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# Energy, exergy and economic analyses of a novel system to recover waste heat and water in steam power plants

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ABSTRACT

Power plants are one of the most energy consuming industries in the world. Therefore improving their performance could save a huge amount of energy and water. In this paper, a novel system is proposed to recover the wasted heat and water in a steam power plant and then exergy and economic analyses are applied to the system to study its feasibility. The results show that by using this recovery system, total output power of the system increases by 1.2%. The new system has the capability of producing 82.5 kg/s fresh water from blowdown streams. It also converts the brine stream of desalination system into hydrogen and hypochlorite. The economic analysis shows that the payback time of the system is 0.68 year which indicates that the system is very beneficial.



## 1. Introduction

Water shortage is one of the most important problems that the human beings are faced with. Based on data published by world health organization, over 1 billion people do not have access to clean potable water. The first solution that comes to mind is using desalination processes, namely reverse osmosis (RO), multi effect desalination or multi stage flash. The biggest problem associated to this idea is that these kinds of desalinations consume a huge amount of energy and they are very expensive. To resolve the energy consumption problem of desalination systems, many have suggested to use renewable energy sources [1,2]. But since renewable energy sources are still more expensive than fossil fuels, their utilization in the system will increase capital cost of the plant. As a result, preserving existing resources is of paramount importance. It is also considerably cheaper than construction of new facilities.

A huge amount of water is used in industry sector throughout the world, where a big portion of inlet water is wasted either in the process or released into the ambient as a waste stream. Many researchers tried to minimize the waste water and reach to the zero liquid discharge condition. Wang et al. [3] tried to improve the conventional vanadium extraction process to minimize the waste water by using a combination of electrodialysis and cooling crystallization. They studied the effect of membrane types and operating parameters. Heins and Schooley [4] carried out an investigation about integrating zero liquid discharge processes into SAGD heavy oil recovery systems. Farahbod et al. [5] analyzed a solar desalination pond which is fed by waste brine and produces concentrated liquor and distilled water.

Power plants are one of the most water consuming industries and they waste a huge amount of water in their process. Ifaei et al. [6,7] proposed two novel configurations to reduce water loss in steam power plant with natural draft wet cooling towers. They integrated absorption heat pump and vapor compression refrigeration with the base case Rankine cycle and performed exergy, thermoeconomic and environmental analyses to compare the performance of the proposed system with the base case condition. DePaepe and Dick [8]tried to recover injected water in the combustion chamber. They used different types of condensers to do this and compared them in terms of energy and economic. Wang et al. [9] used Nano porous ceramic membrane capillary condensation separation mechanism to recover water vapor and its latent heat from flue gas in a coal power plant. Using the aforementioned system, not only is water recovered, but also energy efficiency of the plant increases. Vandani et al. [10] proposed a new system for waste heat recovery of boiler blowdown in steam power plants and analyzed the system in terms of energy and exergy. Also by using evolutionary algorithms, they optimized the plants perfor-

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mance. Seigworth et al. [11] coupled a membrane process with evaporation desalination process to achieve to a zero liquid discharge system with minimum capital cost in a power plant in Virginia. By using the aforementioned system, total cost of the system reduced by 680$/day.

Membrane processes, especially RO, are widely used for different desalination purposes. Shenvi et al. [12] reviewed different aspects of reverse osmosis desalination plants. Čuda et al. [13] considered the effect of source water quality, pre-treatment techniques and product quality on RO and presented some explanation about these parameters. They also compared RO desalination and ion exchange system for using in a steam power plant to provide required feedwater. Zhang et al. [14] used ultrafiltration membrane as the pretreatment of a RO system which is fed by cooling tower blowdown of a steam power plant in China. They used two different modules, including inside-out and outside-in styles, and compared permeate qualities, permeability and membrane fouling of these two by changing fluxes. Löwenberg et al. [15] compared powdered activated carbon (PAC) adsorption, coagulation with ferric chloride and ultrafiltration (UF) as three different ways of RO desalination pretreatment of cooling tower blowdown. The main focus of their study was to compare the ability of these technologies in removing dissolved organic carbon from the blowdown.

Despite their worldwide use, RO plants are suffering from two important problems, namely high energy consumption and environmental problems associated to releasing brine water into the ambient. To solve the first problem, different configurations are proposed to reduce the amount of consumed energy. Qureshi and Zubair [16] performed energy and exergy analyses on seven different configurations of energy recovery for RO system which uses brackish water as the feed water and studied the effect of salinity, turbine and pump efficiency and mass ratio. Blanco-Marigorta et al. [17] carried out exergoenvironmental analysis on three different energy recovery methods of RO system, including dual work exchange energy recovery, Pelton turbine and pressure exchanger energy recovery. Eshoul et al. [18] performed exergy analysis on a 2 pass RO unit and compared performance of the system with energy recovery turbine and pressure exchanger with the base case condition. The results indicated that using these two methods, total power consumption of the system reduces by about 30% and 50%, respectively. Also different renewable energies are coupled to RO plants to provide their input energy. Novosel et al. [19] coupled wind and photovoltaic energy to RO system and analyzed performance of the system with different penetration of renewable energy. Gökçek et al. [20] used small scale wind turbines to provide energy for RO desalination plant and analyzed the system in terms of energy and economic.

To solve environmental problems of RO plants, zero liquid discharge concept has been defined. In this concept, a bottom cycle is used to somehow eliminate the pollutants in the brine water and reuse it again. For example, Almasri et al. [21] used a two stage process to eliminate sulfate from Nano-filtration system brine. Tufa et al. [22] presented a novel system to recover water and energy from RO brine by using direct contact membrane distillation and reverse electrodialysis. The proposed system could improve performance of the system and minimize the liquid discharge of the process simultaneously. Oren et al. [23] coupled a reverse osmosis and an electrodialysis system to achieve to a near zero liquid discharge system. They increased the recovery of the system to higher than 98%. Johannsen et al. [24] discussed usage of high pressure RO and their benefits for moving toward zero liquid discharge in different processes.

There are two main wastewater streams in a steam power plant, namely cooling tower blowdown and boiler blowdown waste streams. Mass flow rate of the latter is considerably lower than the first one, but its energy content is high. In this paper, a novel system is proposed to recover waste heat and water of a steam power plant located in Iran. Iran is located in the Middle East and therefore is suffering from water shortage problems like any other countries in the region. Therefore Iran is investigating on any new ideas which help him to preserve its water sources. In this respect, both cooling tower blowdown and boiler blowdown streams are considered in this paper. The object is to recover as much water as possible. Also it is tried to improve performance of the system by recovering waste heat streams. To do so, energy and exergy analyses are performed on the system. Finally, economic analysis is also carried out to study economic feasibility of the proposed system.

## 2. System description

Fig. 1 shows schematic diagram of the Zarand power plant before implementation of the waste recovery system. It is located in southeast of Iran and has a capacity of nearly 30 MW. As can be seen, it has four feedwater heaters, three of them are close and one of them is open. Two wastewater streams are shown in the figure. The first one is cooling tower blowdown. Its pressure and temperature are relatively low and close to the ambient condition, therefore its energy content is low. The second one is boiler blowdown which is in boiler's pressure and temperature. Therefore it has a high quality energy which is going to be wasted. Both of these streams have a similar salinity. To recover energy and water of these streams, a novel system is proposed which is shown in Fig. 2. To recover the wastewater, a RO plant is used in the system. Both boiler blowdown and cooling tower blowdown are combined together and then passes through the RO to produce permeate water. Since, boiler blowdown has high temperature which is beyond the operating range of RO system; two heat exchangers are used prior to the RO system to reduce temperature of this stream. One of the heat exchangers preheats the feedwater of the Rankine cycle and the other one is used to provide hot water for HVAC utilization. Pressure of this stream is also too high. Normally RO systems need a high inlet pressure of saline water. But, since the salinity of blowdown streams is not high, low pressure inlet water is enough. Therefore, a Pelton turbine is used to reduce pressure of inlet stream and produce power simultaneously. On the other hand, pressure of cooling tower blowdown is approximately equal to the ambient pressure. Therefore a pump is used to increase its pressure to the outlet pressure of Pelton turbine. Then these two streams mix together and go through the RO system. The brine stream still has relatively high pressure. To recover the energy of this stream, another turbine is used to produce more power. Outlet stream of the recovery turbine has no energy, but its salinity is high and releasing it to the ambient would be very harmful. To reduce environmental problem and move toward near zero liquid discharge, an alkaline electrolyzer is used to produce hydrogen and hypochlorite. To do so, the electrolyzer needs power which is provided by the two Pelton turbines implemented in the system.

To increase efficiency and fully utilizing waste streams, low energy content of the flue gas is used to preheat the fuel. Natural gas is used as fuel in the power plant. Pressure of the gas network in Iran is high. Therefore a reduction valve is used to lower the pressure. To make the plant more efficient, this valve is replaced by a turbo expander to produce more power. Prior to the expander, a heat exchanger is placed to preheat the fuel and prevent the crystallization. Required energy to preheat the fuel is currently provided by burning some fuel. To decrease the fuel consumption, energy of flue gas is used in the heat exchanger, as shown in Fig. 2.