Fresh Water Generator: A Review

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Abstract. This search presents a study for some types of fresh water generators FWGs, giving an overview of each type and comparing them with other types, and knowing the design criteria for different designs, as well as studying their advantages and disadvantages, including thermal desalting which types are vapor compression (VC), multi stage flash distillation (MSF), multiple effect distillation (MED), and multiple effect evaporator, adsorption desalination, membrane distillation (MD), freezing desalination, and hydrate desalination. Then we studied the non-thermal desalination process, which includes electro-dialysis (ED), ion exchange desalination (IX), extraction desalination process, and additional types of fresh water generators FWGs.

Keywords: thermal desalting, vapour compression, multi stage flash distillation, multiple effect distillation, multiple effect evaporator, adsorption desalination, membrane distillation, freezing desalination, hydrate desalination, non-thermal desalination, electro-dialysis, ion exchange desalination, extraction desalination, Solar steam generation plant.

1. Introduction

Polluted water illness could be a worldwide burden which is estimated to cause more than 2.2 million deaths per year and higher cases of sickness each day [1]. Also, more than 1.2 billion individuals need get to clean drinking water. By 2030, nearly half the world’s populace will be living in water stressed conditions [2]. Wang et al., in (2011) [3], demonstrated that, due to low power use, low operational cost and high thermal efficiency, MED Multi-Effect Distillation has been extensively used in the field of seawater desalination and in chemical industry throughout the world. A recreation show is developed with the intention of demonstrating the viability of this improved conspiracy, which is approved by the manufacturer with test information about single effect freshwater generators. Joo and Kwak (2013) [4], in this revision, they made an evaporative multi-step distiller by a three m²/day saltwater desalination volume utilizing sun based vitality, and detailed the comes about by conducting an estimation of the distiller concert. Yuksel et al. (2018) [5], the use of sea water to generate fresh water depending on temperature value, result in the following that the sea water temperature changes’ effects on new water generation capacity of fresh water generator (FWG) and the model appear that, in case sea water temperature exceeds 30.83°C, the FW generation rate reduction markedly, that means that Sea water temperature is the most influencing factor affecting the performance of a system of FWG. Le and Nguyen (2019)[6], have designed and developed waste heat from diesel engines for desalination equipment of a fresh water generator. The study purposes of Vakilabadi et al. [7], are to apply zero fluid discharge to a steam controller plant that uses a vacuum evaporator and to analyse some of the key work parameters affecting the freshwater rate in the different work cycles, control use and productivity of the system. The advantage is that a higher-temperature stream after root pump evaporates water and doesn't require an external radiator. In the vacuum environment, the sole is also...
evaporated, so the fluid effluent's boiling temperature is low and the vitality consumed reduces. The following paper is followed by a third and fourth field framework, mathematical modelling and exergy study. The results are discussed in the fifth area and are concluded in the last segment. 

Feili et al. (2020) [8], analysis and optimize of a new combined power and freshwater generator system driven by waste heat of a marine diesel engine. The main goal of this study is to know the development of the fresh water generators FWGs systems and to come up with an optimal method for a new design based on an accurate scientific study using environmentally friendly systems with less cost, less energy consumption. As well as study is to understand the fresh water generator, its evolution and performance. Also, compare this studying with the different designs of the FWGs. This study will include the composition, disadvantages, advantages, design considerations and control system for each type.

2. Classification of Fresh Water Generator

Because of the scarcity of water that will occur during the next 10 years, as shown in Figure 1, it has become important to study and classify each type of FWG, compare and analyse it, and know its pros and cons to come up with an optimal design in the future.

![Figure 1. Global need for fresh water between 2010 via 2030 [9]](image1.jpg)

Fresh water generator desalination system can be classified according to Figure 2.

![Figure 2. The categories of desalination processes [9]](image2.jpg)
2.1 Thermal desalting:
For thermal desalination forms, vaporization of water devours such a huge sum of vitality within an enthalpy form of vaporization ($\Delta H_{\text{vap}}$), which is close 2400 kJ kg$^{-1}$ dependent on the evaporation temperature and feed saltiness. The consequent condensation process (not shown here) has been required for realizing desalination [10].

2.1.1 Vapour Compression
Figure 3 shows a diagram of the MVC plant. The supposed mechanical desalination plant for vapour compression (MVC) consists of two one phase warm stage interchangers (equivalent joining: HE1, HE2), first primary vaporization condensation stage warming exchanger (HE), one compressor (C) and one another key gear, and currency pumps ($P_1$, $P_2$ and $P_3$) (VS). The heat exchanger for evaporation and condensation, HE, is the core unit of the MVC plant next to the compressor. The HE have to exchange successfully, under a tiny-as-thinkable temperature contrast (drive impose of heats exchange), evaporation (ocean water) and condensation (item water) to reduce the electricity costs. On the other hand, by pressurizing the created vapour mass stream rate, the compressor must give the drive of that heat transfer. The ocean water mass rates — known as — are first divided into two rivers for HE1 and HE2 preheating. The two ocean water streams are mixed and transmitted to the HE after preheating is done. Within the HE, one part of the ocean water mass fluid disappears (alias $pw$) and the other part of the ocean water mass fluid (alias $bw$). The HE outlet warming heats of the funnel and the fuel are used for preheating ocean water at $T_{\text{sw}}$ temperature up to $T_{\text{swin}}$ temperature. The mass stream rates of the binary and the secondary streams are cooled individually up to $T_{\text{bwout1}}$ and $T_{\text{pwout2}}$, after the characterized shapes in HE1 and HE2. At $T_{\text{swevap}}$ (upper comparing to the disappearing temperature for unadulterm water, $T_{\text{evap}}$) temperatures the ocean liquid dissipates while by $T_{\text{cond}}$ temperatures the item water condenses. The compressor absorbs and pressures the product water vapour up to $T_{\text{cout}}$ temperature[11].

![Figure 3. Schematic diagram of the MVC desalination plant [11].](image-url)
2.1.2 Multi Stage Flash Distillation (MSF)

The appearance of the multistage flash desalination (MSF) in Kuwait date from 1957 is the historical turning point within the history of desalination. Three major parts are included in the MSF framework: Heat Input, Heat Recovery Stages, Halfway Stages and Heat Distribution Stages where waste heat is released into the environment. The flow sheet of MSF [12] is shown in Figure 4.

![Figure 4. Schematic flowsheet of multi-stage flash distillation [12].](image)

2.1.3 Multiple effect distillation (MED)

The MED plant's feeder configuration appears in Figure 5. A onward feed denotes that before first effect, the feed water is heat up. The seawater or sailing water also flows in the identical way as the distillation form. The MED things are combined with the initial outcome on the upper and the latest one on the lowest in a vertical stack. The heat source of the first effect is saturated steam at low temperatures ($T_{s1} < 90^\circ C$). This low-temperature restriction stands designed to prevent mounting when seawater and salt vaporize. Evaporators are plane pipes and preheaters are heat exchangers for shell and tube [13].

![Figure 5. MED Plant motivated by solar vitality. Watercourses are showed using colours: (Water) blue, (gas) red and (saline) green [13].](image)
2.1.4 Multi Effect Evaporator
The initial arrangement evaporator from diesel or other sources is fiery by jacket water from a squander warming motor as in Figure 6. The heating medium is passed through the tubes over the pipes and briny water. Evaporation takes vacuum chambers inside. The created vapour does not pass a brine in the upper case. Sole drops that still contain in the vapour are insulated into the upper portion of an evaporative chamber by the mesh type demister. The evaporator from the first arrangement is transmitted at that point to the moment when it condenses outside the evaporator pipes exchanging that one inactive hotness into the briny water inside the pipes. In second level the gas created is driven to the third position in the same way. The vapour created in the third stage is driven into the condenser after transitory through a demister. The refrigerating water of a condenser runs through the tubes and the steam is condensed outside. Part of a cooling water of the preheated seas is utilized as feeder. The heat salt of stage 1 is replaced by the feed water inlet of stage 2 for superior hot productivity. Stage 2 brine is then transferred to stage 3. The combined sage/air expeller releases overboard the cumulative salt all stages, the discussion and the other non-condensable gasses. A single centrifugal organizing distillate pump releases the cumulative distillate of all stages. Depending on the cooling system of the ship, either a partitioned water booster pump with condenser outlet suction transmits the rational sea water stream of the ejector or a sea water outlet is directly used in case of an adequate water pressure. For guide or entirely automatic process, an evaporator can be designed [14].

2.1.5 Adsorption desalination
The desalination adsorption handle uses the adsorbent – adsorbent characteristics and yields new water on the condenser, through amalgamation ‘adsorption-driven evaporation’ Figure 7 shows the Advertising Framework schematic format. It consists of condenser, evaporator, in addition to four sorption (SE) or a couch. In Discuss Conditioning Research Centre at the National University of Singapore, the pilot adsorption desalination plant was built and worked. The adsorption desalination frame is displayed in Figure 8 and can be processed in two bed and four beds modes. Figure 8. Foremost contrast amid four-bed and double-bed process is in warm water provided in a 4-bed configuration in SE I as well as SE II on desorption beds while in double-bed mode, SE I besides SE II are supplied in the particular bed and hence, separately with SE 1 plus SE II, the hot water has been supplied.
A coolant is provided in four-bed mode in SE third plus SE forth configuration and in two-bed operational mode in analogous with CV2 (SE third plus SE fourth). Now 4-bed operation style, condenser as well as an evaporator have always combined with a minimum absorber and desorber. In an operating phase of the two-bed operation mode [15], nevertheless, there are dual sorption elements linked with the evaporator and condenser.
2.1.6 Membrane distillation (MD)

The membrane distillation is an rising non-isothermal film handle which uses thermal vitality in arrange to supply a vapour stage of volatile molecules display within the feed stream (i.e. mostly water) and condensing of the saturated vapour within the cold side (Figure 9). The driving force in MD is the partial pressure alteration flanked by separately side of the film pores. The temperature difference leads to a vapour pressure difference over the film. Due to the hydrophobic nature of the layer, as it were vapour can pass over the film and not fluid solution being distilled.
the coordinate contact MD is the foremost utilized mode of the MD prepare, particularly for purification and water/wastewater cure. One of reasons is owing to the condensation stage that can be carried out interior the MD module enabling a basic MD operation mode. Though, it ought to be noted that the heat exchanged by conduction through the film, which is considered as the heat misfortune in MD, is higher than in the other MD configurations. During the DCMD process, dissipation and condensation happened at the liquid-vapour interfacing shaped at the pore passages on the bolster and distillate side, separately. A normal DCMD framework utilized for level sheet, capillary or hollow-fibre films is appeared in Figure 10. It is worth citing that DCMD is primarily right for uses in which the main module of the bolster stream contains non-volatile solutes such as salt [16].

2.1.7 Freezing desalination

Figure 11 show the desalination by freezing forms is based on the reality of that ice crystals are made up of basically pure water. It comprises of three discrete steps: ice arrangement, ice cleaning, and ice dissolving. Since it features a number of points of interest, e.g. low vitality requirements, immunity of fouling and corrosion or scaling as well as nearly no pre-treatment etc., the freezing prepare has been developed quickly during the past 50 years. In spite of the fact that more efforts have been attempted, desalination by freezing is still within the frame of studies and pilot plant units; endeavours at its commercial application have not been effective until now. This chapter presents a hindsight to the authentic advancement of the freezing process and portrays the essential stream graph of each solidifying prepare. The principles of the process and capacities of the major process components are talked about in detail [17].
2.1.8 Hydrate desalination

Figure 12 show the Clathrate hydrate-based desalination (HyDesal) has been planned for seawater desalination. HyDesal preparation efficiently sprays within the lesson of methods built on freezing or freeze desalination. In this method, water atoms shape encloses round a visitor gas/liquid element, thereby efficiently unravelling themselves from saline arrangement indeed at temperatures upper than the typical freezing temperature of the water. These hydrate crystals while softened are basically new water besides the visitor part can be re-used in place of desalination. One mole of hydrate comprises approximately 85% water and 15% visitor air, which shows the tall possible of creating moderately clean water as of this handle. The briny is fair a thermodynamic curb besides is avoided from the hydrate encloses [18].

2.2 Non-thermal desalination process

According to description in Figure 2. [9] the other method for desalination is non thermal which describing four different method for desalination without using a heating source. According to that the types are as follow:

2.2.1 Electro-dialysis (ED) In ED , cations (orange) and anions (green) move over the cation trade film and anion trade film, separately, beneath the impact of the connected electrical field. The middle stream hence gets to be deionized as shown in Figure 13. [10].
2.2.2 Reverse osmosis (RO)
RO water molecules move through a semi-permeable film that rejects the particles in the pressurized feed arrangement. The water on the other side of the layer, as shown in the Figure 13, is salt free. In both RO and ED, $G_{\text{sep}}$, which depends on the feed, item and saline flux composition, speaks of the Gibbs free energy of separation to ensure that water is separated and solutes dissolved during desalination. As a whole $\Delta G_{\text{sep}}$ is less than $\Delta H_{\text{vap}}$ [10] at least two orders in size.

2.2.3 Ion Exchange Desalination (IX)
We have suggested a CFIE framework in this work to expel most of the solvent salts into desalt-free saltwater, with a conductivity of 20-70 $\mu$S/cm, as a pre-treatment item of the MBIE or the MFEDI mixed-bed exchange. The CFIE framework is shown in Figure 14 as a sundry bed occupied by solid-acid and weak-base tars simultaneously, and a bed with anion as if full of weak-base tar. The resin is strongly acidic and can adsorb cations across a wide range of pH magnitudes, although the weak-base tar can successfully suction the anions in acid situations and efficiently desorb under marginally antacid conditions. These essential characteristics of both types of resins allow CFIE to function effectively. The CFIE framework is in clump mode, rotated with advantage and regeneration, comparable to MEFDI. The water flows via the mixed bed for removing cations and a sure division of anions first, then the anion bed to eliminate the remaining anions. In the recovery phase, the water is filtered and the DC power is forced on the jumbled bed to successfully recover the applied tars. The mixed bed emanating from electro-regeneration is alkaline and can thus be employed appropriately to chemically regenerate the weak-base resin depleted in the anion bed. The concentrates that are composed throughout the recovery of anion bed are indifferent and can be refunded in genuine applications to a pre-treatment unit like RO for recall [19].

2.2.4 Extraction Desalination Process (ED)
The directional dissolvable extraction (DSE) has been shown to be a recently proposed water desalination process that can be used as directional solvent to isolate pure water from seawater. They utilized a synthesis of the net heat exchange system, which designed and optimized a continuous DSE handle for maximum heat recuperation. They stated that the DSE handle is more energy-efficient when used with octatonic corrosion than with a comparable handle that uses corrosive decani products. An exergy examination was not in any case considered to be a part of its study. The display ponder, based on its findings, focuses on the energy study of the improved DSE preparing stream graph, as indicated in Figure 15.
The optimized process includes a involvement tank, 2 payment tanks and six water circulating pumps for water, solvent and hot water, rejecting the difficulty of the heat exchanger system. The fundamental concept behind this process is that water solvency is increased with temperature within
the directionally dissolvable octatonic acid and a high level of rejection of salty ion within the directional solver. The method starts inside the blending tank in which the water from the sea (State 12) has mixed with the dissolvable direction (State 8). A few years ago, both marine and solvent water are frenzied to a height temperature, allowing water to break down into the octane acid in the midst of the mixing process. The saline meditation in the brine at State 13 is enlarged by absorbing water into the solvent. Saturated by clean water, the solvent is isolated in a high temperature settlement tank from the concentrated saline water 'brine' in dual partitioned streams (States 1 and 14). In order to finally lower its temperature by 4 and 23 states to 40, the saturated dissolvent (State 1) is thrust by heat exchangers. A mixture of soaked directionally solvent and pure water is the result of the cooling preparer. The water, which is dissolvable and pristine, is inserted into two strips within the tank with low temperatures. It collects the filtered stream of water (State 16) and recycles the soaking solvent stream (State 5). The State 9-State 21 maritime and State 6-State-7 solvents are preheated by four heat exchangers. For the outside forms of warming and cooling, three extra heat exchangers are used. The solvent-water bond (State 3) will be cooled at lowest prepared temperature by a heat exchanger (State 4). The second heat exchanger is used in the highest preparation temperature (State 8) to heat the reused solvent (State 7). The third heat exchanger is used to warm seawater to maximum handle temperature from State 21. A total of six pumps are used in the continuous preparation for the solvent, seawater and hot water [20].

Figure 15. Enhanced guiding solvent extraction (DSE) manner flow graph [20].
2.3 Additional types of FWG

2.3.1 Thermal type seawater desalination with barometric vacuum and solar energy

As well known, it cannot be denied that seawater desalination is the as it were commercial arrangement able of flouting over the worldwide water deficiency see Figure 16. Be that as it may, since seawater desalination is the method devouring a great sum of vitality, sparing vitality to deliver freshwater is amazingly vital in different seawater purification forms.

Vitality utilization of desalination prepare is assessed by the record named definite vitality utilization (SEC), which suggests the vitality for creating 1 kg of freshwater. For this cause, the renewable vitalities have been connected to the seawater purification for energy saving.

More often than not, in such an item, the sun powered vitalities are received to heat seawater, and to transport seawater and freshwater. In this revision, for the additional decrease of the SEC, the passive vacuity tube founded on the hydro-static head was connected. This revision was basically centred on the freshwater generation rates with the tallness of an inert vacuity tube [21].

![Figure 16. Schematic diagram of the salt water purification system through barometric vacuity and solar vitality [21].](image)

2.3.2 Fresh water from the saltwater by the usage of the waste heat as of diesel machines

Right now, ocean and stream transport is creating unequivocally, transporting products by ships and waterway vessels have been subsidizing primarily to the transference of products within the nation and nations round the creation.
Diesel motors are the heart of a transport, a diesel propeller, and a revolving movement for the propeller. In the working of diesel motors, the fuel burned within the combustion chamber shapes a burning gas with tall temperature and weight, extension and mechanical work acting on the best of the cylinder, making the cylinder transfers descending, the responding movement of the cylinder is changed into the revolution of the crankshaft much obliged to the energetic of the motor margin arm, the crankshaft transfers the revolving movement for the propeller through hold, gearbox.

The warm vitality produced amid the combustion of the fuel isn't totally bowed into motorized victory but is somewhat misplaced owing to misfortunes such as the release of gas, warming the barrel profile, barrel cap, cylinder beat and warm up the engine. In the event that the motor isn't cooled at the proper temperature, the motor parts will be crushed by warm stress.

To preserve the temperature of the machine; sums at the correct temperature one must cool the engine in New water, New water will get warm from the unobtrusive components of the engine will warm up and be driven out, this new water will be cooled by seawater to the proper temperature and after that returned to cooling the machine concurring to the another cycle, [22].

2.3.3 Solar steam generation plant
A solar steam generator consists of a PTC collector field, a heat tank, and a heat exchanger called a steam generator, and provides the steam motif for the MED plant. Figure 17 shows a scheme of a solar steam generation plant [23].

![Solar steam generation plant](image)

**Figure 17.** Schematic of the solar steam generation plant [23].

3. Advantages and disadvantages of FWG types
3.1 Advantages and disadvantages of Freezing Processes
The advantages and disadvantages of each process are commented on. The freezing process will be utilized broadly within the field of industrial waste water treatment and food industry in the future. The combination of freezing forms and other desalination forms can reduce the rejected brine from desalination and deliver different salts from seawater [17].

3.2 Advantages and disadvantages of MSF
Advantages and disadvantages of MSF can be describing as follow [23]:

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3.2.1 *The major advantages of the MSF technology are as follows:*

- Exceptionally tall unwavering quality and security record.
- Exceptionally tall item water quality.
- Tall independence with respect to feed water quality.
- Accessibility of profoundly experienced manpower for operation and maintenance.
- Capability to supply tremendous amounts of high-quality freshwater to meet the ever-increasing demand for freshwater with a negligible or insignificant effect on the environment.

3.2.2 *The major disadvantages of technology are as follows:*

- Exceptionally low water recovery of the MSF ratio, typically about 10% of the overall feed water to the MSF is recuperated as refined water.
- High thermal vitality input, regularly 290kJ/kg of item water, which puts the MSF handle inside the foremost raised essentialness utilization category in comparison to other commercially accessible desalination processes.
- Rigidity in control and water cogeneration frameworks due to the dependence of MSF on the steam imported from the SBTG as the main source of energy.
- Moderately tall capital taken a toll.

3.3 *Membrane Distillation (MD) (Advantages and Disadvantages)*

3.3.1 *Advantages of the Membrane Distillation (MD) process*

The MD prepare was to begin with conceived as a division prepare that might work with a slightest exterior vitality need and the slightest capital and arrive for the plant.

Required gear for the MD handle are much less, which deciphers to an investment funds in terms of genuine state; and working temperatures are much lower, since it isn't essential to warm the strategy liquid over its bubbling temperature. These profits result in less heat misplaced to the environment through the equipment surface.

On the other hand, the bolster temperatures in MD ordinarily extended from 35 to 85°C. Subsequently, low review, waste and/or elective energy sources such as solar, wind or geothermal energies can be coupled with MD frameworks for an economical and vitality effective desalination and water/wastewater medicines.

In fact, MD plants fuelled by sun powered vitality have been appeared to be taken a toll competitive with RO in inaccessible ranges [16].

3.3.2 *Disadvantages of the Membrane Distillation (MD) process*

The most important point for MD process disadvantages points [24]:

- Membrane have short life so they have to replace in about (3-5 years).
- Biological fouling.
- Slow process
- It has a high operating cost
- It requires low operating pressure (up to 4 bars)

3.4 *Ion Exchange Advantages*

The CFIE scheme has many pluses, counting simple means, easy operation, no chemicals consumed, and no wastewater formed [20]
3.5 Different types of FWG with their advantages [18]

Table 1: Advantages/Disadvantages of Other Technologies [18]

| Process             | Advantage/ Restrictions                                                                 | Water Recovery (%) | Cost ($/ton of water) | Definite Vitality Consumption (kWh/m3 of water) |
|---------------------|-----------------------------------------------------------------------------------------|--------------------|-----------------------|-----------------------------------------------|
| Distillation (MSF)  | – In tallness essentialness price (Temperatures of 80 –95 °C) – Moo water recovery       | Up to 20%          | 0.56 -1.75            | 13.5 – 25.5                                   |
|                     | – Appropriate for high concentration of TDS                                               |                    |                       |                                               |
| Membrane (RO)       | – Requires pre-treatment                                                                 | Up to 55%          | 0.45 – 0.66           | 1.85 – 36.3                                   |
|                     | – Weight of 50 –80 bars                                                                   |                    |                       |                                               |
|                     | – Exceptionally delicate to impurities                                                   |                    |                       |                                               |
|                     | – Energy-intensive                                                                       |                    |                       |                                               |
|                     | – Substitution of membrane frequently                                                    |                    |                       |                                               |
|                     | – Loo water recovery                                                                      |                    |                       |                                               |
| HyDesal             | – Little maintenance                                                                      | 35 – 40%           | 0.46 – 0.52           | 0.60 – 65.29                                  |
|                     | – Big Water retrieval                                                                    |                    |                       |                                               |
|                     | – Suitable for a great concentration of TDS                                               |                    |                       |                                               |
| Freeze Desalination | – Energy-severe                                                                          | Up to 20%          | 0.34                  | 11.9                                          |
|                     | – Low total water Retrieval                                                              |                    |                       |                                               |

4. Design consideration

4.1 The membrane ideal for RO should correspond to the following requirements [25]:
- relative cost-effectiveness,
- lifelong and reliable structure,
- creep resistance,
- thermal and chemical stability of seawater,
- resistance to whole types of foulation (inorganic, organic, microbiological, colloidal)
- High temperature resistance,
- high water permeability,
- high rejection of salt

4.2 Materials of construction for fresh water generator

The shell is ordinarily manufactured from steel (or non-ferrous metal like cupro-nickels) which has been shot impacted then coated with a few frame of protective.

The important points around protective coatings are:
• They must be inactive and prevent corrosion.
• They must stand up to the impact of corrosive cleaning and water treatment chemicals.
• They must have a great bond with the metal [22].

5. Conclusions
The research for means to purify water has become much greater, and one of the most important methods that have been devised is the desalination of sea water using special desalination plants, through which impurities and dirt are removed from the water in addition to heavy metals. Therefore, this research has dealt with the most important methods used in desalination of drinking water. Because of the complex purification methods and the cost of spending energy on them, useful solutions have come to this problem, including reducing the pressure inside the tank. This can be achieved using a vacuum pump, and it significantly reduces the amount of vitality required for desalination. For example, water at a pressure of 0.1 atm boils at 50 °C instead of 100 °C.

6. References
[1]. Prüss-Ustün A, Wolf J, Bartram J, Clasen T, Cumming O, Freeman M. C, and Johnston R 2019 Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: an updated analysis with a focus on low-and middle-income countries. International journal of hygiene and environmental health. 222(5), 765-777.

[2]. Zhang X, Chen N, Sheng H Ip C, Yang L, Chen Y, and Niyogi D 2019 Urban drought challenge to 2030 sustainable development goals. Science of the Total Environment. 693, 133536.

[3]. Wang X, Christ A, Regenauer-Lieb K, Hooman K, and Chua H T 2011 Low grade heat driven multi-effect distillation technology. International Journal of Heat and Mass Transfer. 54(25-26) 5497-5503.

[4]. Joo H J & Kwak H Y 2013 Performance evaluation of multi-effect distiller for optimized solar thermal desalination. Applied thermal engineering. 61(2) 491-499.

[5]. Joshi V P, Joshi V S, Kothari H A, Mahajan M D, Chaudhari M B, and Sant K D 2017 Experimental investigations on a portable fresh water generator using a thermoelectric cooler. Energy Procedia. 109 161-166.

[6]. Nguyen L H 2019 Design And Fabrication Of Distillation Equipment Of Fresh Water From The Seawater By The Use Of The Waste Heat From Diesel Engines. Journal of Mechanical Engineering Research and Developments (JMERD), 42(2), 79-83.

[7]. Vakilabadi M A, Bidi M, Najafi A F & Ahmadi M H 2020 Energy exergy analysis and performance evaluation of a vacuum evaporator for solar thermal power plant zero liquid discharge systems. Journal of Thermal Analysis and Calorimetry. 139(2) 1275-1290.

[8]. Feili M, Ghaebi H, Parikhani T, &Rostamzadeh H 2020 Exergoeconomic analysis and optimization of a new combined power and freshwater system driven by waste heat of a marine diesel engine. Thermal Science and Engineering Progress. 18, 100513.
[9]. Ng K C, Thu K, Kim Y, Chakraborty A, and Amy G 2013 Adsorption desalination: an emerging low-cost thermal desalination method. Desalination. 308 pp 161-179.

[10]. Deshmukh, A, Boo C, Karanikola V, Lin S, Straub A P, Tong T and Elimelech M 2018 Membrane distillation at the water-energy nexus: limits, opportunities, and challenges. Energy & Environmental Science. 11(5) 1177-1196.

[11]. Lukic N, Diezel L L, Fröba A P, & Leipertz A 2010 Economical aspects of the improvement of a mechanical vapour compression desalination plant by dropwise condensation. Desalination. 264(1-2), 173-178.

[12]. Toth A J 2020 Modelling and Optimisation of Multi-Stage Flash Distillation and Reverse Osmosis for Desalination of Saline Process Wastewater Sources. Membranes. 10(10) 265.

[13]. Saldivia D, Rosales C, Barraza R and Cornejo L 2019 Computational analysis for a multi-effect distillation (MED) plant driven by solar energy in Chile. Renewable Energy. 132, 206-220.

[14]. Bellefontaine N, Haag F, Lindén O & Matheickal O 2010 Emerging ballast water management systems. In Proceedings of the IMO-WNU Research and Development Forum, Malmö, Sweden, WNU Publications.

[15]. Thu K, Ng K C, Saha B B, Chakraborty A & Koyama S 2009 Operational strategy of adsorption desalination systems. International Journal of Heat and Mass Transfer. 52(7-8) 1811-1816.

[16]. Shirazi M M A & Kargari A 2015 A review on applications of membrane distillation (MD) process for wastewater treatment. J. Membr. Sci. Res. 1, 101-112.

[17]. Lu Z and Xu L 2010 Freezing desalination process. Thermal desalination processes. 2.

[18]. Babu P, Nambiar A, He T, Karimi I A, Lee J D, Englezos P & Linga P 2018 A review of clathrate hydrate based desalination to strengthen energy—water nexus. ACS Sustainable Chemistry & Engineering. 6(7) 8093-8107.

[19]. Hu J, Chen Y, Guo L & Chen X 2015 Chemical-free ion exchange and its application for desalination. Desalination. 365 144-150.

[20]. Alotaibi S, Ibrahim O M, Wang Y & Luo T 2019 Exergy analysis of directional solvent extraction desalination process. Entropy. 21(3), 321.

[21]. Choi S H 2017 Thermal type seawater desalination with barometric vacuum and solar energy. Energy. 141 1332-1349.

[22]. Maheswari K S, Murugavel K K & Esakkimuthu G 2015 Thermal desalination using diesel engine exhaust waste heat—an experimental analysis. Desalination 358, 94-100.

[23]. Al-Wazzan Y & Al-Modaf F 2001 Seawater desalination in Kuwait using multistage flash evaporation technology—historical overview. Desalination. 134(1-3), 257-267.

[24]. Pangarkar B L, Deshmukh S K, Sapkal V S & Sapkal R S 2016 Review of membrane distillation process for water purification. Desalination and Water Treatment. 57(7) 2959-2981.

[25]. Emamdoost N, Jafari A and Kouhi Kamali R 2020 Implementing multiple-effect distillation and reverse osmosis thermal coupling to improve desalination process performance in combined water and power plants. Energy Conversion and Management. 221 113176.