# Thermo-economic evaluation of a power and freshwater production system including a liquid metal magnetohydrodynamic unit driven by a concentrated solar tower and biogas

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**ABSTRACT**

**The use of liquid metal magnetic hydrodynamic energy units, despite reducing maintenance costs and improving reliability, requires a high-temperature source, which must be supplied by fossil fuels. The present study aims to cover this shortage by proposing a new design for liquid metal magnetic hydrodynamic power and desalination cogeneration plant by applying concentrating solar power. The results show that 73.2 kW and 21.06 m3/day power and freshwater can be produced by the proposed cogeneration plant, respectively. The energy utilization factor and total exergy efficiency are 97.45 and 26.34%. The results also indicate that the receiver accounts for the highest exergy destruction, followed by the heliostat with 270.4 kW and 240.9 kW, respectively. Increasing the efficiency of the humidifier/dehumidifier or reducing the mass flow rate of the second magnetic hydrodynamic loop improves the energetic and exergetic performances of the system. Besides, the receiver and solar tower have the highest cost of investment and maintenance, and the total unit cost of the system is 103.4 $/GJ.**

**KEYWORDS**

***Liquid metal magneto-hydrodynamic*(LMMHD), *Cogeneration*, *Concentrating solar power*(CSP), *Humidification-dehumidification(HDH)*, *Exergo-economic*.**

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## 1. Introduction

Due to the promising potential of CSP technologies in multi-generation processes, it is much more efficient to widen the scope of CSP application. In the present study, the liquid metal magnetic hydrodynamic (LMMHD) system is considered as the main cycle, and the humidification-dehumidification (HDH) system is considered as the sub-cycle of the proposed design. High-temperature power generation systems such as the supercritical carbon dioxide cycle, the closed Brighton cycle, and the organic Rankine cycle (ORC) have been combined with CSP technologies to provide cost-effective electrical power via solar radiation in recent years. Mohammadi et al. [1] presented two integrated energy systems derived by CSP and found out that employing a partial cooling cycle instead of a base recompression cycle improves the thermal efficiency by 10%. Among the renewable sources, utilizing solar energy in energy systems is more practical and efficient. On the other hand, most districts have the problem of supplying freshwater due to intense solar radiation [2]. Palenzuela et al. [3] developed a method for simulation of desalination and energy systems based on CSP and tested their proposed mechanism in real plants in Abu Dhabi and Almeria. They concluded that the CSP-RO configuration is optimized only when its specific power consumption (SPC) is less than 5.4-5.6 kWh/m$^3$. Previous economic models indicate that the cogeneration of LMMHD units exploited from fossil fuels with a capacity of 1-20 MWe is more competitive than conventional turbine power plants [4]. Moreover, the simple structure of LMMHD power plants due to the lack of complex and dynamic components makes the system more reliable and causes low maintenance costs [4]. The most comprehensive investigation in this field was conducted by Satyamorti et al. [4]. They utilized the riser in the MHD generator to present an accurate simulation of the solar LMMHD power plant. However, they did not elaborate on the second law of thermodynamics and equipment costs in their study. Also, no detailed information was provided about the influence of design parameters on exergy performance criteria in their study. The present research aims to address this scientific gap by studying the first and second laws of thermodynamics and thermo-economic analysis on the LMMHD system for simultaneous production of freshwater and electrical power. The use of heat dissipation in the LMMHD system for desalination is another innovation in the present study. A low-temperature desalination system is used to recover the incoming heat through the condenser. Another justification for choosing an HDH unit is that the investment cost of the HDH unit is much lower than that of the MED system.

## 2. System discretion

The development of a novel desalination and energy cogeneration system based on solar energy as the main heat source and natural gas as an auxiliary heat source is shown in Fig. 1. The proposed cogeneration cycle encompasses three main subsystems: concentrating solar power (CSP) system, the humidification-dehumidification (HDH) system, liquid metal magnetic hydrodynamics (LMMHD) energy unit. The CSP consists of two central receivers and a heliostat field. In the LMMHD system, lead alloy and lead-bismuth are used in the first and second MHD loops, while water flows in other parts of the LMMHD cycle. The main components of the LMMHD system are as follows. A steam generator, an auxiliary steam generator, a regenerator, a pump, a condenser, two risers, two separators, two mixers, two downcomer pipes, two nozzles, two MHD generators, two diffusers.

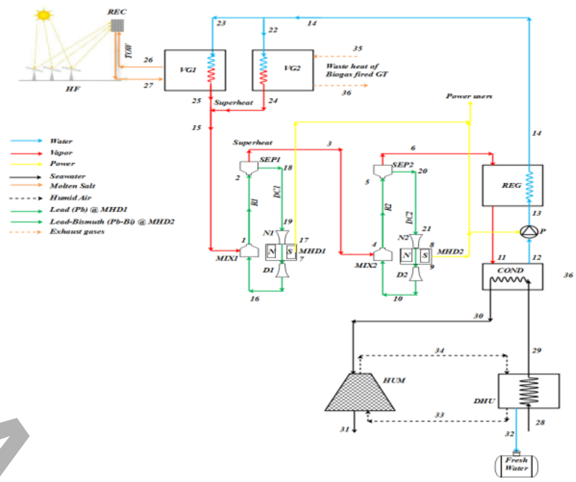


**Figure 1. New designed desalination/power system based on MHD energy production unit working by solar tower.**

## 3. Methodology

The governing equations of the proposed system is done by employing the EES software including properties and solving calculations. Conservation equations for the studied system is written as below [5]:

$$\sum \dot{m}_{in} - \sum \dot{m}_{out} = 0 \tag{1}$$

$$\dot{Q}_{C.V.} + \sum \dot{m}_{in} h_{in} = \dot{W}_{C.V.} + \sum \dot{m}_o h_o \tag{2}$$

The exergy balances are expressed as [5, 6]:

$$\dot{E}x_{D,i} = \sum_{i=1}^{n} \dot{E}x_{in,i} - \sum_{i=1}^{n} \dot{E}x_{out,i} \tag{3}$$

$$\dot{E}x_{ph,i} = \dot{m}((h-h_0) - T_0(s-s_0))_i \tag{4}$$

$$\dot{E}x_{ch,i} = \dot{n}_i\left(\sum_i y_i \overline{ex}_i^{ch,0} + \overline{R}T_0 \sum_i y_i \ln y_i\right) \quad (5)$$

Some assumptions such as steady state are considered in the operation of the system. The following equations are also used for performance evaluation.
Energy utilization factor (EUF):

$$EUF_{cog} = \frac{\dot{W}_{net} + \dot{m}_{32} h_{fg@T_{32}}}{\dot{Q}_{VG1} + \dot{Q}_{VG2}} \quad (6)$$

Exergy efficiency of the cogeneration system:

$$\eta_{Ex,tot} = \frac{\dot{W}_{net} + \dot{E}x_{32} + \dot{E}x_{31}}{\dot{E}x_{F,VG1} + \dot{E}x_{35} - \dot{E}x_{36}} \quad (7)$$

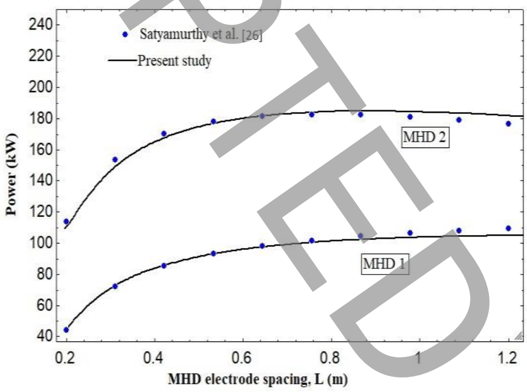


**Figure 2. Confirmation of liquid metal MHD energy generator based on reported results by ref. [4].**

## 4. Results and discussion

A comprehensive comparison is carried out between the results of present study and those of studies by Satiamorsi et al. [4] for validation. Fig. 2 demonstrates the simulation results for an LMMHD system. The effects of the MHD electrode space on the energy rate for each MHD loop are compared. As Fig. 2 illustrates, a good compatibility is observed between the results.

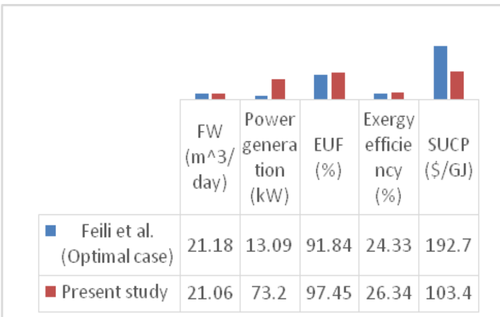


**Figure 3. Comparison of the results of the present work with those of the study by Fili et al. [7].**

Table 1 reveals the results of the energy and exergy analysis of components and system. The receiver cause the highest exergy destruction with 256.9 kW, which is about 29.41% of the total exergy destruction. Heliostat with an exergy destruction rate of 228.2 kW is ranked second, which equals 26.12% of the total dimensionless exergy destruction of the system. In contrast, the lowest exergy destruction value is for the pump with less than 0.001 kW. The achieved results are compared with a similar work and displayed in Fig. 3. With producing almost the same amount of freshwater, the performance of the present design is better than the optimal design proposed by Fili et al. [7].

**Table 1. Exergy destruction of components in of the system**

| Component | $\dot{E}x_D^k$ (kW) | $\dot{E}x_L^k$ (kW) | $\eta_{ex}^k$ | $\dot{Z}^k$ ($/h) |
|---|---|---|---|---|
| Receiver | 270.4 | 236.5 | 29.86 | 17.81 |
| Tower | - | 0 | - | 7.679 |
| Heliostat | 240.9 | 0 | 75 | 2.047 |
| Pump | 0.0005556 | 0 | 99.93 | 1.024 |
| Regenerator | 1.97 | 0 | 88.59 | 0.007617 |
| condenser | 80.6 | 0 | 45.71 | 0.01893 |
| Humidifier | 23.25 | 21.38 | 53.66 | 0.01975 |
| Dehumidifier | 21.59 | 0 | 58.23 | 0.01039 |
| MHD 1 | 44.64 | 0 | 39.05 | 0.01673 |
| MHD 2 | 17.24 | 0 | 72.48 | 0.02656 |
| VG 1 | 53.57 | 0 | 75.17 | 0.3365 |
| VG 2 | 51.03 | 289.5 | 26.9 | 0.3505 |

## 5. Conclusion

In this study, a new cogeneration system for freshwater and power generation based on the liquid metal magnetic hydrodynamic (LMMHD) power plant and humidification-dehumidification (HDH) unit is proposed. Concentrating solar power (CSP) is designed for the proposed integrated system. The main results are articulated as follows:

- The proposed cogeneration system produces 73.2 kW power and 21.06 m3/day freshwater.
- The receiver accounts for the highest exergy destruction among all the components, with 270.4 kW, which is equal to 33.6% of the total exergy destruction.
- The lowest amount of exergy destruction belongs to the pump with less than 0.001 kW.
- The receiver and solar tower have the highest investment, maintenance, and unit cost of 103.4 $/GJ.

## 6. References


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