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A Survey on Experimental Investigations and Simulation on Solar Powered Reverse Osmosis Water Desalination System

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***Abstract* -The current paper is based on a review of experimental studies and simulations of solar-powered reverse osmosis water desalination systems. Reverse osmosis has long been recognised as the most effective technical method for treating contaminated water, brackish water, and saltwater. Reverse osmosis is a process that converts saltwater water into freshwater by passing it through semi-permeable membranes. It is possible to remove salts, germs, viruses, and suspended solids using reverse osmosis because the membrane is a thin film composite composed of nonwoven polyester, polysulfone, and a polyamide barrier layer. Because the driving force for water movement is pressure, the membrane process necessitates the use of energy in order to create water. As a result, reverse osmosis facilities need a reliable power supply source in order to function properly.**

***Index Terms* - Solar Powered, Reverse Osmosis, Water Desalination, Salts, Germs, Viruses.**

INTRODUCTION

According to the World Health Organization, sanitation and hygiene were responsible for 842,000 fatalities in 2019. The bulk of these deaths occurred in poor countries. As a result, access to clean drinking water is considered one of the most pressing worldwide concerns, and this is especially true for developing nations such as India. Reverse osmosis has long been recognized as the most effective technical method for treating contaminated water, brackish water, and saltwater. Reverse osmosis is a process that converts saltwater water into freshwater by passing it through semi-permeable membranes. It is possible to remove salts, germs, viruses, and suspended solids using reverse osmosis because the membrane is a thin film composite composed of nonwoven polyester, polysulfone, and a polyamide barrier layer. Because the driving force for water movement is pressure, the membrane process necessitates the use of energy in order to create water. As a result, reverse osmosis facilities need a reliable power supply source in order to function properly. Solar-powered reverse osmosis plants are an interesting option for plants constructed in distant areas of poor nations where power supplies are intermittent but the area is endowed with high solar radiation intensity, such as the arid tropics. Solar-powered reverse osmosis has been identified as one of the most promising technologies for reducing greenhouse gas emissions as well as for stand-alone reverse osmosis systems in rural and isolated areas. In the previous decade, reverse osmosis has developed into a well-established technology that has been effectively applied in several sites throughout the globe. The amount of energy required to create water, on the other hand, has remained a significant source of worry. Water treatment plants need around 3-4 kWh per cubic meter of feed water to create freshwater from saltwater and brackish water, respectively. The amount of energy required varies based on the total dissolved solids content of the feed water.

LITERATURE SURVEY

In terms of renewable energy, solar energy is one of the most crucial sources since it is almost limitless, clean, and ecologically benign. Currently, solar photovoltaics is the most quickly growing technology (PV). The poor efficiency with which solar energy is converted into electricity, ranging from 5 to 17 percent, is a significant hurdle to its widespread use. Over 80% of the solar light that is captured by the PV cells is turned into waste heat by the cells. There are two methods in which this heat may be generated: First and foremost, the power equivalent to I2R, which is produced as a result of the current (I) passing through the resistance (R) of the solar cell Second, thermal energy is a representation of the fluctuation in the number of photons absorbed as well as the electrical energy created by electron-hole pairs in a certain time interval. It is critical that the temperature of the PV cells in an array be maintained at a stable level. Because of the negative temperature coefficient (about-0.4 percent per degree Celsius increase in temperature) of the solar PV panel, as the temperature of the panel rises, the efficiency of the panel in converting solar energy into electric current diminishes. In recent years, several researchers have looked at the temperature dependency of photovoltaic efficiency and energy conversion in solar PV panels. Overall, solar photovoltaic panels generate more heat energy than they do electrical energy. We have taken selected papers for the study purpose and their details are as follows:

Aburub, A., et all. (2017) [1] presented the performance of water heated, cross-flow humidification dehumidification (HDH) desalination system with brine recirculation designed, constructed, and operated in a controlled environment. They introduced HDH devices that were simple to construct, simple to maintain, and ideal for distant places with little technical expertise. The impact of mass ratio (MR) on GOR, RR, humidifier, and dehumidifier efficacy was studied. The system was tested at 60-75 ºC hot water temperatures and 4-18 L/min hot water flow rates. The developed system can produce 92 liters of distillate water per day, has a GOR of 1.3, and the component efficacy ranges from 92–97 percent for dehumidifier and 53–79 percent for a humidifier.

Ahmad, N., et all. (2015) [2] presented analytical modeling, simulation with experimental verification of photovoltaic system driving reverse osmosis water desalination. In a photovoltaic system, the influence of fixed and tracking PV panels on collected insolation and PV power was studied. The RO division created a full membrane model that predicts feed water pressure and permeates flow rate. The proposed PV and RO models were verified by experimental data singly and together (combined PVRO). Using this verified model, the influence of PV panel slope and azimuth angle on permeate flow rate was explored year-round. The clean water flow rate increments for annual tilt, monthly tilt, single and double axis tracking PV panels are determined. A year-round ideal tilt angle of PV panels due south was close to 0.913 times Dhahran's latitude. Annual permeate gain with annual optimum tilt and monthly optimal tilt of PV panel installation vs to flat panel installation was 10% and 19%. Using single and dual-axis tracking systems, the PV orientation (tilt angle and azimuth angle) may be adjusted. The annual permeate gain of single and double-axis continuous tracking PV panels is 43% and 62%.

Ahmed, F. E., et all. (2019) [3] discussed the most recent developments in photovoltaic powered reverse osmosis (PV-RO), solar thermal powered reverse osmosis (ST-RO) with respect to membrane materials, process configuration, energy recovery devices, and energy storage. Globally, desalination capacity has increased significantly to meet rising water demand. To reduce the carbon impact of high-energy desalination procedures, the focus has switched to employing renewable energy sources. Sun-powered desalination offers a sustainable answer to water shortages in locations where solar irradiation is abundant. The compatibility of any desalination process with solar technology is determined by the kind of energy required and its availability. Because photovoltaic and solar thermal solar energy technologies are rapidly developing, there is considerable interest in linking solar energy with desalination to improve energy efficiency. Also covered were recent developments in sun-powered membrane distillation (MD) and solar still materials. The future forecast involves solar-powered forward osmosis and evaporation. The technology and energy usage of solar-powered desalination devices have been studied.

Alghoul, M. A., et all. (2016) [4] quantify the effect of climatic-design-operation conditions on the performance and durability of a PV-BWRO desalination system. Small-scale brackish water reverse osmosis (BWRO) desalination facilities are not as profitable as large-scale ones. Integrating renewable energy systems with small-scale units might hypothetically help their commercialization. In reality, RO units are modular, allowing them to adapt to renewable energy sources. Small-scale PV-RO desalination systems might be useful in distant places where BW is more widespread. A 6-month small-scale unit is developed, built, and tested. Only a 2 kWp PV system with five membranes and a feed TDS of 2000 mg/l and a permeate TDS of 50 mg/l were allowed. Data on solar radiation and temperature were studied to establish their impact on the unit's present and future activities. A two-stage design was shown to be optimal for 600 W RO load, membrane type, and design configuration. The PV system was able to provide the load while the RO unit maintained steady permeate flow and salinity. Using the PV-BWRO system for 10 hours would create 5.1 m3 of fresh water at 1.1 kWh/m3. There are several hours of high temperatures during PV module operation (over 45°C) and battery room conditions (above 35°C), both of which might significantly affect power output and battery autonomy. Optimum thermal management of PV module and battery bank room conditions is vital in maintaining optimal operating temperatures.

Ali, E. S., et all. (2017) [5] investigated the effect of reverse osmosis brine recycling employing adsorption desalination on overall system desalinated water recovery. The input, pretreatment, and brine disposal costs of reverse osmosis seawater desalination systems account for around 25% of the overall cost. Adsorption desalination creates high-quality drinkable water and a cooling effect. The brine from the RO system feeds the adsorption desalination system. It is powered by low-temperature heat sources like solar energy. MATLAB triggered the adsorption desalination system. The suggested combination approach improves recovery while decreasing permeate salinity. Aside from improved system performance, a cooling effect is created that may be used for cooling.

Ali, I. B., et all. (2014) [6] investigated systemic modeling of a small-scale Brackish Water Reverse Osmosis (BWRO) desalination unit. This device was powered by a photovoltaic-wind hybrid system with no batteries. The RO desalination process involves mechanical, hydraulic, chemical, and thermal fields. Thus, this study proposes an interdisciplinary strategy. The bond graph is a well-known dynamic modeling tool for such a multi-physical system. A BWRO test bench is characterised experimentally to evaluate the developed bond graph model of the examined desalination process. The simulation findings show considerable results when compared to the experimental results.

Antar, M. A., et all. (2013) [7] conducted experiments on a single- and two-stage air-heated humidification–dehumidification desalination system (HDD) driven by solar energy. The system is located in Dhahran, Eastern Province, Saudi Arabia. Natural water sources are scarce in this environment. Desalination is being used in Saudi Arabia. It is the global leader in desalination. Modern desalination facilities use fossil fuels and require a lot of electricity. Since the region has an abundance of solar energy, efforts are undertaken to use solar energy to provide fresh water for distant places. It has been noted that HDD systems may effectively provide fresh water in isolated regions where pipeline access is difficult. The technology employed in this research is a solar-heated closed-water closed-air cycle with a single or two-stage operation. The air is heated using evacuated tube sun heaters. In a humidifier, warm air is sprayed with saltwater in a countercurrent direction. When using the two-stage system, additional heating and humidification processes occur. The humidified air is subsequently dehumidified using water (condenser). The dehumidifier air is recirculated to the solar heaters. The dehumidifier's water cycle is split in two due to the water's high temperature. The first cycle sends water from the cooling water tank to the condenser and back to the tank. In the other, water is pumped from a tiny tank to humidifiers and sprayed. The rejected brine goes back in. The tiny tank keeps the cycle water warm by interacting with hot humidifier air. A float valve connects a make-up tank to this tank to compensate for evaporating water. Sensors in the system detect dry and wet bulb temperatures, flow rates, and solar radiation flux. It is recorded every 10 minutes by a data gathering system Die Ergebnisse zeigen die Wirkung der wichtigsten Steuerparameter auf die Systemleistung.

Ayav, P. İ., et all. (2007) [8] presented a theoretical and experimental study of solar distillation in a single basin constructed at İzmir Institute of Technology Urla Campus. The world demand for potable water is increasing steadily with a growing population. Desalination using solar energy is suitable for potable water production from brackish and seawater. The still has a base area of 2100 mm × 700 mm with a glass cover inclined at 38°. In order to obtain extra solar energy, an aluminium reflector (2100 mm × 500 mm) is also assembled to the still. They model the still and conduct its energy balance equations under minor assumptions. They take into account the temperatures of the glass cover, seawater interface, moist air, and bottom in theoretical calculations and measurements. The comparison of the theoretical and experimental results highlights the benefits of the proposed model of the still and the efficacy of its energy balance equations.

Buragohain, S., et all. (2020) [9] installed A pilot-scale 1 kW photovoltaic (PV) system at Auniati Satra near IIT Guwahati for studying the effects of its operating parameters at different loading conditions corresponding to the environmental conditions prevalent in Guwahati, Assam (India). To fulfill rising load needs, decentralised energy production at the community level is required. During the day, the PV system was exposed to eight different loading conditions: 20%, 30%, 40%, 50%, 60%, 70%, and 80%. Insolation, PV energy, PV charge, temperature, and battery capacity data were analysed hourly. The optimal loading condition in standalone mode is 45-50 percent load with normal solar insolation and may be increased to 70 percent throughout the day with high solar insolation. In grid-connected mode, up to 45% of load applications saved money by reducing power use from the local grid. The ac supply may expose it to virtually full rated capacity.

BURGAÇ, A. et all. (2021) [10] investigated both ambient conditions and the design parameters. The contributions of the study are to determine variation in the specific power consumption and related total power requirement of the single-stage reverse osmosis desalination plant model with the ambient conditions and design parameters. Humanity's most pressing necessities are clean water and electricity. The growing population and the demand for freshwater make desalination a hot subject. One prominent desalination method is reverse osmosis. Reverse osmosis has a lower energy usage than conventional desalination procedures and is more resistant to feedwater salinity. The ambient conditions are crucial factors determining desalination efficiency. Conversely, the design specifications of a reverse osmosis desalination plant are crucial. For power needs, design characteristics and ambient circumstances are discussed in the findings. The simulations are run at a constant manufacturing rate to evaluate how each parameter affects product attributes. Increased seawater temperature reduces electricity usage while increasing end product salinity. The findings showed that design parameters should be tuned for system size and feedwater salinity. A case study is also done at a place in Marmara, Turkey. Chaaben, A. B. et all. (2011) [11] studied a new modeling approach of a small photovoltaic reverse osmosis (PV-RO) desalination unit. The suggested model treats the unit as a MIMO process. The most extensively used desalination technology is reverse osmosis (RO), which is used to desalt saltwater and purify brackish water. Using these methods necessitates a control system as a result, a dynamic system model with experimental validation is required. An empirical transfer matrix shows the relationships between the output and input variables. The unit has a state model. The suggested model is validated by several experimental data. As a consequence, the unit model may be simply utilised to create a process control loop to ensure optimal operating conditions and decrease water production costs.

Chaker, R. et all. (2010) [12] presented a Photovoltaic (PV) simulation system powering reverse osmosis (RO) desalination unit with no energy recovery device (ERD). Transient System Simulation (TRNSYS®) is used to simulate the system. The PV system comprises 55 W solar panels coupled to a storage battery through a DC-DC charge controller. A pump supplies feed water to the RO system. Contains one Filmtec spiral wound membrane. The simulation results for freshwater production revealed a total capacity of 110 m3 per year with a continuous input of 1.5 m3h-1. With increasing raw water input flow and PV surface, the monthly freshwater production grows. They also found that when raw water salinity increased, so did freshwater production. This study is supported by experimental findings.

Chen, C., et all. (2019) [13] discussed the water resources and solar energy utilization status in China and presents a comprehensive review of a possible solution: coupling desalination technologies with sustainable energy. Freshwater and energy are the two main problems for human life and sustainable growth. China's massive population requires a lot of freshwater. To provide a steady supply of clean water, desalination is an intelligent and promising technique. However, excessive energy usage and greenhouse gas emissions have hampered desalination growth. Solar energy is unique in that it may be used in many ways. The desalination market in China is analysed, and energy consumption for various desalination procedures is outlined. We compare two solar-powered desalination technologies. This research will assist China's desalination sector move from traditional energy sources to solar-powered desalination.

Cherif, H., et all. (2011) [14] elaborated the energy and water production estimation on a large-scale time from Photovoltaic–Wind hybrid system coupled to a reverse osmosis desalination unit in southern Tunisia. Hybrid desalination systems promise to be a potential alternative for isolated and desert places. The energy is utilised to make drinkable water. These include wind speed, solar irradiance, and steady-state models. The findings reveal that the hybrid system (solar and wind) provides year-round energy availability, despite day, season, and year variations. The reverse osmosis desalination machine driven by a Photovoltaic–Wind hybrid system is suitable for southern Tunisia (salinity 6 g/l). The Djerba region's brackish feed water compositions were chosen. Double stage desalination employing spiral modules is widely utilised, and steady-state model validation is shown.

Dimitriou, E., et all. (2017) [15] presented the development of a dynamic mathematical model of a spiral wound reverse osmosis membrane module aiming to investigate the mass transfer in the membrane under non-constant operating conditions. SWRO desalination systems driven by RE may dramatically decrease prices, specific energy consumption, and CO2 emissions. Directly connecting an SWRO desalination system to RE technologies like photovoltaics may reduce the specific energy consumption owing to the desalination unit's part-load operation. Solar energy is erratic; therefore, membranes may function beyond their normal working ranges. Thus, studies on the effects of varied operations (non-stable pressure and flow rate) on membranes are required. The model's primary goal is to anticipate the membrane's performance under varying operating situations. When the influence of physical membrane compaction is included, the findings reveal a water flow reduction of 0.2 103 kg/m2s owing to the abrupt rise in applied pressure.

El Moussaoui, N., et all. (2019) [16] simulated and analysed the functioning of a solar desalination system coupled with four flat plate solar collectors with each having a surface of $3m^2$. They achieved this by numerically simulating heat balance equations in Matlab. This study found that stages 1 to 4 produce around 36 percent, 28 percent, 21 percent, and 15 percent of the overall production, respectively. The total energy performance shows the solar distiller working well and producing enough drinking water for the residents of Douar Al Hamri, where the solar desalination system will be built.

Filippini, G., et all. (2019) [17] investigated the possibility of coupling the desalination plant with a photovoltaic (PV) solar farm with the aim of generating electricity at a low cost and in a sustainable way. The literature provided a complete mathematical model for the PV system. The model can forecast the cost of a PV system in terms of capital cost and energy cost per kWh based on input data such as solar irradiation, daylight duration, and module technical specifications. So the desalination model was integrated with the solar PV model to determine the cost of freshwater per cubic metre. The planned facility, and particularly the PV solar farm, was economically tested in four locations: Isola di Pantelleria (IT), Las Palmas (ES), Abu Dhabi (UAE), and Perth (AUS).

Franc¸ a, et all. (2000) [18] designed, analyzed, and optimized a small-scale solar-powered desalination system with regard to power needs and energy consumption. Both numbers scale linearly with TDS in the feed solution. Desalination of brackish water with a TDS of 3,000 ppm needs around 1.5 kWh/m3. This rises to 9.5 kWh/m3 for saltwater with a TDS of 34,000 ppm. The kind of membrane, system design, and especially the high-pressure pump's efficiency all impact energy usage. The cost of desalination has been approximated for a small-scale plant that scales linearly with input water TDS.

Freire-Gormaly, M., et all. (2019) [19] presented a novel design tool for photovoltaic powered reverse osmosis installations which considers membrane fouling during intermittent operation to ensure more reliable and long-lasting systems. In isolated off-grid areas, photovoltaic powered reverse osmosis water filtration devices might offer a reliable water source. To handle the fluctuation of renewable energy, these systems are generally run intermittently with lengthy shut-down times. To calculate system costs, the tool employs a genetic algorithm with a simulation model that includes a physical system model and a cost model. The physical model dictates local energy generation. The water system model determines water production using an experimentally proven membrane fouling model. The approach was shown via many case studies (varying location, water output, and dependability). To build dependable and cost-effective systems, the fouling model must be used. The system layout did not change with a location for lower daily water consumption, suggesting mass production. For low-cost solar-powered reverse osmosis systems, the design framework will help.

Ghafoor, A., et all. (2020) [20] carried out the techno-economic feasibility of a solar-based desalination system through a RO system for a plant capacity of 500 L/h. Water shortage has raised the demand for brackish water desalination. Conventional desalination is an energy-intensive and costly procedure. Fortunately, solar energy is readily available and may be used to substitute conventional energy in desalination. Desalination using reverse osmosis (RO) and photovoltaic (PV) technologies sounds appealing. To determine its economic viability, techno-economic feasibility studies must be carried out region by area. Increasing feed water temperature boosts membrane production. The RO plant produced 60% permeate and 40% brine. The three-point manual tracking of a PV system boosted PV power by 20–25 percent while cooling the PV system increased PV power by 5–10 percent. The payback time of the solar PV-based RO system is 1.83 years.

Ghoneim, A. A., et all. (2019) [21] examined the employment of high concentrated photovoltaic (HCPV) modules to drive reverse osmosis (RO) desalination unit in Kuwait weather. The RO systems that use HCPV modules offer various advantages, including cheap operating costs, ease of use, and environmental friendliness. The efficiency of triple-junction HCPV modules in Kuwait is evaluated using an analogous circuit model for a single diode compatible with TRNSYS software. The performance of an HCPV-powered RO unit intended to deliver 20 m3 of drinking water per day to a distant hamlet in Kuwait is evaluated and optimised. The efficiency of the RO unit in Kuwait is evaluated using TRNSYS procedures. The models are verified by comparing them to published experimental data. Modifying the system parameters such as water salinity, water feed pressure, permeate water pressure, concentrate water pressure and permeate flow rate may improve RO-HCPV efficiency. Moreover, the HCPV module slope and orientation are adjusted in numerous simulations until the HCPV system size meets the energy demand. The averted CO2 emissions are estimated to assess the RO-HCPV system's environmental impact. The findings reveal that an HCPV module oriented 26° due souths may provide the highest power. A consistent supply of 1.7 m3/h corresponds to about 6,400 m3/year of freshwater. Finally, the optimal HCPV module slope for maximising conserved CO2 emission is 2.1 tons/year for Kuwait.

He, W., Wang, et all. (2015) [22] proposed a novel RO seawater desalination plant powered by PV (Photovoltaic) and PRO (PVROPRO) and the feasibility of two stand-alone schemes, SSRO (salinity-solar powered RO) operation and SRO (salinity powered RO) operation, are investigated. On first assesses thermodynamic feasibility. The stand-alone feasibility is examined numerically using RO, PRO, and PV array models, and the SSRO and SRO operating windows are developed. It is also investigated how concentration polarisation and reverse salt permeation affect the mass transfer. Finally, utilising yearly Perth solar data, a PVROPRO plant case study is developed. The maximum weekly output rate exceeds PVRO. That of a PVRO facility on its own. The weekly PW (product water) production rate is lowered by 16–20%, and the annual reduction is 18.07%.

Jamil, M. A., et all. (2021) [23] designed, fabricated, and tested domestic-scale solar stills in one of the harshest climatic condition areas of Pakistan, Rahim Yar Khan. A year-round summary of the area climatology is provided, including wind speed, solar potential, and ambient temperature. Pakistan is one of the nations that has already reached a water shortage, and the latest epidemic has made matters worse. This is because the country's funding has been diverted from other development initiatives like water treatment and transportation infrastructure. As a result, water-borne infections have risen dramatically recently. To improve the situation, this problem must be addressed urgently. Some solutions include shifting the emphasis from mega-projects that take a lot of energy, money, and time to small-scale water treatment systems. Analysis suggests the suggested solution may properly handle drinking water issues in Pakistan's poorest districts. An investment of PKR 3000 ($20) yields average water productivity of 1.5 L/d/m2. This data will be used to create comparable systems in other dry places across the world.

Kabeel, A. E., et all. (2021) [24] presented study aims to enhance the performance of tubular solar still through the mathematical and experimental investigation of proposed modifications applied to the conventional tubular solar still. The modification used v-corrugated absorbers and wick materials to optimise evaporation rate, using the enormous condensing surface area that characterises tubular solar stills to boost distillate water output. A corrugated black jute fabric was placed on the v-corrugated absorbent surface. The bottom half of the corrugated black jute cloth was soaked in water while the remainder of the cloth was saturated by capillary action. Under Egyptian weather circumstances, the modified tube still with v-corrugated wick materials compared to a normal tubular still with a flat absorber surface. The findings reveal that the standard tubular still produces 4150 ml/m2, while using v-corrugated wick materials produces 6010 ml/m2, a 44.82 percent increase in productivity. The average efficiency for the traditional tubular achieved 35% over the test days, while the v-corrugated wick materials usage improved the average efficiency to 51.4%.

Khayet, M., et all. (2011) [25] employed Response surface methodology (RSM) and artificial neural network (ANN) to develop predictive models for simulation and optimization of the reverse osmosis (RO) desalination process. A RO pilot plant using a polyamide thin film composite membrane in spiral wound configuration was tested using sodium chloride aqueous solutions. The input variables were C, T, Q, and P. The salt rejection factor times the permeate flow has been proposed as a response. Both RSM and ANN models are based on experiments. In this study, two empirical polynomial RSM models were developed. For non-linear issues, the ANN model built using RSM was valid throughout the whole range of feed salt content. ANOVA was used to assess the importance of response surface polynomials and the ANN model. The calculation of residual degree of freedom was done to assess the ANN model's relevance. Finally, the generalisation graphs were used to evaluate the prediction capacities of RSM and ANN modeling methods. This was established via Monte Carlo simulations of the four input variables, typical brackish water at 6 g/L, and saltwater at 30 g/L. Experimentally, maximum RO performance indices were reached under ideal circumstances.

Khayet, M., et all. (2010) [26] constructed and optimized a solar thermal and photo voltaic-powered reverse osmosis (RO) desalination plant for brackish water desalination. The orthogonal central composite experimental design and response surface methodology (RSM) were used to develop predictive models for simulation and optimization of different responses such as salt rejection coefficient, specific permeate flux, and RO specific performance index. The input variables studied were feed temperature, flow rate, and pressure. ANOVA was used to assess the RSM polynomial models' relevance. They have been calculated using the step adjusting gradient approach. Under ideal circumstances, an optimum RO specific performance index was determined experimentally. The RO optimised plant promises 0.2 m3/day potable water production at 1.3 kWh/m3.

Kim, J., et all. (2013) [27] presented an optimization model of solar-powered reverse osmosis (RO) desalination system. RO systems work by forcing salty water through semi-permeable membranes. Small towns need clean water to thrive. In dry areas, seawater or brackish water from wells is sometimes more accessible. Because desalination consumes a lot of energy, it makes sense to utilise a sustainable energy source like solar energy. Then a freshwater stream catches the membrane-passed water molecules. It combines photovoltaic (PV) panels and battery storage to smooth out PV power production fluctuations and allow system operation even after sunset. Design parameters include PV solar collector size, battery storage capacity, and RO membrane module and power components. A lower cost per unit of produced freshwater is desired. Genetic algorithms provide optimal designs for two sites near the Red Sea and Sinai.

Kroiß, A., et all. (2014) [28] presented the development of a novel seawater-proof PV/T system with the aim of low cost and high electrical and thermal performance. The development of seawater-proof PV/T systems may expand the currently restricted PV/T application sectors to a new one: sustainable reverse osmosis (RO) desalination. The PV/T system's drawback of heat at low temperatures may be turned into an advantage: higher seawater temperatures enhance RO freshwater production while higher seawater temperatures increase PV efficiency. Using conventional components like a polypropylene heat absorber and a commercial PV system saves money. A PV/T prototype was tested for thermal and electrical efficiency at various fluid temperatures, mass flow rates, and environmental conditions. A comparison with modern PV/T systems is made.

Kyriakarakos, G., et all. (2017) [29] developed a variable load Energy Management System (EMS) based on Fuzzy Cognitive Maps (FCM). Two case studies are simulated to test variable load operation. In recent decades, great effort has been made to integrate desalination technology with renewable energy systems including photovoltaics, wind turbines, and batteries, in order to lower costs and power desalination units in areas where electricity is scarce. Reverse osmosis desalination machines normally run at a nominal point. However, using reverse osmosis desalination machines at reduced load reduces specific energy usage. In both circumstances, a PV battery system is originally designed for a desalination unit working at full load. The capacity factor of the desalination unit analysed differs between the two case studies: 30% for the first scenario (about 7 hours daily operation at full load) and 70% for the second (translating to about 17 h of daily operation at full load). The ON-OFF EMS is then replaced with the FCM variable load EMS and the annual drinking water output is compared. The findings clearly demonstrate that upgrading an existing PVROD system to a variable load operation scheme may significantly enhance drinking water output, ranging from about 41% for the first case study to nearly 54% for the second.

Laborde, H. M., et all. (2001) [30] presented an optimization strategy for the design and operation of a small-scale solar-powered reverse osmosis desalination system. It has been examined and optimised for power usage. Both values scale linearly with TDS content in the feed solution. Desalination of brackish water with a TDS of 3000 mg/L needs around 0.84 kWh/m3. This rises to 7.0 kWh/m3 for saltwater with a TDS of 35,000 mg/L. The kind of membrane, membrane arrangement, recovery rate, membrane area, and high-pressure unit efficiency all impact energy usage. A small-scale desalination system's cost has been calculated. It ranges from US$3.3/m3 for 3000 mg/L to US$7.8/m3 for saltwater. The model calculations are compared to preliminary experimental data.

Lacroix, C., et all. (2019) [31] presented an innovative, thermally powered RO desalination process. Reverse osmosis (RO) is a low-energy desalination technology. This innovative thermo-hydraulic technique employs solar thermal energy to pressurise seawater above its osmotic pressure, allowing desalination to occur. This pressurisation is achieved by a working fluid moving a piston or membrane in a reservoir, comparable to an Organic Rankine Cycle. The evaporator is heated by low-grade heat from flat-plate solar collectors, while the condenser is cooled by the treated seawater. It should produce 500 L of drinking water per m2 of solar collectors per day, with a thermal energy usage of about 6 kWhthm3. In order to improve its design and enhance its performance, the whole process has been dynamically modelled. This report gives preliminary solar-driven desalination performance data.

Lai, X., et all. (2018) [32] proposed a hybrid system consisting of RO (reverse osmosis) and SE (Stirling engine) to utilize the moderate temperature heat for the brackish water desalination. The performance of two combinations was studied. Unlike Config I, Config II uses ERD (energy recovery device) to collect residual pressure energy from outlet feed solution to pre-pressurize inlet feed solution. The effects of SE heater material temperature and RO hydraulic pressure differential on freshwater recovery and energy consumption were studied. Config. I has the best recovery rate of 17.3% while Config. II has the highest freshwater production of 34.2. Config. II achieved the lowest specific energy consumption of 2.5 and specific thermal energy consumption of 35.9 compared to Config. I. The performance of ideal and non-ideal SE models was also compared.

Leijon, J., et all. (2020) [33] proposed a hybrid system including solar and wave power. A solar-wave-power hybrid system an investigation of ocean wave-powered reverse osmosis is presented. It is possible to simulate the reaction of a renewable energy system using commercial desalination equipment. For this study, they utilised wave data from Kilifi in 2015. Based on these estimates, a wave-powered desalination system might produce more electricity than a wave-powered power converter. It's possible to desalinate using up to three wave energy converters. Reverse osmosis desalination systems may perform at lower power levels and lower freshwater flow rates, according to the tests. Wave power and PV systems can be used for desalination with or without battery storage.

Li, G., et all. (2020) [34] proposed a solar-powered stand-alone sweeping gas membrane distillation desalination system to provide flexible freshwater for remote island households without reliable infrastructures, such as water and power supplies. The system runs solely on solar energy. A solar thermal collector provides heat energy while a solar photovoltaic array provides direct current electricity. To assess system performance, a mathematical model was built and tested in real-world settings. On the other hand, the condenser's dehumidification efficiency was examined. It was found that solar collector area, photovoltaic area, and desalination operating parameters affect system freshwater output and Gained Output Ratio. The system's monthly freshwater production was also projected based on Hong Kong weather. In summary, the suggested system produces between 9.98 and 23.26 kg/d of freshwater (9.98 kg/d in January and 23.26 kg/d in July), adequate to cover a normal family's daily water needs (two adults and two children). To maximise freshwater output, the solution flow rate to airflow ratio should be 4.0–6.0. The average thermal efficiency of solar thermal collectors is 50%, almost three times that of solar photovoltaic panels (about 15 percent). Solar collector area has more influence on system performance than photovoltaic area. The system's ultimate water production cost is 18.34 $/m3. This research proposes a small-scale entirely solar-powered desalination system for island and coastal families.

Maleki, A., et all. (2016) [35] determined and investigated the optimum design for a stand-alone hybrid desalination scheme, able to fulfill the freshwater demand of a remote area located in Davarzan, Khorasan, Iran. The plan includes a reverse osmosis desalination plant driven by solar and wind energy with battery storage. Many weather stations are needed to anticipate energy output, and a new weather forecasting approach is recommended (solar irradiance, wind speed, and ambient temperature). The method is tested on actual data from northern Iran. This study proposes using harmony search and combining it with chaotic search to find the optimum parameter values for a hybrid renewable energy system that best meets the load while reducing life cycle costs and not exceeding the maximum permissible chance of power supply failure. Harmony search is a simple heuristic that can escape local optima. This system's decision variables (number of batteries, total swept area of spinning turbine blades, and total area occupied by solar panels) are optimised using a chaos-based harmony search.

Mansour, T. M., et all. (2020) [36] focused on employing an Energy Recovery System (ERS) to enhance the performance of the small RO plant for remote areas. The scarcity of drinkable water, particularly in underdeveloped nations, has interested academics. Desalination is one of the most effective solutions. Because it uses less energy than other desalination technologies, reverse osmosis (RO) is preferred over thermal desalination. The performance of RO desalination plants has been improved. The unit had a 2.4 m3/day capacity and two double-acting cylinders with ERS control components. An experimental design is employed to test the suggested ERS's efficacy. A simulation model is created to change the plant's system parameters. The experimental and model findings of system pressure were compared. The experimental and simulation model values agreed well. Emphasis on recovery ratio's impact on electricity savings The ERS reduced electricity use by 80%. The tiny RO desalination plant with and without ERS has a considerable decrease in overall cost.

Mokheimer, E. M., et all. (2013) [37] modeled and simulated a hybrid wind/solar-powered reverse osmosis desalination system. The simulation findings were utilised to optimise the system for the lowest cost per cubic metre desalinated water. The performance of the hybrid wind/solar RO system was studied for a typical year in Dhahran, Saudi Arabia. The performance was investigated with a 1 kW continuous RO load for 12 and 24 hours. It was shown that the optimal system that powers a 1-kW RO system for 12 hours per day uses 2 wind turbines, 40 PV modules, and 6 batteries, with a levelized cost of energy of 0.624 $/kW h. According to the optimal system, 6 wind turbines, 66 PV modules, and 16 batteries provide a 1-kW load for 24 hours with a levelized cost of energy of 0.672 $/kWh. The energy usage for desalination varies depending on the raw water salinity. This suggests that the planned ideal hybrid wind/solar water desalination system will cost between \$3.693/m3 and \$3.812/m3, which is cheaper than the literature range.

Monjezi, A. A., et all. (2020) [38] presented a novel method for coupling solar photovoltaic thermal (PVT) cells to reverse osmosis (RO) desalination introducing seawater as the cooling medium to increase the thermal efficiency of solar energy generation and subsequently maximising the rate of freshwater production. urbanisation and population increase have depleted freshwater supplies, exacerbating water shortages in rural areas. While industrial-scale desalination facilities have received significant attention in the last decade, small-scale off-grid desalination devices for rural populations have been disregarded. A battery unit will provide a consistent supply of freshwater, reducing membrane fouling in renewable energy-powered membrane desalination machines. The integrative system was modeled for Alexandria's seawater parameters and climate. The suggested technology reduces the specific power consumption rate of RO desalination by 0.12 kWh/m^3 while boosting the electricity generating capacity of PVT cells, resulting in a 6% decrease in the needed solar panel surface area.

Park, S. J., et all. (2003) [39] developed a mathematical model to simulate the performance of a prototype wind-powered reverse osmosis desalination system. The model is made up of two sub-models. The first sub-model uses wind energy to produce pressurised feedwater. Its intake is pressured feed water, and its output is flow and salinity of the product water or permeate. From June to December 2001, the University of Hawaii tested a prototype wind-powered RO desalination plant. This study's mathematical model forecasts the performance of wind-powered RO desalination plants under various design scenarios. Linear programming is used to optimise the system. A design guide for wind-driven reverse osmosis systems is created using the optimization findings.

Qiu, T. Y., et all. (2011) [40] identified and evaluated potential areas of technical improvement to solar-powered desalination systems that use reverse osmosis (RO). They compared ideal and actual SEC to identify inefficiencies. The optimal SEC is compared between batch systems powered by pistons and continuous systems with single or many stages with energy recovery. In a sunny coastal area, up to 1850 m^3 of water per year per m^2 (m^3/m^2) of land covered by solar collectors might potentially be desalinated. Under the same circumstances, 11570 m^3/m^2 freshwater could be produced from brackish water (3 bar osmotic pressure). These ideal values are compared to literature-reported values. Depending on input water composition, system architecture, and energy recovery, the real energy consumption is 40–200 times greater. Modern systems quantify and depict energy losses at different stages of conversion using Sankey diagrams. We examine ways to decrease losses. As a result, proposals for R&D are made, focusing on new technologies. The efficiency of the solar-powered RO system may be improved significantly.

Rahimi, B., et all. (2021) [41] investigated the integration of solar panels with the grid to power small-scale reverse osmosis systems (namely up to 2000 m3/day) was conducted in Iran, as a country with a low price of electricity. Solar-powered reverse osmosis desalination systems are a sustainable and eco-friendly desalination option. However, the intermittent nature of solar energy poses significant technological and economic hurdles. These systems may now compete with grid-connected reverse osmosis systems with recent technology advancements and feed-in tariffs. A city on the northern shore of the Persian Gulf with water scarcity but significant solar radiation is chosen as a case study. The effects of energy recovery devices, energy storage systems, and membrane features are explored in five situations. Finally, each scenario has a full cash flow analysis. Ending with solar-powered reverse osmosis facilities that may transfer unused or excess solar energy to the grid.

Riyahi, N., et all. (2021) [42] purposed to use solar energy to supply desalination energy in Kish Island. They performed thermodynamic and economic analysis of combined reverse osmosis (RO) desalination system with a solar panel on Kish Island. Because Kish Island lacks a year-round river, access to clean/freshwater powered by solar energy is critical to protecting the ecosystem and boosting the island's appeal. So, a huge section of the island may get freshwater from the sea utilising water pre-treatment and reverse osmosis. The desalination plant's capacity is about 7,200 cubic metres per day to deliver fresh water to the island's urban population (about 40,000 people). To design the desalination unit's energy requirements, first identify the proper membrane from the simulation results, and then calculate the system's annual power usage of 9,620,000 kWh. The system effluent TDS was 141.3 mg/L and the Recovery percentage was 60.3 percent. Also, owing to space limits and modeling findings, 15,228 solar panel units were recommended to achieve optimal power consumption.

Runze, D., et all. (2020) [43] designed and tested experimentally a portable solar-photovoltaic atmospheric water generator and is composed of a water generating module, a water purifying module, a power supply, and control module, and a buoyancy module. Results revealed that at Tin = 27, RHin = 92%, Qa = 600 m^3/h, and desalination rate of 99.65%, the optimum water production rate of 460 mL/h was reached. Production of 5.52 L/d is more than double the WHO drinking water requirement (2.5 L/day) while energy consumption is under 200 W. The effects of important operational parameters on device performance were studied, and device performance was compared to documented AWG products/prototypes. The gadget might be used as a tiny rescue platform for those in danger in tropical waters, carried aboard a ship as a precaution.

Shaaban, S., et all. (2017) [44] investigated the performance of reverse osmosis plants in hot climate conditions. A typical reverse osmosis system was designed, constructed, and investigated. Desalinated water is needed in hot climates. Reverse osmosis (RO) is presently the most dependable method for desalinating brackish and saltwater. But it uses a lot more electricity than other methods. The ROSA program was used to analyse seven membrane components. The experimental data were used to confirm the ROSA software's simulation findings. Using variance-based sensitivity analysis, optimal design and operational parameters were determined. The current study reveals that feedwater temperature affects tap and brackish water membrane elements more than feedwater pressure and concentration. The feed concentration affects seawater membrane elements more. The extensive analysis of the membrane components suggests that reverse osmosis wastewater reclamation might be a substantial source of low-cost freshwater for hot climate nations.

Sharif, A. O., et all. (2014) [45] presented a study on the potential of osmotic energy for power production. Their study included both pilot plant testing and theoretical modeling as well as cost estimation. A Hydro-Osmotic Power (HOP) plant may produce clean power at £30/MWh if a suitable membrane is employed and the osmotic potential difference between the two solutions is larger than 25 bar, which is common in many locations worldwide. Depending on the salinity difference, the membrane system contributes 50–80% of the HOP plant cost. Thus, improving membrane technology and selecting appropriate membranes will have a substantial influence on the process's practicality and marketability. Because membrane permeability impacts HOP process feasibility, this research discusses the effect of fluid-membrane interaction on system permeability. To further enhance the HOP process, both fluid physical characteristics and membrane micro-structural factors must be studied.

Shatat, M. I., et all. (2010) [46] described the experimental investigations of the performance of multi-stage water desalination still connected to a heat pipe evacuated tube solar collector with an aperture area of 1.7 m^2. They designed the multi-stage solar still water desalination system to recover latent heat from evaporation and condensation processes in four stages. The test setup used 110 halogen floodlights to imitate the change in solar radiation during a normal mid-summer day in the Middle East. The device generates around 9 kg of freshwater each day and has a solar collector efficiency of approximately 68%. However, high heat losses in the system reduced the total efficiency of the laboratory test rig to 33% at this point of the inquiry. The distilled water was tested within WHO limits. In order to replicate the still's functioning, a set of conventional energy and mass conservation differential equations were created for each step. Computer models of evaporation and condensation within a multi-stage still were produced. The experimental and theoretical predictions agreed well. Their work also presents conclusions on determining the reasonable design dimensions and number of stages of the still for a particular solar collector aperture.

Song, D., et all. (2021) [47] invented a piston-type integrated high-pressure pump-energy recovery device (HPP-ERD), which synchronously pressurizes the raw seawater and recovers hydraulic energy from the concentrated brine was introduced. The energy recovery device (ERD) helps reduce the energy consumption of SWRO desalination. Many research has been done on large-scale ERDs, but few on small-scale ERDs (capacity less than 50 m3/d). The HPP-ERD construction and operation are described. Three HPP-ERD prototypes are tested in a laboratory mimic platform, and the findings show that HPP-ERD can save energy. The HPP-ERD is used to survey a realistic 50 m3/d SWRO project. An investigation of the proposed project's performance over a month demonstrates the HPP-adequate ERD's energy-saving capabilities and durability. Finally, economic analysis shows that using the HPP-ERD instead of a single high-pressure pump can significantly reduce both the payback period and the desalinated water cost of the proposed project.

Tchanche, B. F., et all. (2010) [48] performed an Exergy analysis of micro-organic Rankine heat engines to identify the most suitable engine for driving a small-scale reverse osmosis desalination system. Three modified Rankine engines with regeneration (regenerator or feed liquid heaters) are examined using an exergy-topological technique combining exergy flow graphs, exergy loss graphs, and thermoeconomic graphs. The study considers three working fluids: R134a, R245fa, and R600. The gadgets work differently with various fluids. Exergy destruction in R134a systems was measured and shown using exergy diagrams. Turbine, evaporator, and feed liquid heaters have the most exergy loss. An evaporator, turbine, and mixing units are key components. Regenerative heat exchangers work well with dry fluids; feed liquid heaters work well with wet fluids but lose energy efficiency. Although many changes enhance energy conversion and exergy destruction, the advantages are not great enough to make further modifications of the basic Rankine engine economically viable for heat sources below 100°C. For example, a regenerator improves the system's energy efficiency by 7%, while maintaining the exergetic efficiency of a basic Rankine cycle using R600 as the working fluid. Examine the effects of heat source temperature and pinch point temperature on engine performance. For Rankine-based power systems, the findings show that energy analysis coupled with mathematical graph theory is an effective way to compare alternative regeneration effects in terms of their contribution to system improvements.

Wu, B., et all. (2018) [49] optimized the size of a reverse osmosis desalination-based diesel and photovoltaic power plant for increasing freshwater availability and meeting the electrical load demand of a stand-alone region in Iran. Hybrid energy systems can provide drinkable water and power to isolated places. The suggested hybrid system's battery bank size, solar system area, and diesel generator fuel consumption are adjusted to reduce the system's life cycle cost. An effective metaheuristic approach based on tabu search is utilised to build a power management plan. The findings are compared to harmony search and simulated annealing. These economic aspects of the hybrid system are explored in relation to changes in fuel cost, interest rate, photovoltaic and battery beginning costs. This system is more cost-effective and ecologically friendly than a single photovoltaic or diesel system in the studied area. Moreover, tabu search outperforms the other algorithms tested.

Xia, G., et all. (2014) [50] proposed a solar-powered transcritical CO2 (carbon dioxide) power cycle for reverse osmosis desalination based on the recovery of cryogenic energy of LNG (liquefied natural gas). In addition to the solar collector subsystem, there is an LNG subsystem and a RO (reverse osmosis) desalination subsystem. A thermal storage unit is added to the system to ensure its long-term stability. A mathematical model is created to mimic the system. The impacts of daily exergy efficiency, mechanical work output, and daily fresh work output on system performance are explored. A genetic program uses parametric optimization to optimize daily freshwater output. The findings reveal that the CO2 turbine intake pressure is appropriate to achieve the daily maximum exergy efficiency. The daily exergy efficiency may decrease as condenser temperature rises, but rises when oil mass flow rate and NG turbine intake pressure rise. Under the specified parameters, parametric optimization may achieve a daily exergy efficiency of 4.90 percent and supply 2537.33 m^3 freshwater.

Yargholi, R., et all. (2020) [51] defined the integrated carbon dioxide power cycle with a geothermal energy source to supply the required reverse osmosis desalination power for freshwater production. It is a CO2 power cycle with infrared energy recovery from liquid natural gas (LNG) to create extra electricity. A sodium hypochlorite generator is thought to stop brine discharge. This generator used the desalination brine water as an input. The desalination system and sodium hypochlorite generator use cycle electricity. Then sophisticated exergy analysis is explored. Exergy study shows that the condenser in this model destroys the most exergy at 952 kW. Also, 88 percent of the exergy destruction of a CO2 turbine is inevitable, equaling 301 kW. So this component improves exergy destruction.

By studying various research papers of researchers we have fixed our research objectives is as follows:

[1] To explore heat transport features of solar photovoltaic panels from a theoretical and experimental perspective.

[2] To study PV panel performance with and without heat transfer.

[3] To collect thermal energy and explore its usefulness.

[4] To reduce energy waste, collected energy should be used immediately.

[5] Explore ways to enhance the permeability of Thin-film composite Reverse Osmosis membranes and thereby reduce energy usage.

PROPOSED METHODOLOGY

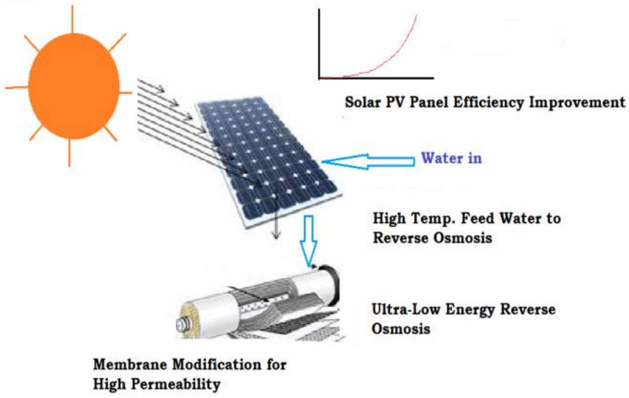

FIGURE 1.
GRAPHICAL REPRESENTATION OF RESEARCH

Step 1: It is planned to cool the solar photovoltaic panel by allowing water to flow from the top and bottom of the panel at different speeds.

Step 2: Ongoing monitoring will be carried out on the panel's temperatures, both while it is being cooled and when it is not.

Step 3: A further theoretical investigation will be carried out using the ANSYS CFD program, which will model the temperature of the photovoltaic panel under certain sun insolation.

Step 4: Experimental data will be used to verify the simulation results since they are in close conformance with the simulation results.

Step 5: The temperature of the water will be measured as it rises in temperature. The heated water will be exposed to a household reverse osmosis membrane element before being pumped back into the system.

Step 6: It will be necessary to monitor the functioning of the reverse osmosis membrane element (i.e., solute rejection and flow rate) during the experiment.

Step 7: A sodium hypochlorite solution at pH 11.0 will be applied to the membrane element to boost its productivity, and its performance will be monitored as a result.

Step 8: In order to improve the productivity and temperature sensitivity of the membrane, a supra-molecular assembly of chitosan over polyamide will be assembled on the surface of the thin-film composite RO membrane. The following characteristics of the changed membranes and the virgin TFC RO membrane will be determined: Surface morphology using an atomic force microscope, chemical structural changes using an attenuated total reflection microscopeReflectance-Fourier transform infrared spectroscopy, surface hydrophilicity measured by the contact angle, and surface charge measured by a Zeta potential analyzer were all used in this study.

CONCLUSION

From the current investigation, we can conclude that reverse osmosis has long been recognised as the most effective technical method for treating contaminated water, brackish water, and saltwater. Reverse osmosis is a process that converts saltwater water into freshwater by passing it through semi-permeable membranes. It is possible to remove salts, germs, viruses, and suspended solids using reverse osmosis because the membrane is a thin film composite composed of nonwoven polyester, polysulfone, and a polyamide barrier layer. Because the driving force for water movement is pressure, the membrane process necessitates the use of energy in order to create water. As a result, reverse osmosis facilities need a reliable power supply source in order to function properly.

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