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بدینوسیله گواهی می گردد مقاله با عنوان:

Simulation of Mechanical Vapor Recompression Process for Treatment of the Wastewater of Crude Oil Desalting Unit

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در پنجمین کنفرانس تخصصی ترمودینامیک که در یک و دو آذر ماه ۱۳۹۶ در دانشکده مهندسی دانشگاه فردوسی مشهد برگزار شد، با موفقیت ارائه گردید.

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Simulation of Mechanical Vapor Recompression Process for Treatment of the Wastewater of Crude Oil Desalting Unit

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Abstract

In this paper performances of single and multiple-effect evaporation (SEE/MEE) mechanical vapor recompression (MVR) systems, for wastewater treatment of the crude oil desalting plants are compared, using ASPEN PLUS software. All the simulated SEE/MEE systems were optimized for feed salinity of 70 g/kg, containing 5000 ppm oil and zero liquid discharge, by allowing the brine salinity discharge to be close to salt saturation conditions (300g/kg). The results showed that the MEE-MVR including thermal integration system has the best performance for desalination of the wastewater, in terms of energy consumption and operational expenditures (OPEX). Sensitivity analysis were carried out on the effect of the feed salinity and salt type in MEE-MVR system. Increasing salinity (NaCl), up to 120 g/kg, resulted in higher energy consumption, however OPEX decreased as salinity increased above 140 g/kg. Waste water containing $CaCl_2$ needed more energy to be treated, compared to water containing NaCl and $MgSO_4$.

Keywords: Desalination, Wastewater, Mechanical vapor recompression, Single and multi-effect evaporation

1. Introduction

Desalting/dehydration plants (DDPs) are often installed in crude oil production units, in order to remove water-soluble salts from produced oil. The resultant wastewater from DDPs often contains inorganic salts, suspended solids and water-soluble traces of metals [1]. Therefore, due to the environmental concerns, such a wastewater must to be treated before releasing it into the environment and/or reinjected into the reservoir; however, its high salinity often destroys injection pumps [2]. As an instance, the amount of total dissolved solids (TDS) of wastewater produced from some DDPs in south of Iran (reported by National Iranian South Oil Company) exceeds 150,000 ppm [3], so the crucial need for treatment of such DDP's wastewater has raised substantial attention.

The choice of treatment method depends on TDS content of the treated wastewater [4]. Among conventional wastewater treatment techniques (e.g., reverse osmosis [5], electrodialysis [6], multi-effect evaporator [7] and membrane [8]), the evaporation methods are more effective due to their

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simpler pretreatment, higher product purity and longer life of the separating surface [9]. However, the current evaporation techniques require a large amount of external heating vapor; also, their operation is complex [10, 4].On the other hand, mechanical vapor recompression (MVR) is an alternative method to treat highly concentrated wastewater [10], in which the produced vapor from evaporator is compressed to reuse its energy [2].

For the first time, United States used MVR system on ships, during World War II, to produce freshwater [11]. The MVR systems are typically diesel or electric powered and may be used on ships, offshore oil rigs, and in water-limited regions of the world [11]. Higher efficiency at lower costs is the main target to the design of desalination systems [9]. The MVR system is compact and does not require external heating source. This system is less susceptible to fouling. In addition; it can be used to treat wastewater streams with TDS up to 200,000 ppm [12]. Other advantages of this system include high product purity, operation reliability and flexibility, high thermodynamic efficiency and low energy costs [13, 6].

In this paper, different types of MVR systems, resulted by combination of single- / multi-effect evaporation with single- / multi-stage recompression including thermal integration, were simulated and optimized, using ASPEN PLUS software. These models were compared and the more efficient one was selected, using different sensitivity studies.

2. Process description and simulation method

System description: MVR system contains mainly five segments, including compressor, flash evaporator, heat exchanger, brine and product pumps, and vacuum system [10]. Vacuum system extracts the non-condensable gases and maintains system pressure; so that a good heat transfer process can be attained during operation [10, 11].

The feed wastewater enters a preheater at ambient temperature. The preheater is a plate type heat exchanger, which uses the product energy to preheat the feed wastewater [10]. The preheated feed, after mixing with the recycled concentrated stream, is pumped to the tube side of a heat exchanger, and turns into a hot stream [11]. The hot stream enters a flash evaporator, in which it is evaporated partially [9] and then the generated vapor is compressed [11]. The compressed vapor, which is a superheated steam, is introduced into the shell of the heat exchanger [10, 11], where both its sensible and latent heat is transferred to the mixed stream flowing through the tube-side; and hence condenses [10]. A small amount of the hot stream from flash evaporator may be sent to the second effect system, in which the solution is evaporated further and/or sent to a centrifuge to separate the remaining water formed the crystals [10, 11]. The remaining hot stream is then recycled.

Simulation of the system: In this study, ASPEN PLUS software was selected to simulate the system and analyze the energy consumption. As process simulation software, ASPEN PLUS possesses the capability to simulate steady state processes in chemical industry. Additionally, this software contains many databases including physical, chemical and thermodynamic properties for a wide range of chemical compounds, as well as selectable thermodynamic models required for accurate simulation of any given chemical system [11]. The main assumptions considered for the simulations were as follows:

- Steady state operation.
- Heat losses in all thermal and mechanical equipment were neglected.
- Pressure drops in all thermal equipment were negligible.
- The condensate (product) had zero salinity.
- Vapor streams from each evaporator were considered as ideal gases.
- Starter energy required for the multi-stage compressor was insignficant.
- There were no non-condensable gases.
- The power consumptions of pump 1 and pump 2 were ignored
- The concentrated wastewater leaving both flash evaporation units were in saturated liquid phase

The thermodynamic package of NTRL-electrolytes was selected for the process simulation. An initial mean value of 70,000 ppm (or 70 g kg−1) was considered for the feed salinity in MVR system design [14], about half of the reported value in National Iranian South Oil Company. Most importantly, concentrate discharge salinity was supposed to be equal to 300 g kg−1 (very close to salt saturation condition of ~350 g kg−1); in order to achieve zero liquid discharge (ZLD) operation. Table 1 presents other assumptions considered for the operating conditions used in the simulations.

Table 1. Problem data for the case study based on the wastewater production [15].

Feed stream	
Mass flow rate	37.5 m^3 h^{-1} (10.42 kg s^{-1})
Salinity	70 g kg^{-1} (NaCl)
Oil content	5000 ppm
Temperature	25 °C
Pressure	50 kPa
Multistage compressor with intercooling	
Type/material	Centrifugal/carbon steel
Isentropic efficiency	0.75
Maximum compression ratio	3 per stage
Cooling services	20-25 °C
Cost data	
Electricity cost	850.51 US$ (kW year)$^{-1}$
Cooling services cost	100 US$ (kW year)$^{-1}$

3. Results and discussion

Different MVR systems for wastewater treatment were simulated and compared in this study. Fig. 1 shows the optimized model of a single-effect evaporation process with a single-stage compressor (SEE-SVR). In this process, the feed wastewater was preheated (for about 924.12 kW from condensate stream) and then was sent to the evaporator at 48 °C. In the evaporator, which operated at 57.64 °C and 13.62 kPa, about 7.75 kg/s of the preheated stream was evaporated; then the generated vapor was compressed up to 29 kPa. The compressed vapor was then condensed and almost 18528 kW heat is released as its temperature is reduced from 148 to 67.00 °C. This energy was used to preheat the stream in effect evaporator.

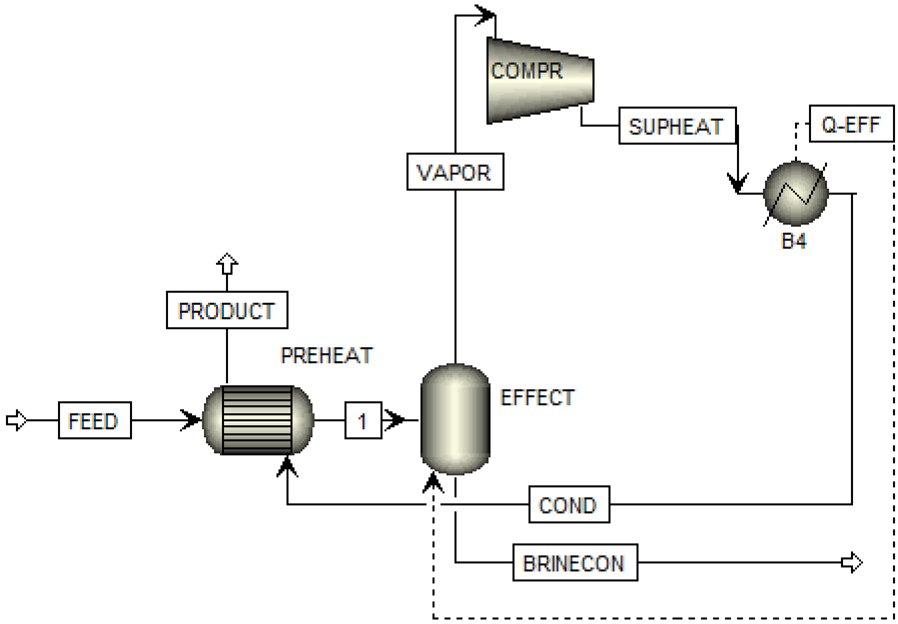

Figure 1: SEE-SVR process flow diagram in Aspen PLUS software.

The single-effect evaporation process with a multi-stage compressor (SEE-MVR) was also simulated. In this case, the heat flow of evaporator effect was equal to 18475.20 kW. The optimized SEE-MVR process required a 2-stage compressor with capacities of 256.19 kW and 988.48 kW, respectively. In addition, The 2 stage compressor needed 292.07 kW of energy for cooling services.

The multiple-effect evaporation with multi-stage vapor recompression (MEE-MVR) was then designed, in which two flashing tanks was used to separate the distillate vapor, providing a more energy recovery (Fig. 2). In this case, the condensate stream was entered the preheater at 63.72 °C in order to reuse its energy (about 1067.31 kW) for preheating the feed.The preheated stream (at 51.56 °C) was sent to the first and second evaporators. The produced vapor from the second effect evaporator was mixed with that of the second flashing tank, and then the generated vapor with the flow rate of 3.88 kg/s at 87.63 °C and 59.52 kPa was compressed to 150.11 kPa. Furthermore, the compressed vapor was condensed and about 10209.13 kW heat was released during cooling from 189.14 to 44.82 °C. This heat was deployed to preheat the stream in the first evaporator effect. Moreover, the vapor from the first effect was condensed and about 10208.21 kW heat was released as it was cooled from 100.00 to 81.43 °C. The discharged excess heat was used in second evaporator effect. In this case, the process required a 2-stage compressor with capacities of 114.63 kW and 740.81 kW, respectively. In addition, the 2 stage compressor demanded 105.29 kW of energy for cooling services.

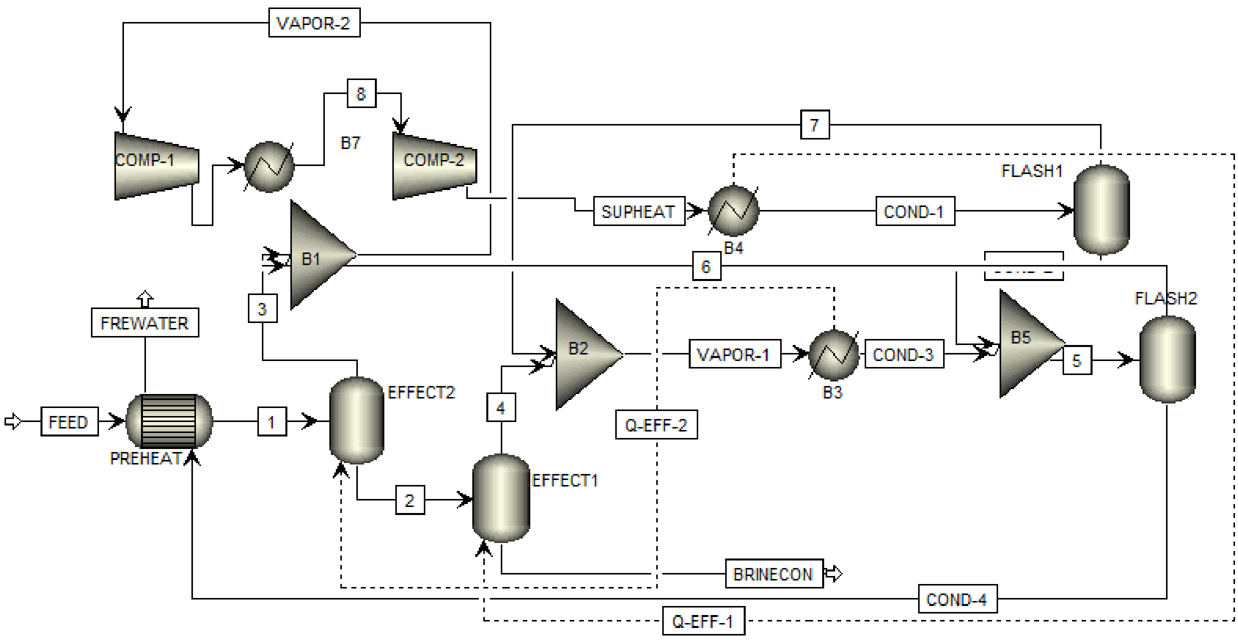

Figure 2: MEE-MVR process flow diagram in Aspen PLUS software

The multiple-effect evaporation process with single-stage vapor recompression (MEE-SVR) along with two flashing tanks was also designed and simulated. In this case, the heat flow of each evaporator effect were 10208.20 kW and 9602.21 kW, respectively. Moreover, the single- stage compressor did not require energy for cooling services.

The electric power consumed and operational expenditures (OPEX) are compared for the different simulated MVR systems, in Fig. 3. OPEX contain the electricity and cooling services for the multistage compressor and was calculated as follows [12]:

$$OPEX = Ec \cdot \sum_{j=1}^{J} Wj + Cc \cdot \sum_{j=1}^{J} Qj^{cooler} \quad (1)$$

where *Ec* is the cost parameter for electricity, (US$ (kW year) −1), *Wj* is the compression work (kW), *Cc* is the cost parameter for the cooling services (US$ (kW year) −1), and *Qj* is the heat flow (kW). Among all the SEE/MEE systems, the MEE-MVR including thermal integration system had the best performance in terms of energy consumption and OPEX, as shown in Fig. 3. In this case, the OPEX related to the consumption of electricity and the intercooler were 728 k US$ year−1 and 11 k US$ year−1, respectively.

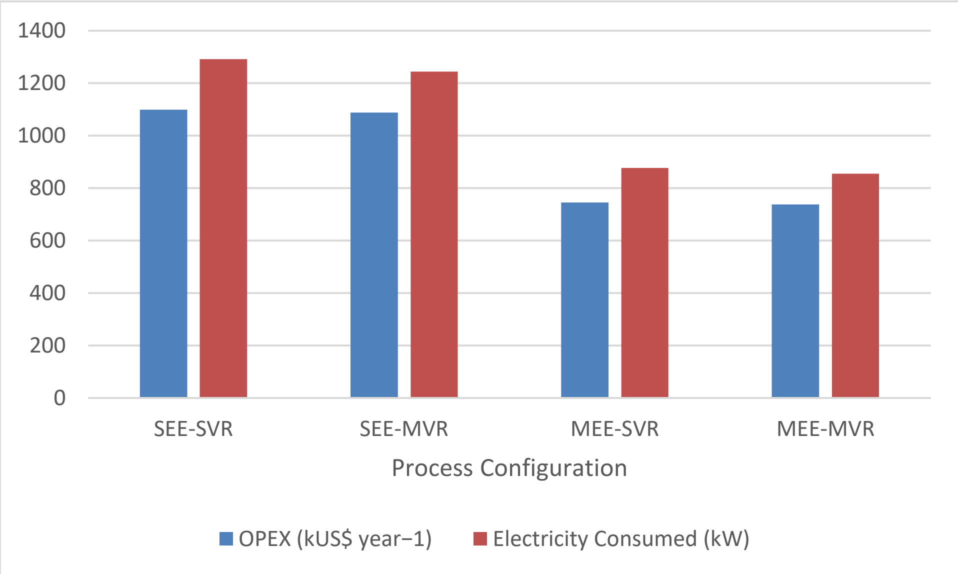

Figure 3: Comparison between the OPEX and electrical consumed for the processes SEE-SVR, SEE-MVR, MEE-MVR and MEE-SVR under 70g/kg feed salinity.

A simple sensitivity analysis of the MEE-MVR model was performed to assess the influence of the feed wastewater salinity on system performance and process costs. Fig. 4 displays the effect of the wastewater salinity on the MEE-MVR process costs. As shown in Fig. 4, up to 120 g/kg of salinity, higher feed salinity resulted in a higher power consumption. The salt concentration of the feed solution causes the boiling-point to rise, which would lead to the greater compressor power of the system. However, OPEX decreased as augmented increased from 140 g/kg. Fig. 5 presents the effect of salt type in feed solution on the power consumption. The salinity of all the tested solutions were equal. Since the boiling point of calcium chloride solution is greater than sodium chloride and magnesium sulfate solutions, higher energy was needed for the process of the feed containing $CaCl_2$. It needs to be mentioned that in all cases, the discharge brine salinity remained identical (i.e., 300 g kg−1) to achieve a discharge close to ZLD conditions.

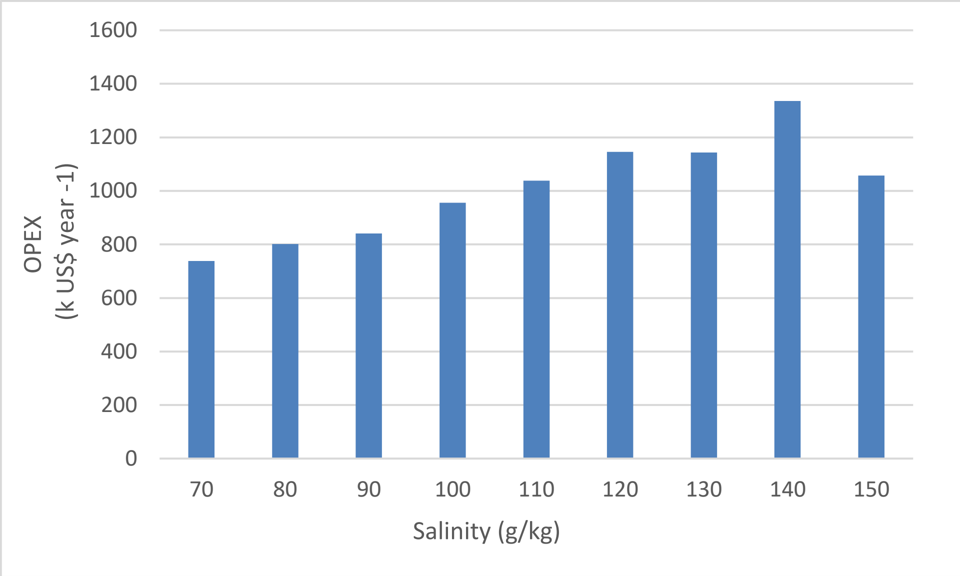

Figure 4: Effect of the wastewater salinity on the process costs of MEE-MVR.

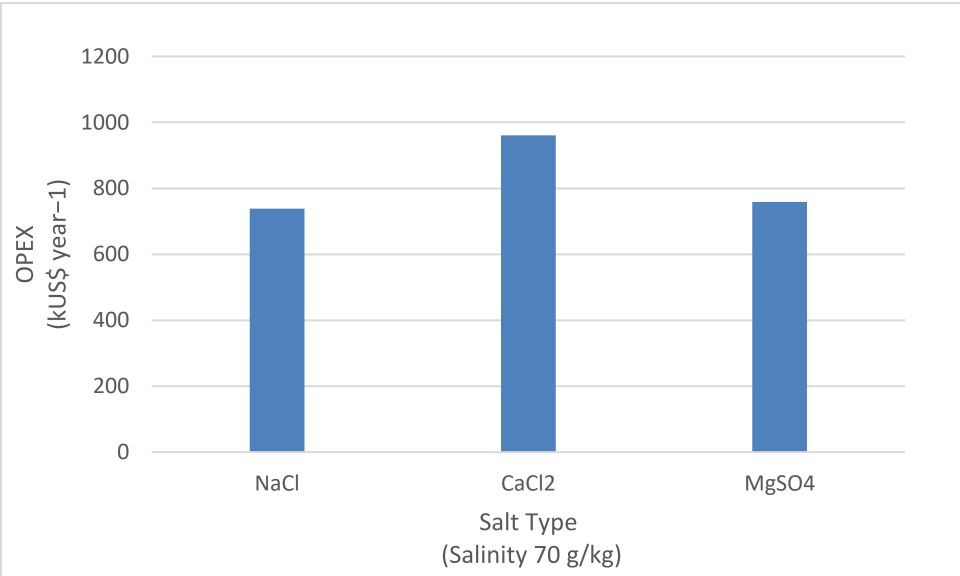

Figure 5: The effect of salts type the OPEX for the process MEE-MVR

4. Conclusions

In this investigation MVR systems are proposed and used to treat wastewater, especially wastewater with a high salt content (sodium chloride wastewater, in this case). The process was built in ASPEN PLUS software. Additionally, simulation of the system was established, which included SEE-SVR , SEE-MVR, MEE-SVR and MEE- MVR processes. The simulation results showed that among all SEE/MEE systems, the MEE-MVR system had the best performance in terms of energy consumption and OPEX that were 728 k US$ year−1 and 738 k US$ year−1, respectively.

A simple sensitivity analysis of the optimal MEE-MVR system was performed to assess the influence of the feed wastewater salinity and salt type on system performance and process costs.

The simulation results presented that the proposed system strongly dependented on the treated wastewater salinity. Moreover, due to high boiling point of $CaCl_2$ solution in comparison to $MgCl_2$ and Nacl ones, higher energy and OPEX was needed.

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