

# Thermodynamic and economic optimization of multi-effect desalination unit integrated with utility steam network



Mohsen Salimi, Hamed Akbarpour Reyhani, Majid Amidpour\*

Department of Mechanical Engineering, K.N. Toosi University of Technology, Energy Systems Division, No. 19, Pardis Street, Molla Sadra Ave., Vanak Sq., P.O. Box 19395-1999, Tehran, Iran

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## ABSTRACT

The integration of a multi-effect desalination (MED) unit with utility steam network system has been evaluated in this study. The generated steam from utility system has been used as a motive steam of MED unit. The opportunity to use excess steam of each steam levels of steam network of utility system has been investigated. The prices of steam for each one of the steam levels are calculated. The MED unit is designed for integration with each steam level. Thermodynamic and economic analyses demonstrate that utilizing steam from MP steam level has the highest rate of desalinated water production and using steam from LP steam level has the best exergy efficiency and period of return. Therefore steam has been extracted from LP steam level. Parametric study and sensitivity have been performed to characterize the effect of each one of the variables on the MED unit. Then, thermodynamic optimization for maximizing produced desalinated water and economic optimization for minimizing the period of return are performed. Thermodynamic optimization results in freshwater production rate increase from 10.431 to 20.149 kg/s. In the end, two-objective optimization results have been presented.

## 1. Introduction

The freshwater and power are the most crucial commodities for sustainable human life. To cope with the high rate of growth of human living standards, especially in developing countries, the security of supplying these commodities should be guaranteed. Dual purpose plants are constructed to decrease the cost of power and freshwater. Two studies have reported that as far as 30% of desalination costs are for its energy needs [1,2].

Utility steam networks are energy-intensive systems. This system is used to produce cooling water, heating steam, hot water, mechanical power and electrical power. Khoshgoftar Manesh et al. [3] presented a new procedure for upgrade the integration of desalination system with steam network. Exergoeconomic optimization and total site analysis were adopted in their study. Janalizadeh et al. [4] carried out exergoenvironmental and exergoeconomic assessment of thermal and reverse osmosis desalination systems with a utility system. Their objective was to find optimum integration of a utility system with a desalination system. The total site analysis was adopted for understanding the integration. Also, a targeting procedure was used in this study. Khoshgoftar Manesh et al. [5] presented a new method for cogeneration targeting to estimate heat, power and desalinated water production rate in total site. The low-grade heat of site utility was utilized for thermal

desalination. MED, MSF and reverse osmosis desalination have been assessed in this study.

Sanaye and Asgari [6] carried out Four E analysis optimization of combined cycle power plants coupled with a thermal desalination unit. A gas turbine partial load and temperature of ambient effects were investigated in this study. The sensitivity analysis about fuel cost variation was performed in the mentioned paper. Akbarpour Reyhani et al. [7] performed economic and thermodynamic optimization of SOFC-GT integrated with MED unit. They carried out economic and thermodynamic optimization of utilizing genetic algorithm. Salimi and Amidpour [8] investigated the integration of internal combustion engine with MED-TVC unit. In this study, modeling, simulation and sensitivity analysis were carried out. Shuja Azhar [9] et al. proposed new integrated multi-generation system with renewable energy sources. The integrated system was designed to produce fresh water, power, heating and space cooling.

Al-Mutaz and Wazeer [10] presented a multi-effect desalination unit mathematical model to estimate the optimum number of effects. An economic optimization of effects number was carried out in this study. Druetta et al. [11] performed mathematical modeling and optimization of MED unit. The unit contains several process layouts which has been optimized simultaneously. Druetta et al. [12] introduced an optimization model of MED unit. In this paper, the total cost of multi-effect

\* Corresponding author.

E-mail address: [amidpour@kntu.ac.ir](mailto:amidpour@kntu.ac.ir) (M. Amidpour).

desalination system was minimized. A sensitivity analysis of the primary parameters was presented. Zhao et al. [13] presented thermal and economic analyses of MED system feeding with high-salinity wastewater. Corresponding parameters have been examined to employ MED system in the refinery. The mathematical models were based on mass and energy and balances of effects, condenser and flashing boxes. Cartrini et al. [14] introduced thermoeconomic analysis of a CHP system integrated with MED-TVC plant. A novel productive structure was presented to account thermoeconomic cost. The main aim of this study was to propose an indicator to assign production costs on freshwater and electricity. Sharaf et al. [15] proposed a thermoeconomic analysis of MED-VC processes powered by solar thermal cycles. In this paper, different layouts of MED-VC plants were compared. Also, two different techniques to power desalination units were examined. Sadri et al. [16] presented a mathematical model for Multi-effect desalination unit with TVC taking into account BPE and several thermodynamic losses. Multi-objective optimization of MED-TVC-RO desalination system was presented based on irreversibility concept. Mahmoudi et al. [17] performed multi-objective optimization of absorption heat transformer integrated with a desalination system. In this study, a multi-objective optimization was carried out to minimize product unit cost, maximize exergy coefficient and maximize fresh water flow rate. Ameri and Jojani [18] conducted performance evaluation and multi-objective optimization of organic Rankine cycle coupled with MED unit. They applied optimization for three different working fluids. Salimi and Amidpour [19] investigated the integration of desalination systems into CHP systems utilizing R-curve tool. R-curve is used to identify effective way to lower operation cost of CHP system. Wu et al. [20] provided a mathematical model for multi-generation of water and power. The proposed integrated system's main units were steam turbine, RO and MSF plants. A new genetic algorithm was presented to solve the problem as MINLP problem. An economic optimization was used to minimize the proposed system's total annual cost. Almutairi et al. [21] developed a model for a cogeneration plant utilizing real data. An ME-TVC-MED unit integration impact on overall efficiency was investigated. In this study, several possibilities were suggested to upgrade the presented system. Wu et al. [22] studied an integrated system consisted of coal-based power plant, MSF and RO units. The appropriate optimal structures for different demand of power, heat and water were presented. The process model for each unit and economic model were presented. By solving NLP model to minimize the total annual cost, the optimal cogeneration system was obtained.

In this study, integration of multi-effect desalination system with steam network of utility system with excess steam in each pressure level has been examined. The main goal of this study is to present a proper procedure to integrate multi-effect desalination unit with steam network of utility system and design MED system, accordingly. The principal objectives of this paper are to evaluate the proposed integrated system through exergy efficiency and freshwater production rate to optimize it for higher efficiency and better financial return rate for presented integration. The design and optimization of MED highly depend on the economy of its motive steam. Therefore, for each steam pressure level, the steam price is calculated. Integration of MED with each steam level has been compared economically and thermodynamically. Parametric study and sensitivity analysis are performed for the most economic steam level, and economic and thermodynamic optimization has been performed for multi-effect desalination unit.

## 2. Design method

For typical chemical plant, heat and power are provided by utility system. Different types of fuel can be consumed in its boilers and provide needed steam for different processes through various steam mains and generate power by steam turbines. The produced steam from processes can be injected to the different steam mains. Fig. 1 demonstrates the schematic of steam network of the utility system. Each steam

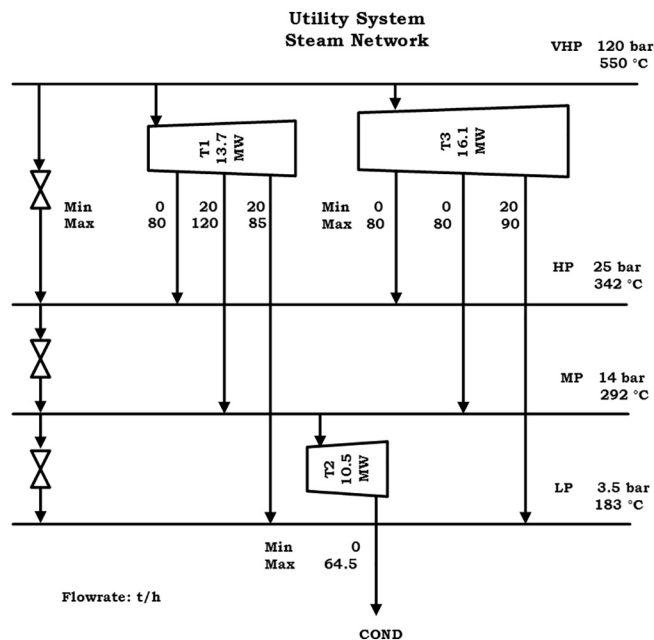


Fig. 1. Utility system steam network [23].

pressure level has a 2 kg/s steam surplus.

Integration and multi-objective optimization of MED-TVC unit with steam network of utility system is the main novelty of this paper. Firstly, MED-TVC unit design is evaluated for each steam level. The thermodynamic and economic results of these integrations have been compared with each other and optimum steam level for integration is reported thermodynamically and economically. Secondly, two-objective (thermodynamic and economic) optimization of a multi-effect desalination plant considering minimum condenser temperature difference, ejector compression ratio, pump isentropic efficiency and number of effects is performed whereas each one of these parameters has simultaneous impact on production rate of desalinated water and capital cost of system.

Table 1 shows initial designs parameters of MED-TVC unit. For each one of the steam levels, the integration of MED-TVC unit is examined.

## 3. Thermodynamic models

### 3.1. MED-TVC thermodynamic model

MED-TVC thermodynamic modeling has been explained in this section. Fig. 2 demonstrates an MED-TVC unit schematic. To accomplish thermodynamic modeling, equations of mass and energy balance have been summarized as follows. Below presumption has been chosen for modeling of this unit [24]:

- ✓ MED-TVC operates in a stable condition and every single one of the flows of the unit are steady state.
- ✓ Effects (evaporators) 2 to N heat transfer areas are the same.
- ✓ Produced freshwater has no salt in it.
- ✓ The desalination unit brine salinity is supposed to be < 70,000 ppm.
- ✓ Thermal loss of desalination unit to the environment is assumed to be zero.
- ✓ To reach optimum unit operating condition, the temperature difference of each one of the effects is the same. Therefore all effects temperature can be determined by below equations [24]:

$$\Delta T = \frac{T_1 - T_n}{N - 1} \quad (1)$$

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