Desalination 324 (2013) 111–117

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

Optimum design of cogeneration for power and desalination to satisfy the demand of water and power☆

Wu Lianying *, Hu Yangdong, Gao Congjie

Key Laboratory of Marine Chemistry Theory and Technology, Ministry of Education, Ocean University of China, China
College of Chemistry and Chemical Engineering, Ocean University of China, Qingdao 266100, Shandong, China

HIGHLIGHTS

- A detailed mathematical model of the cogeneration for water and power is provided and described as a MINLP problem.
- The new mixed-coded genetic algorithm is put forward and used to solving the provided model.
- The optimization is performed from economic points of view to minimize the total annual cost (TAC).
- The optimal configuration and operation condition are obtained to satisfy electricity and fresh water demand simultaneously.

ARTICLE INFO

Article history:
Received 22 April 2013
Received in revised form 4 June 2013
Accepted 5 June 2013
Available online 6 July 2013

Keywords:
Cogeneration for power and desalination
Desalination
Genetic algorithm
Optimum design

ABSTRACT

Cogeneration for power and desalination could not only improve the economic benefit of the power plant, but also afford the high quality water to solve the freshwater shortage. Considering the demand of power and water, a detailed mathematical model of the cogeneration system targeting the minimum total annual cost (TAC), which includes the power plant, multistage flash (MSF) and reverse osmosis (RO), is proposed and described as a mixed integer nonlinear programming (MINLP) problem. The modified genetic algorithm (MGA) with mixed coding is put forward to solve the model developed by us. A case study, which is supposed to supply 250 MW of power and 12,000 m^3/h of water for Huangdao District of Qingdao City, is analyzed in order to illustrate the model capabilities. The results show that the operation pattern of the cogeneration system could be varied in terms of the water demand. When the water demand is lower than 8000 m^3/h, the combination of power plant associated with MSF is adopted and the condensing-extraction steam turbine is selected. When the water demand of water is higher than 8000 m^3/h, the tri-combination of power plant, MSF and RO is the optimal choice, in which back pressure steam turbine is selected.

1. Introduction

Cogeneration is defined as the combined production of two or more useful forms of energy from the same primary energy, thus allowing financial return and less impact with respect to the atmospheric emissions. The thermal power plants not only produce the electric energy, but also supply large amount low pressure steam. At the same time, the thermal power plants require a mass of freshwater to generate the high pressure and high temperature steam. The MSF and the RO are respectively driven by thermal energy and electricity to produce freshwater. So the integrating thermal and membrane desalination process with power generation in the same site are currently considered as a viable alternative. The advantages of the triple hybrid power–MSF–RO over the dual power–MSF and single purpose MSF or RO plants were reported [1–3].

Many researchers have investigated in the cogeneration systems. A state-of-the-art review for simple and fully integrated hybrid desalination systems is presented in [4]. An overview of research endeavors carried out by hybrid desalination systems is also presented. A small-scale cogeneration system based on reciprocating engine is coupled in [5]. An exergoeconomic method is proposed in [6] for a combined gas/steam cycle associated with a MSF-RO desalination system. A thermodynamic model for integrated multi-effect evaporation thermal vapor compression (METVC) and humidified gas turbine cycle is presented in [7–9]. Nevertheless, there is no economic analysis and optimization approach in their researches. The performance of a cogeneration plant (combined power plant and desalination) is analyzed by R. Chacartegui [10] with a stationary lumped volume model and the design and optimization

* Corresponding author. Tel.: +86 53266781875.
E-mail address: wulianying@ouc.edu.cn (L. Wu).

0011-9164/$ – see front matter © 2013 The Authors. Published by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.desal.2013.06.006

guidelines are presented. A dual purpose plant for supplying given amount of power and fresh water is modeled and optimized from thermodynamic and economic point of view [11]. The thermodynamic and economic aspect of METVC is studied without performing a complete economical analysis [12].

Some optimization models of combined desalination and cogeneration systems associated to the superstructure concept are presented in the literature [13–19]. An evolution of the modeling processes can be observed in the technical literature in which mixed integer non-linear programming technique is proposed for associating desalination systems and combined gas/steam cycles and culminates by presenting a disjunctive programming model for optimizing such systems.

Despite that many contributions dealing with the design of dual purpose desalination plants have been published, only few of them focus on the simultaneous optimization of the configuration and operating conditions.

Different arrangements are possible in order to satisfy electricity and freshwater demands and the selection of the optimal system is a difficult task because it depends strongly on many factors such as the power to water ratio, cost of fuel, capital cost and local requirements. Alternative configuration must be considered in order to select the most suitable cogeneration desalting plants. Therefore, the formulation of models for the synthesis and analysis of different design alternatives are very important and useful.

In this paper, the superstructure model of a triple hybrid power–MSF–RO system is developed and described as a MINLP problem, which contains all the potential interaction of material streams and energy streams involved in the combined systems. The optimization is performed based on economic points of view and a heuristic optimization algorithm, namely, modified genetic algorithm is applied. Afterward, the optimal configuration and operation condition is obtained to satisfy electricity and fresh water demand simultaneously.

2. The schematic of the cogeneration system

Fig. 1 illustrates the schematic of the combined power–desalination system for simultaneous generation of the electric power and fresh water. The power generation cycle includes boiler, steam turbine that produces the electric energy and the thermal energy. The desalination plant includes the MSF and RO. All parts of the cogeneration system were modeled and simulated to evaluate performance of the combined system.

The fuel is combusted in the boiler to produce the superheated steam. The steam is sent to the steam turbine to generate the electric energy, which is used for MSF, RO and the grid. The whole or part steam extracted from turbine is feed to the brine heater of MSF and condensed to recycle the boiler. The seawater is sent to the MSF and heated as they flow through the pre-heater tubes of the heat rejection section. Subsequently, it is divided into two parts. One part is used as the makeup water to the heat recovery section and the other part is sent to RO as the feed water and return to the sea. The fresh water produced by MSF and RO are blended as the total water production. The blow-down brine of MSF and RO is feed to the common processing system.

3. Mathematical model

To simplify the cogeneration system, this model is based on the following assumptions:

(1) Boiler, steam turbine and the MSF unit are adiabatic. The heat losses are neglected.
(2) The isentropic efficiency of the steam turbine is calculated. The working mode of steam turbine could be selected back pressure or extracted steam based on the demand of desalination.
(3) The cogeneration system for power and desalination, including steam turbine, MSF and RO, works in steady condition.
(4) Physical properties of all streams, such as enthalpy, specific heat capacity and so on, are calculated in mean inlet and outlet temperatures.
(5) Water is assumed as working fluid on the boiler and steam turbine.
(6) The distillate product of MSF is assumed to be salt free.
(7) The distillate of the MSF plant section can be blended with the RO permeate to obtain suitable water quality. So the single stage RO process can be used.

The plant consists of two desalination sections (MSF and RO). The energy demand is supplied by power plant where electric and thermal energy are co-produced. The detailed equations of the model are as the follows.

3.1. Co-generation plant

The co-generation plant consists of a boiler, a steam turbine, and an alternator. The superheated steam produced by boiler is sent to the steam turbine, which is connected with an alternator in order to produce electric energy. The outlet steam or extracted steam from steam turbine is feed to the brine heater of MSF. The electric energy produced is used for MSF, RO and grid.

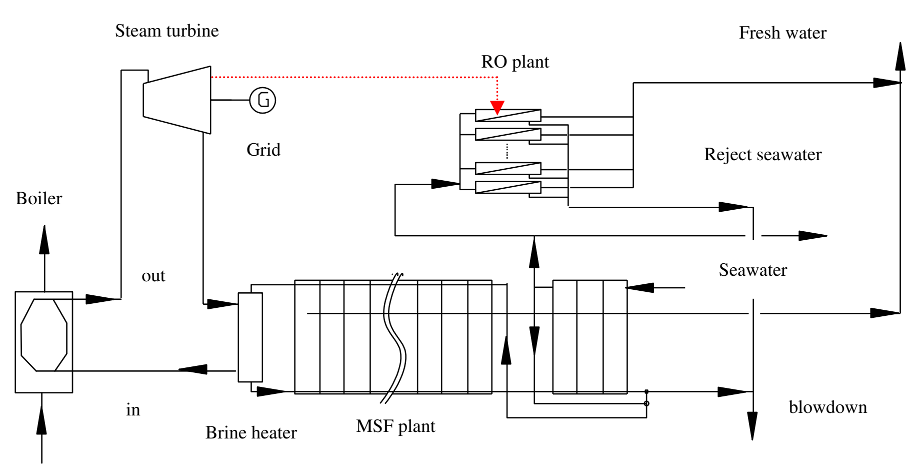

Fig. 1. Schematic of cogeneration of power and desalination.