineries, treatment is divided in four levels: primary treatment involves physical treatment processes, secondary treatment comprises operations where soluble matter is removed, and tertiary and quaternary treatments "polish" the effluent to the final discharge standards. The shortage in proper water supplies, the increase in environmental limits and the raise in water cost of industrial processes caused more attention to reducing the water consumption and producing waste water in processed industries [1,2].

The problem of reduction of water consumption and wastewater generation has some similarities with the problem of energy minimization. Water and energy are two of the most essential resources for running chemical processing plants. The former is needed not only as a solvent in mass-transfer processes but also as a heat-transfer medium in heat exchangers. Specifically, various organic and inorganic contaminants in another phase can often be removed with process water. Thus, clean water is widely considered as an effective mass separating agent in washing or separation operations (such as absorption and extraction). In addition, the aerated and purified water is consumed in the utility systems to produce steam and/or cooling water for use as heat carriers [3]. Inside the process, depending on the water distribution flow between the units, heating or cooling of water streams may be necessary. The wastewater streams could be subject to thermal limitations, as well as contaminant environmental limitations. Therefore, effluent streams might require cooling to achieve the required discharge conditions. In some cases, significant amounts of water need to be heated, such as for sterilization and process-washing. Therefore, in such situations, both the temperature and quality of the water are important. Since the water-using units and wastewater treatment units are often required to be operated at different temperatures, a strong interaction does exist between the corresponding WAN and HEN designs. Consequently, energy and water management needs to be considered simultaneously [4]. Species concentrations, temperature, flow rates, phase and stability of the operating conditions within a process plant represent different aspects that must be considered in waste minimization analysis. For the simultaneous water and energy minimization, there are two major systematic strategies: first based on mathematical programming and second based on conceptual-graphical techniques. Savulescu and Smith proposed a conceptual design method, the water-energy pinch analysis, to solve the combined WAN-HEN optimization problem the so-called "separate system approach" was adopted to create the overall network design with a graphic tool-the two-dimensional grid diagram [5, 6]. Savelski et al., employed mathematical techniques which identifies the target of water systems subject to energy integration, and completes the design of heat integrated water systems. Their procedure is confined to treat the single pollutant case, and it is based on a linear programming formulation that relies on necessary conditions of optimality and a heat transshipment model. An LP model is first solved to obtain minimum water usage and minimum heating utility target values. Once the energy and water targets have been identified, an MILP model is generated.[7,8] In this work, as a case study, the water minimization along with energy-efficient in gas refinery is considered. In the first case, systems with fresh water using only and in second case, systems with maximum re-use of water considered.

2. Methods

In this paper, we used conceptual and graphical techniques for simultaneous management of water and energy to single contaminant state. For this system, the water and energy targets need to be identified. In this work water network of Sarakhs gas refinery, as well as, heat integration of this water inlet-outlet operation unit streams is considered. In existing water network, 5 major waterusing operation units including Boiler, Cooling Tower, Evaporator, Resin-Washing unit and human consumption are selected. Total fresh water consumption of refinery is 125 ton/hr (34.7 kg/s). In order to simplify the analysis of the energy aspects of water streams, following assumptions adopted:

i. Each water-using operation unit is specified by the maximum inlet and outlet concentration of contaminant.
ii. Optimum temperature of each water-using operation unit is average of supply and target temperature.
iii. There are no flow rate losses or gains through an operation unit.
iv. Each operation unit operates isothermally, so there are no heat losses or gains.
v. There is a water source with temperature of 20 °c.
vi. Temperature of discharge wastewater is 25 °c.
vii. Operations are Single contaminant (TDS).
viii. The non- water using or tiny- water using operations have been neglected.
ix. The system operates continuously.
x. Specific heat capacity for all the streams is 4.2 kg/kg °c.
xi. Fresh water is pure.

Water-using operation unit's data for this case study are presented in following table.

Table 1. Water-using operation data

Operation Unit	C_{in} (ppm)	C_{out} (ppm)	T_{opt} (°C)	Q(kg/s)	Contaminant mass load(g/s)
1- Boiler	0	700	100	6.7	4.7
2- Evaporator	0	3500	83	9.8	34
3- Human Consumption	500	1800	20	5.6	7.5
4- Resin Washing	750	1250	25	1.6	0.7
5- Cooling Water	1250	3500	51	11	24.75

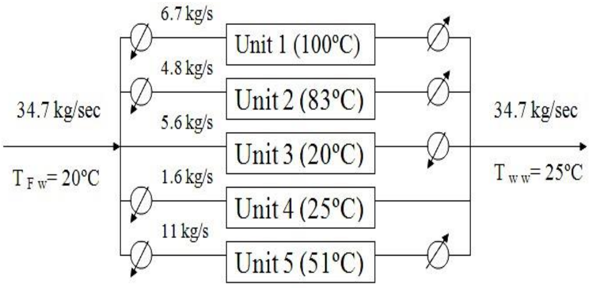

Figure 1. Individual streams for water network of refinery.

3. Results and Discussion

For the case of fresh water use in each operation unit, fresh water passes through units once and is then discharged. Figure 1 indicates the water-using operation network. The water consumption is determined to be 34.7 kg/s. for the individual stream, the composite curves presented in figure 2. The energy target given by the composite curves for the minimum temperature driving force of 15 °C is 1883.7 kW of hot utility duty and 1155 kW of cold utility duty. Temperature of pinch is 27.5 °C. Number of hot and cold streams for this option is 8. With design of individual stream's heat exchanger network in Aspen Pinch software, number of heat exchangers became 11.

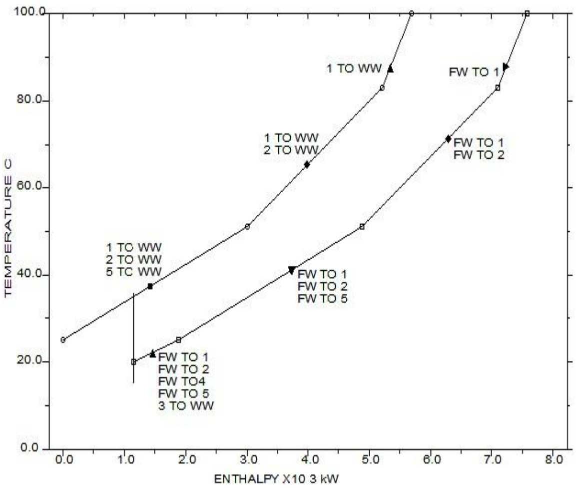

Figure 2. Energy composite curve for individual stream.

In this option, we consider isothermal stream mixing in water network. Figure 3 illustrates water network with isothermal stream mixing. Number of hot and cold streams for this situation is 8. Isothermal stream mixing within water network does not decrease minimum temperature driving force. Profiles of composite curves and energy target are illustrated in figure 4. The obtained energy target of this diagram is 1883.7 kW of hot utility duty and 1155 kW of cold utility duty. Temperature of pinch is 27.5 °C. The heat exchanger network for this set of streams is shown in fig 5. Number of heat exchangers for this case are 9.

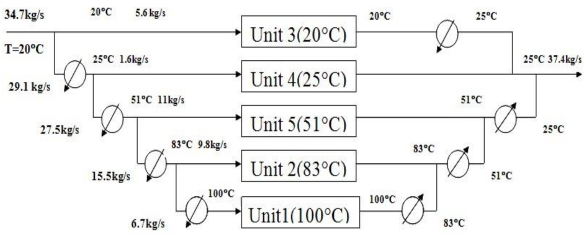

Figure 3. Isothermal stream mixing for water network of refinery

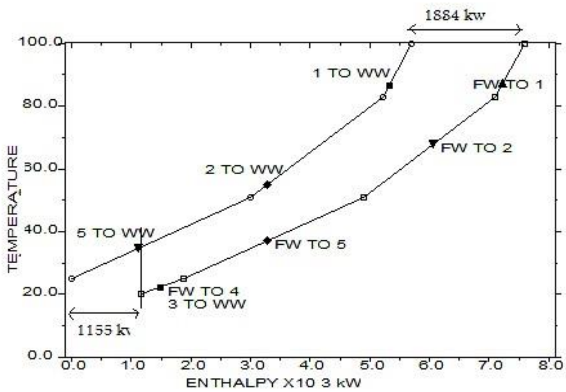

Figure 4. Energy composite curve for isothermal stream mixing

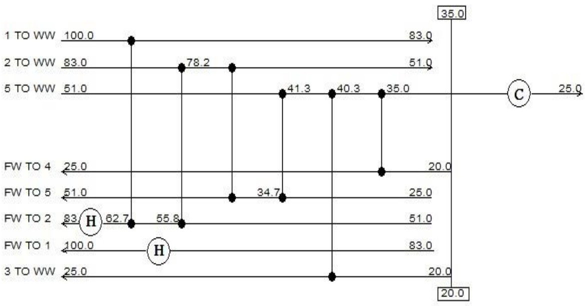

Figure 5. Heat exchanger network for isothermal stream mixing

The third option is non-isothermal stream mixing that is illustrated in figure 6. Number of hot and cold streams for this option is 2. The energy target for the minimum temperature driving force of 15 °C is 4030.3 kW of hot utility duty and 3389.9 kW of cold utility duty. The heat exchanger network for this set of streams is shown in fig 7. Temperature of pinch is 56.4 °C. Number of heat exchange unit for this situation are 3.

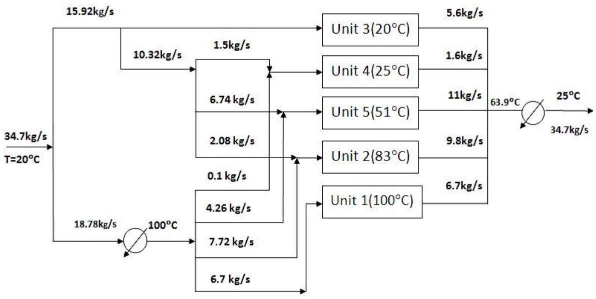

Figure 6. Non-isothermal stream mixing for water network of refinery

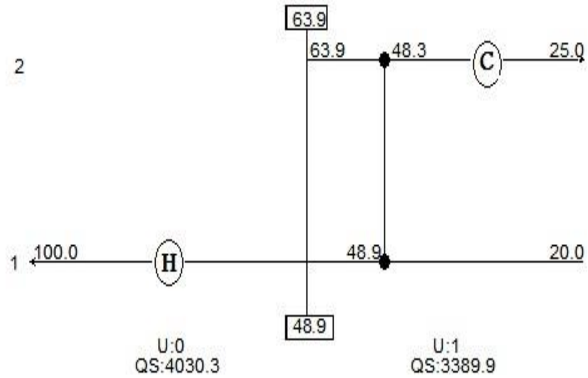

Figure 7. Heat exchanger network for non-isothermal stream mixing

Now we analyze water network with maximum reuse of water. In this case Minimum fresh water consumption obtained equal to 21 kg/s using CID method (Concentration Interval Diagram). Final water network is shown in figure 8. In the new water network, unit 5 (cooling tower) that has the highest consumption of water, doesn't use fresh water. Figure 9 illustrate energy composite curve for this network. Number of hot and cold stream are 9. The energy target for the minimum temperature driving force of 15 °C is 1399.2 kW of hot utility duty and 962.2 kW of cold utility duty. Temperature of pinch is 56.4 °C.

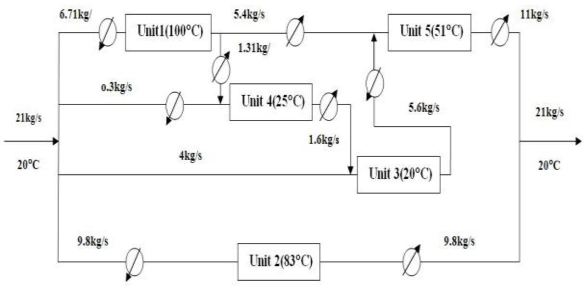

Figure 8. Final network with maximum reuse of water

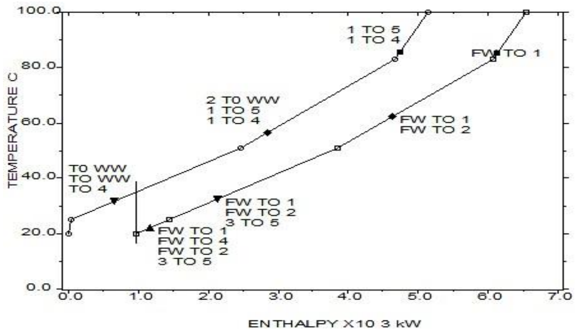

Figure 9. Energy composite curve for new water network

4. Conclusions

In this paper, two major conditions were considered. In first mode, situations of individual stream, isothermal stream mixing and non-isothermal stream mixing were investigated and the results of surveys are presented in table 2. Using non-isothermal mixing, number of streams and heat exchangers are decreased, however energy targets are increased. In the case of isothermal stream, Number of heat exchangers are less than individual stream. In the second mode, water network with maximum reuse of water analyzed. Minimum fresh water of 21 kg/s was obtained. Hot utility duty is 1399.2 kW and cold utility duty is 962.2 kW. Number of hot and cold streams are 9. Consumption of fresh water is decreased a bit great, because Cooling tower as a major water-using operation unit, doesn't use fresh water in final network and a single contaminant approach was considered too.

Table 2. Results of surveys for different situations

Situation	Number of streams	Q_h (kw)	Q_c (kw)	Number of heat exchanger
Individual stream	8	1883.7	1115	11
Isothermal stream	8	1883.7	1115	9
Non-isothermal stream	2	4030.3	3389.9	3

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