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Technoeconomic Analysis of Multi-Effect Distillation System in Gujarat, India

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ABSTRACT

Water desalination using geothermal fluid with low-enthalpy is a long-term solution to the planet's water deficit that can be coupled with thermal-based desalination systems. This research offers an extensive approach for techno economically analyzing a geothermal multi-effect distillation system to be set up in Gujarat, India. To analyze and optimize processes such as an industrial chemical reactor, numerical modeling and simulation are essential. In order to better comprehend the influence of design considerations on evaluation outcomes, we emphasize an extensive variety of parameters. Heating steam temperature, feed water salinity, boiling temperature, and geothermal resource quality are some of the variables. The accuracy of our fundamental plant's outcomes was evaluated by altering their values. According to the geographical location, using a low boiling temperature and an elevated motive pressure of steam results in a higher Performance Ratio. A thorough economic analysis of the layout of this geothermal multi-effect distillation system as discussed in the paper would assist us understand and appreciate the plant's practicability and provide a broader perspective on the subject.

1. INTRODUCTION

One of the basic necessities for all life on Earth is water. However, due to various contaminants and environmental changes, the quantity and quality of drinkable water have decreased within the last few decades. Seawater, ice fragments in the Polar Regions, and groundwater are the three types of accessible water that exist. Saline water makes up about 97% of the earth's water and freshwater accounts up the remaining 3%. A third of freshwater that is available is used for horticulture. Freshwater accessible to human scopes is less than 1%. We must desalinate brackish or saltwater in order to meet the demand for freshwater. (Prajapati et. al. 2021) Desalination is a tried-and-true technique for drawing clean water from the ocean, but it has an adverse effect on the environment and calls for sustainable energy sources. (Dashputre et. al. 2023) Desalination techniques need a lot of energy, which renewable energy sources can supply.(Prajapati et. al. 2021) Concurrent electricity generation, cost effectiveness, and environmental friendliness characterise geothermal desalination. It doesn't release any greenhouse gasses because it uses clean, renewable energy. The location of the geothermal resource, the feed and cooling water supplies, the water market, and the disposal site for concentrates are some of the elements that affect the plant's viability. Geothermal energy can power plants based on reverse osmosis or directly produce heat for desalination. (Dashputre et. al. 2023)

Techno-economic analysis (TEA) is widely regarded as a crucial instrument for assessing the financial viability of industrial operations. The rising competitiveness among organizations across many industries has led to an exponential development in the application of TEA recently. Process modelling, capital cost estimation, equipment sizing, operating cost estimation, cash flow analysis and Process design, are among the comprehensive analyses that make up the methodology used in TEA. These analyses must be finished in the order listed. A broad range of economic indicators (such as plant operation, plant design, transport, market behaviour, etc.) are necessary due to the intricacy of the issues at hand. (Chai et. al. 2022) When production is carefully optimized, techno-economic assessment can reduce environmental impact and offer energy and cost-effective incentives. (Reggiani et. al. 2022) The local energy cost differential, plant refit, treatment, and site-specific expenses related to raw materials such as transportation and tariffs have all contributed to increased generated water delivery prices. Because it is so volatile, it is very difficult to estimate the final cost of water precisely. Therefore, having an extremely transparent and reliable cost estimation approach will be very helpful in choosing the best desalination technology for each site accounting for all significant and influencing cost-related elements. (Shokri & Fard 2023) A techno-economic assessment (TEA) is crucial for profit-oriented stakeholders to evaluate investment returns. Technical parameters alone are insufficient; they must translate into economic indicators. Yet, no universally accepted standard exists for this assessment due to varying technological data availability. (Buchner et. al. 2018)

2. TECHNO ECONOMIC METHODS FOR DESALINATION

2.1 Introduction

Reverse osmosis (RO), Multi-Stage Flash Distillation (MSF), and Multi-Effect Distillation (MED) are examples of techno-economic desalination techniques that employ a variety of procedures to extract salt from water. Forward Osmosis (FO) pulls water across a membrane, whereas Electrodialysis (ED) uses an electric field. Solar energy is used in solar desalination, and hybrid systems integrate many technologies for maximum efficiency. Each technique strikes a compromise between many aspects such as cost, energy usage, and water quality; RO is a popular choice because of its effectiveness. The selection process is contingent upon project requirements and local conditions, with a tendency toward the integration of renewable energy sources for sustainability.

2.2 Procedure for TEA

When choosing desalination techniques, decision-makers give consideration to energy consumption, plant capacity, and capital and operating costs. Various factors lead to inconsistent reported cost information. To accurately assess expenses, an open technique or software package is required. The last ten years have seen a decline in desalination costs, particularly in RO technology, as a result of improvements in designs and energy efficiency. Future cost reduction efforts may be impeded by issues such as supply chain constraints, environmental requirements, and growing energy costs. Future research could expand to include desalination plants globally, incorporating additional metrics like CO2 emissions and employment rates for a more comprehensive analysis of desalination sustainability. (Shokri & Fard, 2023) Saleh & Mezher presented a techno-economic analysis where they analysed externality costs for Multi-Effect Distillation (MED) and Multi-Stage Flash (MSF) desalination technologies in the UAE. Externality costs for MED ranged from $0.297/m3 to $0.702/m3, while for MSF, they ranged from $0.548/m3 to $1.04/m3. The study suggests restructuring water tariffs to include these costs, emphasizing the need for policies to promote water efficiency and sustainability. It introduced a flexible methodology for assessing sustainability impacts, converting disparate data into comprehensible indicators. However, limitations include data scarcity and potential overestimation of certain indicators.(Saleh & Mezher, 2021)

3. CASE STUDIES

Zheng & Hatzell proposed that systems for desalination are required to supply freshwater to rising demands. One way to deal with the requirement for energy generated from fossil fuels is to combine solar energy technology with desalination facilities. In the paper, they constructed a techno economic model to evaluate the feasibility of combining thermal desalination systems with solar collectors. There, the model takes into account how certain deferred water manufacturing expenses and payback periods are affected by system lifetime and scale, price per unit and performance characteristics for each subsystem, local market, and environmental aspects of the plant location. Both geographical and technological limitations are removed by this method. The techno economic model makes an effort to forecast a solar multi-stage flash distillation system's financial performance. For an installation producing 1000 m3 per day, the particular discounted cost of producing water is $0.97/m3, provided that the solar collector unit costs $100/m2 and runs at 40% efficiency. Miami, Florida is the most geographically advantageous place for a solar desalination plant in terms of economic feasibility, based on environmental and market considerations in seven coastal regions in the United States. (Zheng & Hatzell, 2020)

In order to increase the energy efficiency of traditional desalination processes, a novel versatile seawater desalination process has been proposed by Nikkhah & Beykal that incorporates a Lithium Bromide (LiBr) absorption chiller, humidification-dehumidification (HDH), multi-effect evaporator, and mechanical vapour recompression (MVR). The LiBr cycle is activated by the MVR system, and the proposed process leverages the LiBr absorption chiller loop to heat the saltwater before steam is generated in the multi-effect evaporators. By integrating HDH, it is also possible to retrieve excess water from the process flow and condense brine effluent for processing that requires no liquid discharge. To compare the different performances of the combined unit and a stand-alone HDH desalination, multiple metrics are evaluated. A study of sensitivity is done to see how altering process factors affects these systems' overall performance, and techno economic analysis is conducted as well to evaluate the economic viability. The findings demonstrate that the suggested process design, with a levelled production of water costing $8.4/m3 and 6 kW of cooling power that may be utilized for air conditioning, produces a gain-output ratio several times higher than a traditional HDH system of equal capacity. (Nikkhah & Beykal, 2023)

Contreras et. al. formulated a viable approach to producing inexpensive, low-carbon hydrogen by the cogeneration of hydrogen with value-added by-products. This paper proposes a techno economic analysis and a system for producing hydrogen from waste brine while also producing sodium hydroxide and chlorine. The system operates at high sun concentrations (50e500x) using a theoretical triple-junction gallium arsenide (3-J GaAs)-based photo-electrochemical (PEC) reactor. A solar-to-chemical (SCE) efficiency of 15% and a levelled cost of hydrogen (LCOH) generation of $15.76/kgH2 are obtained in the basic case of 200x solar concentration. Sodium hydroxide accounts for 64% of the total by-product revenue, which is crucial for covering the operating costs. By-product revenue is estimated at $45.32/kgH2. The sensitivity study demonstrated that PEC production of hydrogen from waste brine would be feasible and have prices as high as $0.78/kgH2 for favourable combinations of the important variables (sodium hydroxide price, waste brine pre-treatment price, and PEC replacement lifetime). (Contreras et. al. 2023)

Siddiqui & Ishaq proposed that in the worldwide energy shift towards more environmentally friendly and renewable sources, geothermal energy can be extremely important. Sustainable sources of energy, base load power production, energy security and independence, uses for heating and cooling, economic advantages, and assistance with the transition for places dependent on fossil fuels are just a few of the many ways it can help. This study investigates the more effective use of geothermal energy for multi-generational applications that also boosts system efficiency, given the relatively low deployment of geothermal energy despite its enormous potential. In this work, a geothermal system of the binary type is built for multi-generation, which includes the production of hot water, power, and seawater desalination. The system uses a flash distillation technology for seawater desalination and an isobutane-entailing organic Rankine cycle (ORC) to generate electricity. The efficacy of the designed concept is illustrated by a thorough thermodynamic study that includes an evaluation of efficiency according to the first and second laws. The system has a 2262 kW power output and an 11.09 kg/s seawater desalination rate. The system's overall energy efficiency is estimated to be 23.5%. Furthermore, a 28.9% energy efficiency is found. Furthermore, it is found that the ORC's energy efficiency is 7.9%, whereas its exergetic efficiency is assessed at 51.1%. Additionally, the energy and exergetic efficiencies of the flash distillation subsystem are 2.7% and 9.3%, respectively. The effects of changing operational parameters and system circumstances on system efficiency are examined through a number of parametric experiments. (Siddiqui & Ishaq 2023)

Table 1: Comprehensive study on desalination systems from a techno-economic perspective

Sr. No.	Desalination Process	Type of distillation	Principle	Method	Advantages	Reference
1	Solar-Geothermal Desalination	Solar distillation	Evaporation	Using solar thermal energy backed up with geothermal energy for distillation of waste water.	Lesser production and maintenance cost.	(Aviles et. al. 2021)
2	Geothermal Desalination	Multi-effect Distillation + Reverse osmosis	Evaporation + Filtering	Semi-permeable membrane used to segregate unwanted matter and ions.	Geothermal RO is more cost effective than geothermal MED. Functional at low enthalpy regions.	(Loutatidou & Arafat 2015)
3	Solar- Mechanical membrane desalination	PV- BWRO desalination	Evaporation + Filtering	Solar panels used for energy generation for brackish water reverse osmosis desalination.	72% (Approx.) energy cost reduction. 56% (Approx.) total cost reduction.	(Bdour et. al. 2022)
4	Mechanical Membrane Technology	Reverse Osmosis	Filtering	Wind-driven mechanical energy harnessed by geothermal energy to facilitate reverse osmosis.	Functional at low enthalpy regions	(Loutatidou 2015)
5	Geothermal Desalination	Multi-effect Distillation	Evaporation	Hot Sedimentary aquifers to enhance performance of distillation columns by providing heat.	Energy cost reduction along with maintenance cost.	(Rahimi et. al. 2016)

4. PROPOSED METHODOLOGY

For techno-economic analysis, we must select one methodology we wish to proceed with from the options mentioned in the flowsheet given below available to us in Figure 1.

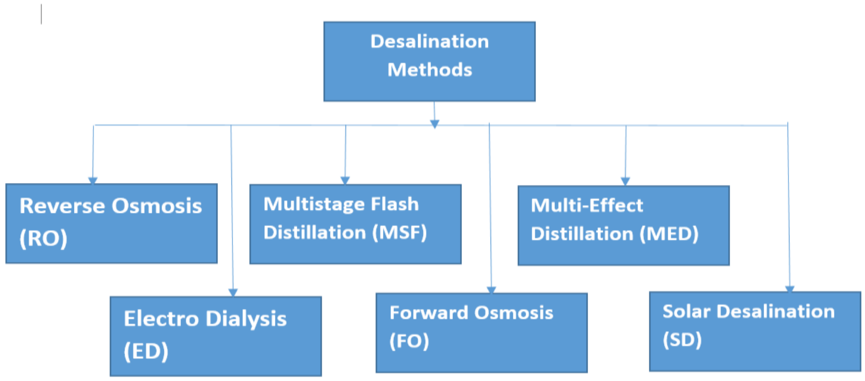

Figure 1: Segregation of methods of desalination

We will be proceeding with geothermal multi effect distillation. Compared to other desalination techniques, geothermal multi-effect distillation (MED) has advantages. It uses reliable, renewable geothermal energy, which lowers running expenses and has a smaller environmental effect. Since MED is so effective at converting heat into freshwater, it can be used in remote locations without access to traditional energy sources. Geothermal MED offers a dependable water supply with low greenhouse gas emissions and long-term sustainability. However, site-specific elements like water demand and geological characteristics need to be taken into account. A thorough techno-economic analysis must be performed in order to evaluate the viability of geothermal MED in comparison to alternative desalination methods. (Prajapati et. al. 2022)

After selecting the methodology, we must look into the technical and economic factors like operating cost, capital cost, energy consumption and plant capacity. The initial investment covers the cost of building the geothermal well development, equipment installation, and MED plant construction. The plant is to be set up in Gujarat, India where the geothermal water is on the surface so the geothermal wells need not be deep. This will reduce the labor & construction cost.

In the heat exchangers, adding Sulfuric acid to the geothermal brine would form a solution which would in return help in reducing the formation of silica and sulfate deposits which results in scaling and fouling. The material of construction should primarily be stainless steel. Multi-effect evaporator with parallel stream must be used as it provides operational flexibility with varied feed streams. Another reason to use parallel stream feed is that the concentration of salt in the water is variable and tends to fluctuate within the range and parallel stream provides flexibility (Figure 2).

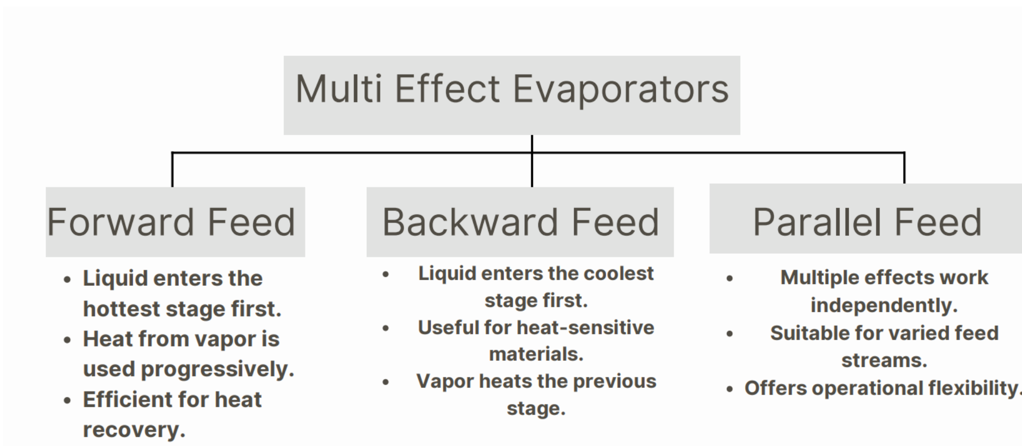

Figure 1: Segregation of multi-effect evaporators

The condenser is used at the end of the last-effect evaporator. Here, the waste residue that is brine, should not be thrown away and instead, can be used in-house or can be sent over to other production organizations as for cooling tower or as a boiler effluent. This way, waste production can be minimized and additional income can be generated. The computer-aided control unit, power generation equipment and auxiliary equipment must be set up for smooth and safe operation of the system.

5. CONCLUSION

Geothermal multi-effect distillation system is a sustainable and clean method for desalination to provide unadulterated water suitable for domestic and industrial usage. The proposed methodology contains various cost optimization and waste optimization techniques for the multi-effect distillation plant set-up in the geographical location of Gujarat, India. However, detailed cost analysis can be provided after a pilot plant is set up in the same geographical location.

6. REFERENCES

Yanjie Zhenga, Kelsey B. Hatzella, (2020) Technoeconomic analysis of solar thermal desalination, Desalination, https://doi.org/10.1016/j.desal.2019.114168

Hasan Nikkhah , Burcu Beykal (2023) Process design and technoeconomic analysis for zero liquid discharge desalination via LiBr absorption chiller integrated HDH-MEE-MVR system
, Desalination, https://doi.org/10.1016/j.desal.2023.116643

Marisol Contreras, Mark Mba-Wright, Christina Wulf, Charles O. Stanier, Syed Mubeen Technoeconomic analysis of photoelectrochemical hydrogen production from desalination waste brine using concentrated solar flux, International Journal of Hydrogen Energy, (2023) https://doi.org/10.1016/j.ijhydene.2023.08.222

O. Siddiqui, H. Ishaq (2023) A geothermal energy driven integrated energy system for fresh water and power production, International Journal of Hydrogen Energy, https://doi.org/10.1016/j.ijhydene.2023.10.126

Abhir Dashputre, Aluru Kaushik, Aparajita Pal, Dhruv Jariwala, Kriti Yadav, Manan Shah (2023) Geothermal energy integrated multi-effect evaporator (MEE) and multi-effect distillation (MED)-based desalination systems: an ecofriendly and sustainable solutions, Environmental Science and Pollution Research, https://doi.org/10.1007/s11356-023-26858-w

Mitul Prajapati, Manan Shah, Bhavna Soni (2021) A review of geothermal integrated desalination: A sustainable solution to overcome potential freshwater shortages
, Journal of cleaner production, https://doi.org/10.1016/j.jclepro.2021.129412

Mitul Prajapati, Manan Shah, Bhavna Soni, Sachin Parikh, Anirbid Sircar, Sweta Balchandani, Shuchen Thakore, Manthan Tala (2021) Geothermal-solar integrated groundwater desalination system: Current status and future perspective, Groundwater for sustainable development, https://doi.org/10.1016/j.gsd.2020.100506

Sylvester Yew Wang Chai, Frederick Jit Fook Phang, Lip Siang Yeo, Lock Hei Ngu, Bing Shen How (2022) Future era of techno-economic analysis: Insights from review, Sustainable Chemical Process design,https://doi.org/10.3389/frsus.2022.924047

Martin C. De Meio Reggiani, Luciana B. Villar, Hernán P. Vigier, Nélida B. Brignole (2022) An evolutionary approach for techno-economic assessment, Computer aided chemical engineering, https://doi.org/10.1016/B978-0-323-95879-0.50235-6

Aref Shokri, Mahdi Sanavi Fard (2023) Techno-economic assessment of water desalination: Future outlooks and challenges, Process safety and environmental protection, https://doi.org/10.1016/j.psep.2022.11.007

Layla Saleh, Toufic Mezher (2021) Techno-economic analysis of sustainability and externality costs of water desalination production, Renewable and sustainable energy reviews https://doi.org/10.1016/j.rser.2021.111465

Georg A. Buchner, Arno W. Zimmermann, Arian E. Hohgrave, and Reinhard Schomacker (2018) Techno-economic Assessment Framework for the Chemical Industry—Based on Technology Readiness Levels https://doi.org/10.1021/acs.iecr.8b01248

Mitul Prajapati, Manan Shah, Bhavna Soni (2022) A comprehensive review of the geothermal integrated multi-effect distillation (MED) desalination and its advancements, Groundwater for sustainable development, https://doi.org/10.1016/j.gsd.2022.100808

Daniel Aviles, Farhad Sabri, Kamel Hooman (2021)Techno-economic analysis of a hybrid solar-geothermal power plant integrated with a desalination system
, International journal of energy research, https://doi.org/10.1002/er.694

Savvina Loutatidou, Hassan A. Arafat (2015) Techno-economic analysis of MED and RO desalination powered by low-enthalpy geothermal energy, Desalination, https://doi.org/10.1016/j.desal.2015.03.010

Bdour, Ahmed N., Noor Al-Sadeq, Muna Gharaibeh, Angeles Mendoza-Sammet, Maria D. Kennedy, and Sergio G. Salinas-Rodriguez. 2022. "Techno-Economic Analysis of Selected PV-BWRO Desalination Plants in the Context of the Water–Energy Nexus for Low–Medium-Income Countries" *Energies* 15, no. 22: 8657. https://doi.org/10.3390/en15228657

Rahimi B.,Chua H.T.,Christ A.,Regenauer-Lieb K. (2016)Techno-economic analysis of geothermal desalination using Hot Sedimentary Aquifers: A pre-feasibility study for Western Australia, Desalination, https://doi.org/10.1016/j.desal.2016.11.009