A Versatile Solar and Electric Water Distiller

Azzeddine Ferrah
Faculty of Engineering,
Sharjah, UAE
aferrah@gmail.com

Marwa Samer, Farah Mohamed, Maitha Abdulla,
Muna Obaid, Shamsa Humaid & Hamda Ahmed
Faculty of Engineering,
Sharjah, UAE

***Abstract*— The present paper discusses the feasibility and the features of a newly designed portable water desalinator/distiller. The goal is to design a small unit for desalinating or distilling brackish or soiled water. The proposed desalinator/distiller is a hybrid system that uses two sources of energy, namely: solar and electrical. It relies on solar energy when being used at locations where electricity is expensive or inaccessible. On the other hand, it uses electric energy when sunshine is unavailable for considerable periods of time, such as under rainy or cloudy skies, or during winter seasons when the sun radiation is weak or not enough to evaporate water. This innovative project is aimed to benefit communities in rural villages, long journey travelers in deserts and arid mountains, people living alongside polluted rivers and lakes, and people living in refugees' camps. It can also benefit people with hard water supplies. The paper investigates and discusses the proposed hybrid desalinator/distiller (HDD). The work presented is based entirely on the work carried out by final year electrical engineering students, during their capstone design project. The project work, presented, is a manifestation of the students learning during previous semesters. It puts into practice the application of thermal and heat transfer principles, that the student learned in earlier courses.**

***Index Terms*—Desalination, desalinator, distiller, solar still, solar energy.**

I. INTRODUCTION

Our planet earth contains about $1.4x10^9$ km^3 of water, which covers approximately 70% of the planet surface area; with 97.5% salt water 80% of the remaining 2.5% fresh water is frozen in icecaps. The amount of fresh water resources is nearly constant since the start of life on earth. On the other hand, the world population has increased more rapidly over a period of less than 200 years [1]. At present, about 40% of the world's population is suffering from serious water shortages. By the year 2025, this percentage is expected to increase to more than 60% [1]. Population growth in developing countries is becoming more and more significant, in sub-Saharan Africa and South East Asia; where access to clean water is already a challenge for the current population, presenting a high risk of increasing water scarcity.

Desalinating sea water is generally more costly than fresh water from rivers or groundwater, water recycling and water conservation. However, these alternatives are not always accessible and reserves are being depleted at a critical rate worldwide. Currently, approximately 1% of the world's population is dependent on desalinated water to meet daily needs, but the UN expects that 14% of the world's population will encounter water scarcity by 2025 [2]

Desalination is particularly relevant in dry countries, such as in the Middle East and North Africa countries, as shown Fig.1, which traditionally have no significant rainfall. Per the International Desalination Association, in June 2015, 18,426 desalination plants operated worldwide, producing 86.8 million cubic meters per day, providing water for 300 million people [3].

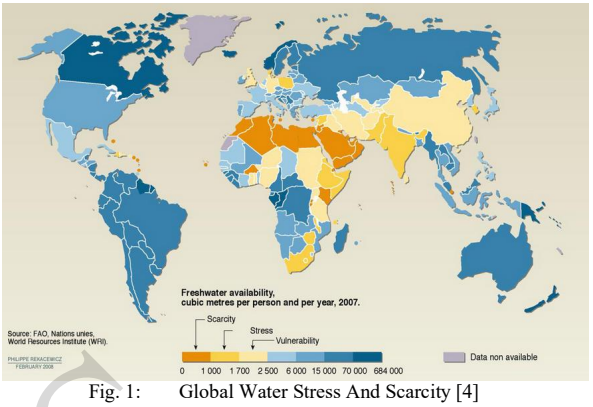

Fig. 1: Global Water Stress And Scarcity [4]

In 2012 Emirates 24/7 reported that the UAE is the World's second largest, after Saudi Arabia, desalination producer, pumping around 1.7bcm of desalinated water a year [5]. Because of the hot climate and the rapid growth in population the UAE and other GCC (Gulf Cooperation Council) countries are among the highest water consumers in the world. The UAE averages as high as 360 liters a day per person and that Abu Dhabi has the highest consumption rate, standing more than 550 liters per person compared with 200 liters in Sharjah [6]. A typical UAE industrial desalination plant is shown in Fig. 2.

About 70% of the world total fresh water is used for irrigation, 20% is used for industrial purposes, and only about 10% is consumed for domestic uses as drinking and cleaning water. In case of a shortage of fresh water, desalination is the process by which usable and drinkable fresh water from any source of saline water is produced to meet the demand.

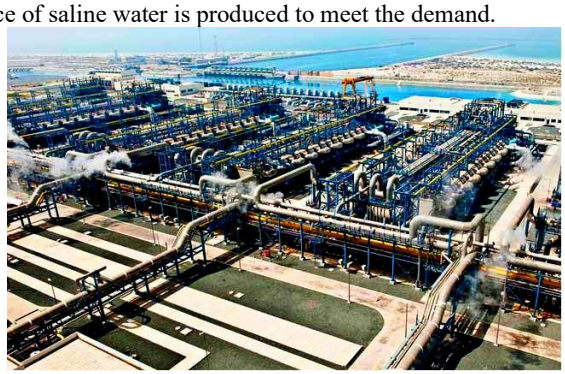

Fig. 2: A Typical sea water desalination plant [2]

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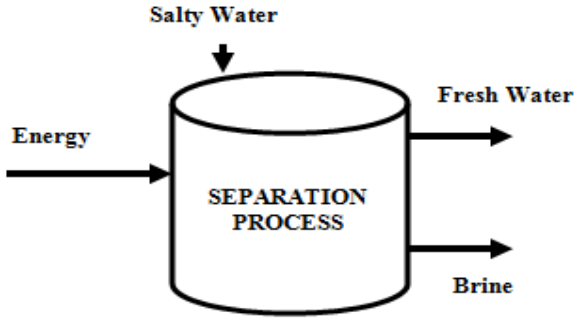
II. WATER DESALINATION METHODS

Water desalination refers to the removal of salts and minerals from water. Saltwater is desalinated to produce water suitable for human consumption and agriculture. One by-product of desalination is salt. Desalination is used on many seagoing ships and submarines. Most of the modern interest in desalination is focused on cost-effective provision of fresh water for human use [7]. In general, desalination processes involve the separation of fresh water from sea or brackish water, where the salts are concentrated in the rejected brine stream, as shown in Fig. 3. The separation process can either Be thermal or membrane based process. Also, the energy used to drive the separation process can be thermal, mechanical,



electrical, renewable, or any other form of suitable energy.

Fig. 3: Basics Of Desalination Process

Thermal based separation processes include the following methods:

- Single Effect Evaporation
- Multiple Effect Evaporation
- Multistage Flash
- Thermal Vapor Compression
- Mechanical Vapor Compression
- Adsorption Vapor Compression
- Absorption Vapor Compression
- Chemical Vapor Compression
- Humidification-dehumidification (HDH)

Membrane based separation processes include the following methods:

- Electro-dialysis
- Reverse Osmosis

Most of the above-mentioned processes are industrial processes and are out of the scope of the present work, which focuses on the HDH method and at a very smaller scale only. The HDH process is an operation where thermal energy is added. The heating steam in this process is obtained from a co-generation power plant, a boiler, or from solar energy.

At smaller scale, solar stills and electric distillers can be used as desalinators to benefit communities in rural villages, long journey travelers in deserts and arid mountains, people living alongside polluted rivers and lakes, people living in refugees' camps, and people living in remote settlements where salty or polluted water is the only type of water available and demand is minimal. On the other hand, pipelining water to such areas is inefficient and costly, and delivery by trucks is unreliable and expensive. Under these uncompromising circumstances, small and portable desalinators are viewed as a means to ensure a highly needed supply of water. An added benefit of water distillation resides in its ability to remove all salts as well as biological contaminants, such as parasites, botulinus, and E. coli, etc.

Solar water distillation produces a very pure water, cleaner than the purest rainwater. This distillation process removes impurities such as salts and heavy metals as well as eliminates microbiological organisms. Solar still production is a function of ambient temperature and solar energy radiation. It can be very effective and completely cost-free at locations where high solar irradiation is abundant and ambient temperature is sufficiently high. The UAE fits perfectly this requirement. The UAE enjoys a high degree of solar radiation throughout the year and high sunshine hours, as clearly shown in the solar map in Fig. 4.

It has an average daily of "Peak Sun Hours" of 4.5 to 6.5 hours throughout the year and an average daily solar radiation ranging from 5.5 to 6.0kWh/m^2/day in July to 2.5 to 3.0kWh/m^2/day in January, giving it one of the highest solar energy densities in the world

A typical monthly irradiance, for the month of September, is shown in Fig. 5, for the geographical location pictured in Fig. 6. The irradiance data was collected at a location within Sharjah (University City) at coordinates 25°18'4''N and 55°28'59" E.

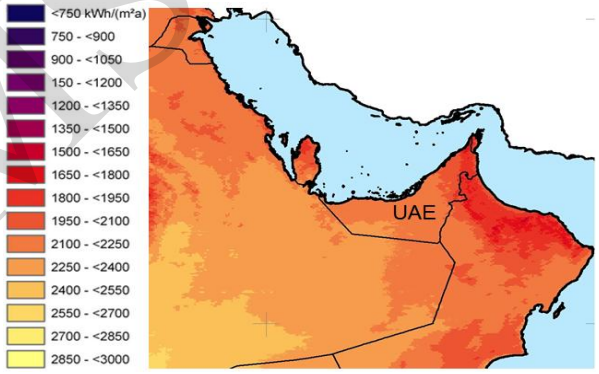


Fig. 4: UAE Solar Map

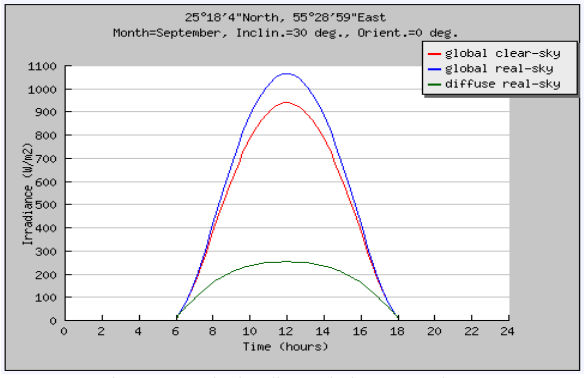


Fig. 5: Solar irradiance during September

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Fig. 6: Location of the Site Considered In This Study

The present students' project aims to contribute to the wellbeing of the above described communities, by designing a versatile portable water desalinator that could work on solar and electric energy, depending on the necessity and availability of either of these sources. The availability of dual sources in the proposed desalinator makes it a hybrid system that will perfectly fit the purpose of water desalination under all weather conditions day and night.

It has to be noted that conventional solar stills will work, at most, only during a very limited number of hours during daytime, depending on location, with no operation at all in the early mornings, in the afternoons, and during night time. The present prototype of the hybrid desalinator being designed will aim to produce a 500 ml of fresh water for drinking only. If the proposed HDD is scaled up, it will be able to produce much larger quantities enough to meet the daily fresh water demand (for drinking and cooking) of an average family. The rate of production per hour will, of course, depend on the energy being used for evaporation. A complete description of the proposed portable water desalinator/distiller is given in the following section.

III. DESCRIPTION OF THE HYBRID DISTILLER-DESALINATOR

The proposed water purification system integrates two systems in one (hybrid). A conventional solar glass stiller and an electric powered HDH, as shown in Fig. 7. The prototype was constructed using locally available materials, apart from a few components that have to be ordered online from overseas. The enclosure of the whole system was also machined locally according to the measurements and dimensions specified.

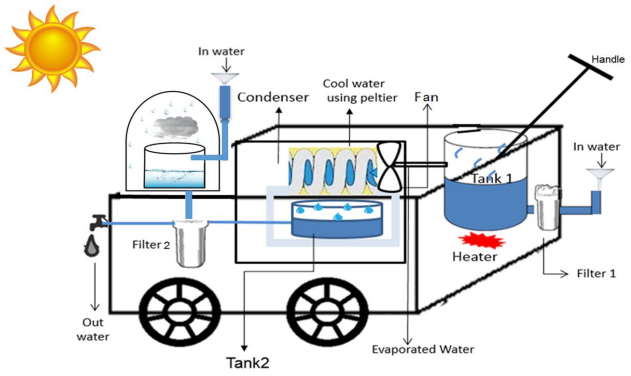

Fig. 7: The proposed hybrid desalinator/distiller (HDD)

For desalination/distillation using solar energy, the "Solar Still" incorporated into the HDD system is used.

The solar still, shown in Fig. 8, works on the principle of "greenhouse" effect. The water to be purified is discharged directly into the internal container of the solar still. This container is made out of a stainless-steel cylinder painted inside and out in black and covered with a glass bowl. The glass bowl is firmly glued to the base of the still. The still is made perfectly air tight to facilitate the process of evaporation and condensation. The glass bowl allows the solar radiation to pass through to the inside container.

The black paint of the internal container surfaces improves the absorption of sunrays (solar radiation). When the water heats up the evaporation process starts and the water vapor starts condensing all over the interior surfaces of the spherical glass bowl. The condensed water drops trickle down the inner curved surfaces of the glass. The water gathered will slowly drip into a small storage space (reservoir), and then is channeled down to the outlet filter before directed to the outlet tap. Through this process salts and minerals will remain at the bottom of the container.



Fig. 8: Solar glass stiller

The usefulness and strength of the "solar still" resides in its cost-free operation and its functionality when there are no other sources of energy at disposal. Nonetheless, a solar still has many shortcomings that include its zero-performance

during winter season, cloudy days, cool days, and windy days. Also, at its best performance solar still takes extremely long hours to yield a very limited quantity of water.

For this reason, the proposed Hybrid Distiller/Desalinator offers an additional feature to compensate for the shortcomings of the solar still. The proposed HDD can also operate using electric energy, wherever and whenever available. It can be used in homes, schools, rural hospitals, cars, camping sites, refugees' camps, and in any other location where electricity is accessible through a mains socket. Also, the electrically powered HDD can work indoors and outdoors and under any weather conditions.

For electric mains operation and a perfect quick water distillation, water is poured into tank 1 for boiling. The water vapor resulting from the water boil is directed through to the condensation chamber, where Peltier coolers are fixed. The condensed water is channeled through to outlet tap. Both inlet and outlet are fitted with water filters. Water levels in inlet and outlet tanks are monitored using water levels detectors. The main core of the electric distiller consists of a heating element (800 W) that can evaporate 500 ml of water poured in the inlet tank within 40 minutes.

The evaporated water is immediately channeled to the condenser for condensation and cooling before storage in the outlet tank ready for use. Fig. 9. shows the evaporator and the Peltier condenser, during one of the preliminary tests, before their final mounting inside the system's enclosure. The complete system, incorporating the solar still and the electric distiller, is shown in Fig. 10. The solar still is boosted with concentration mirrors, as shown, to speed up the evaporation process.

While the distillation process is very effective in removing salts, minerals, parasites, bacteria, and heavy metals, certain pesticides and contaminants like volatile organic compounds (VOCs) convert into vapor and travel out of the boiling chamber. For this reason, the HDD is fitted with carbon pre- and post-filters to effectively eliminate these contaminants.

The electric distiller is completely insulated and housed inside a stainless steel enclosure mounted on 4 wheels for ease of transportation.

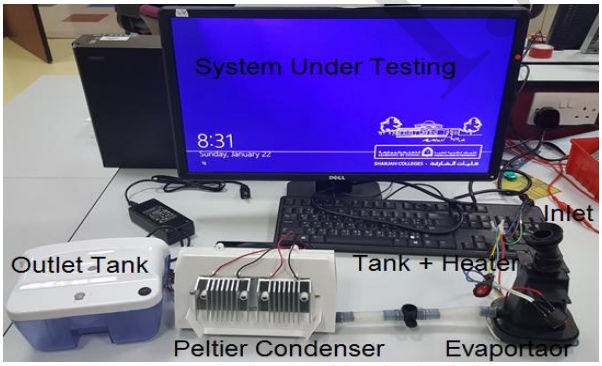

Fig. 9: Main Elements of the Electric Distiller

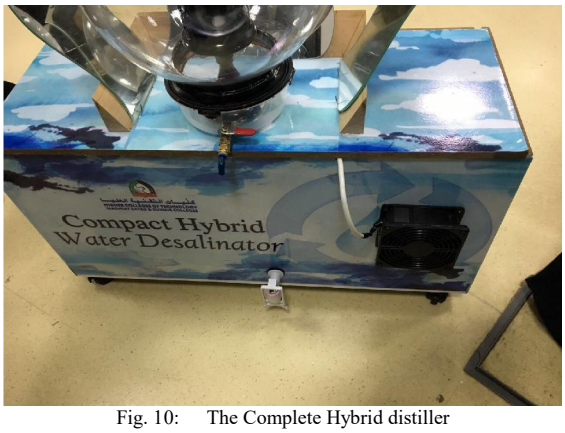

Fig. 10: The Complete Hybrid distiller

IV. PRELIMINARY TESTING RESULTS

The crudely constructed single-stage prototype distiller was initially tested (during the month of November) to ensure the validity of the proposed system. The solar still was tested by pouring 1.5 L of salted soiled water in the inner container. The saline water was prepared using a solution made up of tap water, salt, and soil. The salt was about 5% of the whole solution. The still was left in the sunny open space in front of the engineering block. After 5 hours of exposure to sunlight, water was collected and measured. Repeated tested proved that the prototype glass stiller can produce about 0.5 L of distilled water per 1 kWh (sun-hour). Therefore, for a larger still size production rates can reach 3 liters in the month of July (summer) and 1.5 liters in the month of January (winter).

Whereas, testing the electric distiller indoors, using the same quantity and quality of water, produced 0.75 L in 1 hour only. The results obtained confirm that the electric distiller is at least 75% faster than the solar still distiller.

The quality of produced distilled water was tested by measuring three fundamental parameters, i.e., the PH, the conductivity, and the TDS (Total Dissolved Solids) of the water sample [8]. The quality of the collected samples was assessed using PH and TDS digital meters. The PH meter indicates the PH level in water samples to establish its acidity or alkalinity. The TDS meter indicate the TDS level (in ppm), the conductivity (in µS/cm), and the temperature (in ^{o}C) of the water sample. To make the comparison between the water produced by the HDD and other types of waters, the water quality of 4 leading mineral bottled water brands, in the UAE, was assessed using the same water quality meters and procedures. The tap water, used for testing, is an indicative sample of water pipelined to the area shown in Fig. 7.

Generally, this water is used mainly for irrigation, washing, cleaning, and other household chores, but rarely (if ever) is consumed for drinking. Most people rely on mineral bottled water. The measurement results are summarized in Table I. From Table I, the distilled water obtained through evaporation by boiling is slightly different from the one obtained using evaporation by direct solar radiation. This may be explained by the fact that during boiling few solid particles are transported by vapor to combine with the freshly condensed water. Overall, it can be concluded that the distilled water produced

by the HDD processes has superior quality than all of the waters tested in this work. In addition to health benefits, the cost of distilled water produced by HDD will be only a fraction of the cost of the cheapest bottled brand available in the market. The versatility, flexibility, and the enormous economic benefits of this innovative system are undisputable in areas where water is scarce or costly to acquire.

Table I: Distilled water quality

Values at Room Temperature (25 ºC)			
TDS	***Conductivity***	***PH***	***Temperature***
Solar Still Distiller			
0 ppm	6.5 µS/cm	7	28 ºC
Electric Distiller			
2 ppm	8 µS/cm	7	26 ºC
Saline Water			
>2023	>3800	8.5	24 ºC
Tap Water			
853	1707	7	26.3 ºC
Bottled Water Brand A			
132	267	7.8	21.8 ºC
Bottled Water Brand B			
112	225	7.3	21.7 ºC
Bottled Water Brand C			
91	183	7.6	21.2 ºC
Bottled Water Brand D			
85	171	7	16 ºC

V. CONCLUSIONS

Water Desalination/Distillation is an effective process for household, commercial, and industrial use. It can produce water with a distinct quality and purity that could reach up to 99%. Compact and portable desalinator units are being improved to increase efficiency and water yield, making them more popular, cost-effective, and in high demand.

The present work proposes an innovative design of a versatile hybrid water desalinator that could work on direct sun radiation (during high sun-hours) and on mains electric power during winter season, bad weather, and night time.

The proposed hybrid water desalinator is still undergoing development and improvement, as students' final year project. Initial results obtained, from testing a small prototype, proved to be very promising. Further development and work is underway to improve on the present design, to increase the unit's fresh water yield. Also, alternatives are being considered to replace the heating element in the unit with a low power heater and consider the use of solar energy, as a third energy source that could be added to the direct solar radiation and mains electricity.

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