Chapter

Performance Evaluation of Desalination Technologies at Common Energy Platform

Muhammad Wakil Shahzad, Kim Choon Ng, Muhammad Burhan, Chen Qian, Doskhan Ybyraiykul, M. Kumja, Muhammad Ahmad Jamil, Yinzhu Jiang, Nida Imtiaz and Ben Bin Xu

Abstract

A major fraction of secondary energy consumed for our daily activities, such as electricity and low-grade heat sources, emanates from the conversion of fossil fuels in power plants. In the seawater desalination processes, the energy efficiency is usually expressed in kWh electricity or kWh of low-grade heat per unit volume of water produced. Although kWh energy unit provides a quantitative measure of input energy, it has subtly omitted the embedded quality of supplied energy to desalination plants. In assuming the equivalency across dissimilar energy forms, it results in a thermodynamic misconception that has eluded the desalination industry hitherto, i.e., not all units of derived energy are created equal. An incomplete energy efficacy approach may result in the inferior selection of desalination processes to be deployed; —a phenomenon observed in the trend of installed desalination capacity globally. Operating a less efficient desalination plant over its lifespan would create much economic burdens including a higher unit cost of water, higher CO_2 emissions and greater brine discharge to the environment. This book chapter clarifies the key concept and a thermodynamic framework to rectify the misconception in energy consumption, permitting energy planners and designers to optimize deployment of future desalination plants for energy sustainability. We have derived conversion factors to convert assorted derived energies into standard primary energy for fair comparison.

Keywords: sustainable desalination, thermodynamic limit, universal performance ratio, primary energy

1. Introduction

The global demand for potable water to meet all activities of mankind, in the industrial, domestic and agricultural sectors has been increasing rapidly due primarily to three growth factors, namely (i) an increasing world' population in developing countries, (ii) the quest for higher economic growth in all economies and (iii) the over-abstraction of ground water and the degradation of existing natural water sources on land. Much of fresh water found on land, namely lakes, wetlands and rivers, is gradually being polluted by indiscriminate discharge of man-made pollutants. By the year 2030, Global Water Intelligence [1] has projected an increase in annual potable-water demand from the current level of 5300–6900 billion cubic meters (bcm), equivalent to a compound annual growth rate of over 2%, as shown in **Table 1**. Yet, the existing sustainable potable water supply, mainly from natural precipitation sources, remains constant at 4200 bcm annually. Such a shortfall in the supply-demand of greater than 2700 bcm annually can only be met by reliable desalination methods [2]. Many ad-hoc measures to conserve water consumption and better manage the supply infrastructure can improve the water use inventory in water stressed countries [3]. However, ground water extraction rates are far greater than the rates at which they are replenished and there is over extraction from rivers [4]. Even with a degree of water re-use there will be a deficit between consumption and sustainable supply. Thus, the only practical means of meeting the future global potable water needs is by seawater desalination [5].

For seawater desalination at ambient temperature, the minimum work needed to separate dissolved salt ions of 3.5% by weight from the brine (within the solution) is termed as the thermodynamic limit (TL) of the normal seawater. Invoking the Gibbs equations for the separation process where the mass fractions of dissolved salts, the activity coefficients of water and solute are known, the theoretical work can be readily found to be 0.78 $kWh_{\_primary\ energy(pe)}$ per cubic meter of potable water or alternatively, the amount of potable water could be theoretically attained at TL is 1.282 m^3 per $kWh_{\_pe}$ consumption [6]. The primary energy (PE) is the naturally available work and it is equivalent to the respective calorific value of fuel burned. It implies that the $kWh_{\_pe}/m^3$ of energy consumption at TL is totally devoid of dissipative losses as the processes are deemed ideal, i.e., the available work as described by classical thermodynamics. Unfortunately, such a concept has been grossly misinterpreted in the literature. The recent reports indicated that energy efficacy of exiting methods in seawater desalination have achieved merely 13% of the TL [7–11]. This shows that currently desalination processes are not consuming fossil fuel energy sources efficiently. Thus, there is a great motivation to improve the energy efficacy of desalination processes to meet the sustainable goals of future water supplies.

In this chapter, the authors attempt to address two challenges facing the desalination industry: Firstly, there is a need to have a common thermodynamic framework to define the absolute value of energy supplied to separation processes. The energy consumed by assorted desalination processes must incorporate both quantity and quality aspects at the respective input conditions of processes. Unfortunately, the quality of dissimilar energy supplied to assorted desalination methods hitherto has been inadvertently omitted. We accentuate that a meaningful efficacy comparison of dissimilar desalination methods can be achieved with a common thermodynamic platform of high to low temperature reservoirs. All derived energy consumption of desalination processes is equivalently transformed to the

Water consumption by sectors	Potable water from natural precipitation 10^9 m^3 or bcm	2010 bcm/year	2018 bcm/year	2030 bcm/year	Predicted deficit in water bcm/year
Industry	4200	3100	3600	4500	2700
Agriculture		800	1028	1500	
Domestic		600	705	900	
Total		4500	5333	6900	

Table 1.
The projected demand and supply of potable water for the industry, agriculture and domestic sectors, as reported by global water intelligence (GWI) [1–3].

consumption of primary energy. Such procedures are predicated on either the same equivalent Carnot work output or input depending on the nature of desalination methods used. More importantly, the proposed methodology provides a direct apportionment, in the form conversion factors (CF), in the existing cogeneration power plants setting producing electricity and heat for desalination processes. Secondly, the authors opined that an optimally-designed desalination system can readily attain up to 35% of the TL, as reflected by the many plausible heat engines operating currently in other industries. A quantum improvement in the efficiency of separation processes of seawater desalination is most likely to realize either by (i) developing better performing work-driven systems such as thin-film composite materials or (ii) a higher thermodynamic synergy between the heat-driven processes. In the later section, the authors will highlight a hybrid heat-driven cycle, that were successfully tested at KAUST, attained the best energy efficacy for seawater desalination of 20% [12].

2. Limitations of current evaluation methodologies

At present, the conventional secondary or derived energy units, expressed in kWh of electricity or thermal heat source, are used inadequately for energy efficiency comparison between all types of desalination processes [13, 14]. This practice is insufficient because it has omitted a key aspect of energy quality embedded in the supply fuels. As demonstrated later, the assumption that all derived energy, no matter how dissimilar in forms, are deemed directly equivalent to each other which is thermodynamically inadequate. The units of energy measurement, namely kWh or 3.6 MJ, expresses merely its quantitative aspect but it has ignored the qualitative aspect of the energy used.

For example, same heat input, Q(1 kWh), is supplied to two processes, as depicted on a temperature versus entropy diagram of **Figure 1**. States 1–2 shows higher temperature process and states 3–4 at a lower temperature, i.e., $T_1 >> T_3$. Using the concept of an ideal Carnot cycle at the same heat input, the available work that could be extracted from the former process is higher than the latter. Being an isothermal cycle in a T-S diagram, i.e., $\oint_{12dc} Q = \oint_{12dc} W \ and \ \oint_{12dc} U = 0$, the energy input from a higher temperature source yields a larger amount of useful work due primarily to the better quality of heat input. This is reflected by the dissimilar

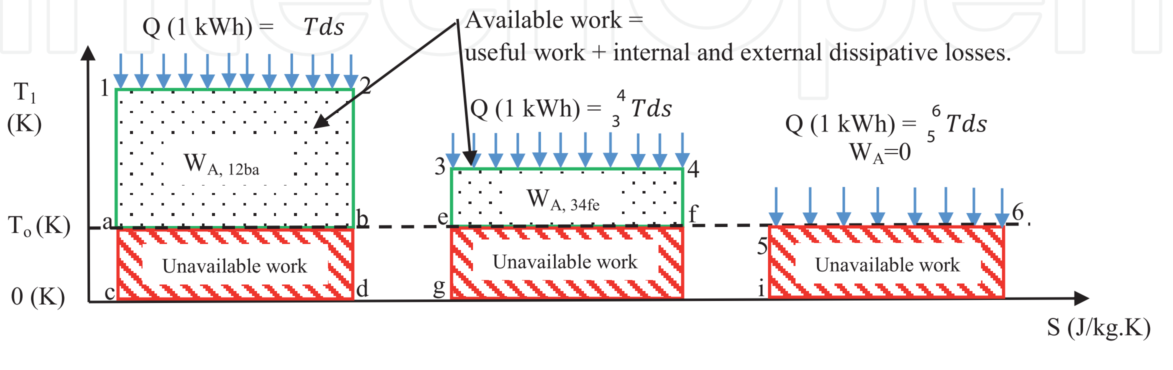


Figure 1.
A graphical demonstration of the energetic quantity and quality to thermodynamic cycles. Despite having same quantity of energy input, say, Q = 1 kWh, a higher available work could be produced from the process of a higher input temperature that is, $W_{A,12ba} >> W_{A,34fe}$. Note that the available work constitutes the useful work, the internal and external dissipative losses incurred by the processes of cycle. At near to ambient temperature, T_o. The cycle-56Ji has zero available work, even it is supplied with the same heat quantity. Despite the same heat input quantity, the cycles have dissimilar amount of unavailable work, and it is attributed to the quality of energy (defined by temperature and pressure) being supplied over the limit of "dead state".

unavailable work that were demarcated by the ambient temperature and the entropy change. Such unavailable work is also commonly known as the dissipation trapped by the "dead state". This aspect of diminishing available work with lower heat source temperature can be observed to reduce to zero at the limit, $T_{source} \rightarrow T_o$. A second aspect of **Figure 1** is cascading of processes in which exhaust of processes at higher temperature can be used as a heat source for a second process operating at relatively lower temperature to optimize the cycle efficiency.

Over many decades, decision makers within the desalination industry have failed to notice the above-mentioned misconception. Should it remain uncorrected, sub-optimal decisions will be made and, in a world, seeking to become carbon neutral the implications are serious. The consequences will be inferior selection of desalination methods for the supply of large quantity of potable water in many water-stressed countries. Operating a non-optimal desalination plant over its lifespan not only burdens consumers economically with a higher unit water cost but the associated carbon dioxide emissions will be higher and probably there will be a higher discharge of chemically laden brine into the sea.

Those interested in pedagogy might care to ask the following rudimentary question, why despite many decades of advancement in science and engineering, how is it possible for the desalination industry to treat dissimilar energy quantities as if they were the same or, as the English would say, compare apples with oranges? We will seek to give an answer at the end of the paper.

3. A level playing field across the processes

Currently, the best available power plants for co-generation of electricity and heat sources are the combined cycle gas turbines plant or CCGTs in short to utilize fossil fuel primary energy optimally. It consumes conventional primary energy, by burning the natural gas or liquid fuels in the combustor, to generate secondary or derived energy. Such derived energy is used conveniently for powering the work and heat-driven processes for treating impaired water to produce potable water, as shown in **Figure 2**.

One notable point is the relative rates of primary energy consumption in producing the derived energy types. A detailed analysis indicates a disproportionate distribution of primary energy use by the assorted processes of a conversion plant. For example, the electricity generation from the gas and steam turbines incurred almost 96 ± 1% of the total input exergy, and followed by a minor portion in the form of bled-steam at low pressures at 2 ± 0.1% for powering desalination processes, whilst the remaining 2 ± 0.1% of input exergy are traced to the heat rejection to ambient by exhaust gases and to the condenser.

The stark differences in exergy destruction nullifies any implicit long-held assumption that some might have of direct parity or equivalence between dissimilar derived energy consumptions. Many would recognize that 1 $kWh_{\_elec}$ is not equal to 1 $kWh_{\_thermal}$ but would not be able to establish a weighting between them. Thermodynamically, not all derived energy is created equal. Unfortunately, the current practice of quantifying energy efficacy across assorted seawater desalination methods is based on "equal parity between all types of derived energy". Obviously, this is a flawed assumption. A simple analogy is found in monetary currencies conversion in between countries. For example, a unit US dollar is not equivalent to another currency such as the Australian dollar. Economists employed a method of purchasing power parity (PPP), based on a basket of essential consumer products that normalized the necessary conversion factors in between all currencies globally. Here we seek to achieve the same for desalination processes.

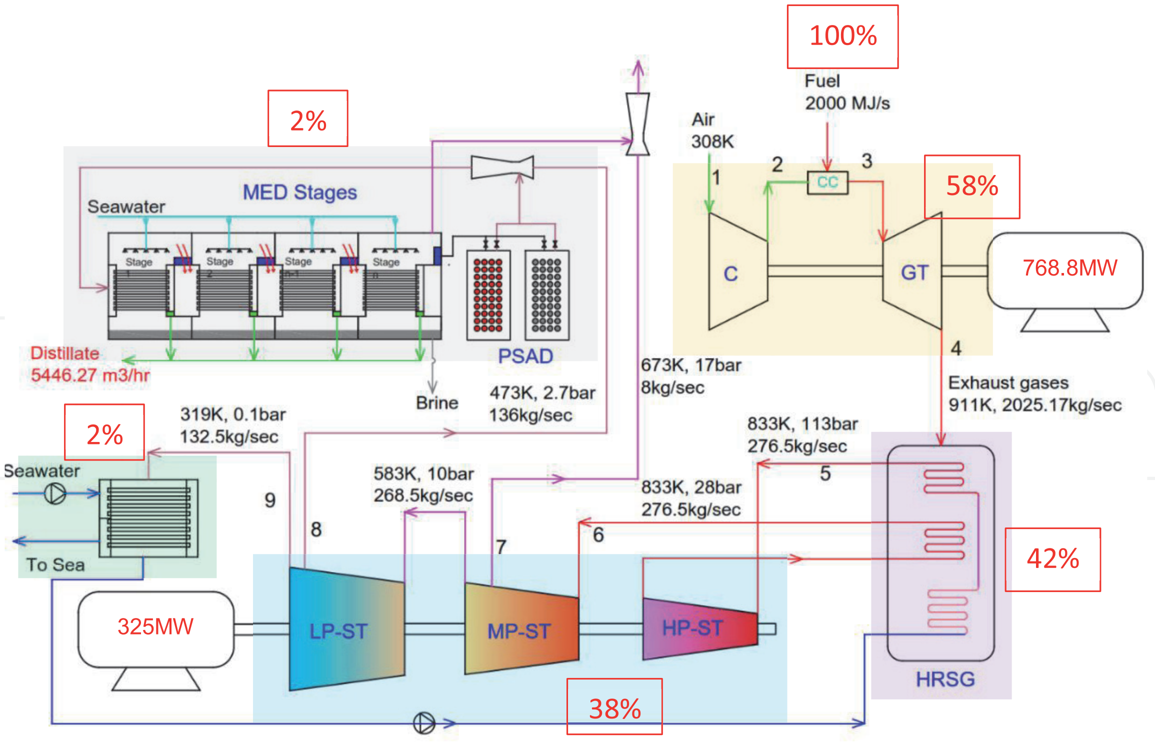


Figure 2.
Typical primary energy consumption in a combined power and water cycle.

4. Thermodynamic framework

The term exergy was devised by Zoran Rant [15] in 1956 by using two Greek words, i.e., "ex" and "ergon" meaning "from work". However, the main concept was first studied by Willard Gibbs in 1873 [16]. The term exergy is defined as "the available work" and it constitutes the maximum useful (shaft) work that could be extracted from of a cycle. Recently, many researchers published on exergoeconomic and thermoeconomic analysis of desalination process [17–20].

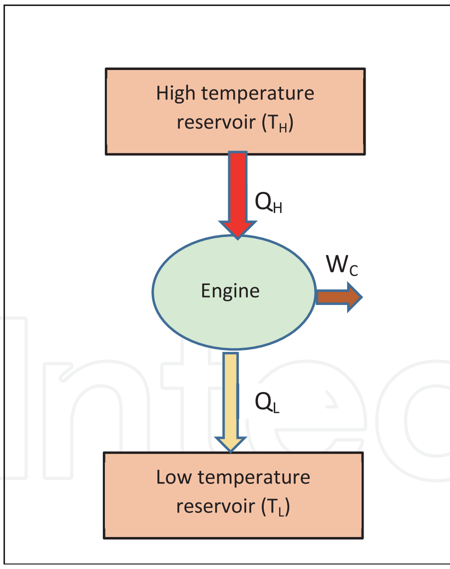
To provide any misconceptions across the various type of seawater desalination processes, the thermodynamics of heat engines, representing the desalination methods, are invoked. The amount of ideal or Carnot work (W_C) that can be extracted from a flow of heat input Q_H, emanating from a higher temperature (T_H) heat source to an engine, producing an ideal work W_C, whilst rejecting heat Q_L into a low temperature (T_L) reservoir, is depicted schematically in **Figure 3**.

Due to incipient dissipative losses, the actual useful work ($W_{act,i}$) produced by an engine is lower than the ideal or Carnot work and thus, the Second Law efficiency ($\eta_i^{''}$) of engine defines the work ratio, i.e., $\eta_i^{''} = \frac{W_{act,i}}{W_C}$. We invoke the derived corollary of Second |Law of Thermodynamics relationship, i.e.,

$$\frac{W}{T_H - T_L} = \frac{Q_H}{T_H} = \frac{Q_L}{T_L}, \tag{1}$$

where T_H and T_L are the process average temperatures corresponding to any desalination methods. For a given Carnot work (W_C,) output from a cycle, the corresponding amount of heat supply (Q_H at T_H) to the engine is deemed as the primary energy input. This can be expressed as the product of Carnot work and the ratio of T_H to the temperature difference (T_H–T_L) between the reservoirs:

$$Q_H = W_C\left(\frac{T_H}{T_H - T_L}\right). \tag{2}$$



Governing Thermodynamic Laws and Corollary:-

First Law of Thermodynamics: $Q_H = W_C + Q_L$.

Corollary of Second Law: $\frac{Q}{T} = constant$.

Invoking the above Second Law, i.e.,

$$\frac{Q_H}{T_H} = constant = \frac{Q_L}{T_L} \quad or \quad Q_L = \frac{Q_H T_L}{T_H}$$

And substitute into the First Law;

$$Q_H - \frac{Q_H T_L}{T_H} = W_C,$$

hence, the relationship between ideal work, heat transfers and reservoir temperatures is given by:

$$\frac{W_C}{(T_H - T_H)} = \frac{Q_H}{T_H}$$

Figure 3.
A heat engine driven by heat transfers at high and low temperature reservoirs and Carnot (ideal) work that can be emanated by it.

Assuming the same work output were to be derived from an adiabatic flame (T_{adia}) of a fuel burned with ambient air and operating between maximum temperature difference across the reservoirs (T_{adia}-T_o), the heat supply to the engine is equivalent to the work potential (exergy) of heat engine. A common thermodynamic platform across the temperatures, T_{adia} and T_o, is proposed where an equivalent heat transfer (Q_{SPE}) at the referenced platform would deliver the same Carnot work, i.e.,

$$Q_{SPE} = W_C \left(\frac{T_{adia}}{T_{adia} - T_o} \right). \tag{3}$$

Given the temperature platform, i.e., $(T_{adia} - T_o)$, Eq. (3) implies the input exergy, Q_{SPE}, is equivalent to a fraction of supplied fuel to generate the Carnot work. Should there be "n" number of engines operating synergistically across the same referenced temperature reservoirs, then the total standard primary energy consumption by all engines is given by the summation of the right hand terms of Eq. (3), i.e.,

$$\sum_{i=1}^{n} Q_{spe,i} = \left(\frac{T_{adia}}{T_{adia} - T_o} \right) \sum_{i=1}^{n} W_{C,i}. \tag{4}$$

where "i" refers to a process in a combined machine. Eq. (4) depicts an important observation of decomposition of total input exergy (work) into fractions as accrued by a host of sequential machines. This is similar to the equivalent primary energy input, i.e., $Q_{\_spe}$, contributed by all processes in a CCGT plant. At known heat transfer rates corresponding to each set of inlet and outlet temperatures of a cycle, the total Carnot work can be cumulatively summed to yield the primary energy of the fuel burned as presented in case example in following sections. Equivalently, the apportionment of standard primary energy consumption incurred by the processes of CCGT, namely the generation of electricity and low-grade steam energy, can now be accurately determined using a conversion factor for ease of application.

Extending the Eq. (4) by taking the ratio of standard primary energy and the Carnot work of a process to their respective total in the cycle gives their equivalency. Also the temperature ratios (1-T_o/T_{adia}) are eliminated.

$$\frac{Q_{SPE}}{\sum_{i=1}^{n} Q_{SPE,i}} = \frac{W_C}{\sum_{i=1}^{n} W_{C,i}} \tag{5}$$

Herein a conversion factor CF_i is defined as the standard primary energy to the actual derived energy. It can be expressed as

$$CF_i = \frac{Q_{SPE}}{W_a} = \left(\frac{\sum_{i=1}^{n} W_{C,i} / \left(1 - \frac{T_o}{T_{adia}}\right)}{\sum_{i=1}^{n} \left(W_{C,i} \eta_i^{''}\right)} \right) = \frac{1}{\left(1 - \frac{T_o}{T_{adia}}\right) \eta^{''}} \tag{6}$$

where the Second Law efficiency of a process is defined as $\eta_i^{''} = \frac{W_{a,i}}{W_{C,i}}$, and T_{adia} is the adiabatic flame temperature of fuel burning in air which characterizes the highest temperature difference (T_{adia}–T_{o}) across the reservoirs of the heat engine.

5. Results and discussion

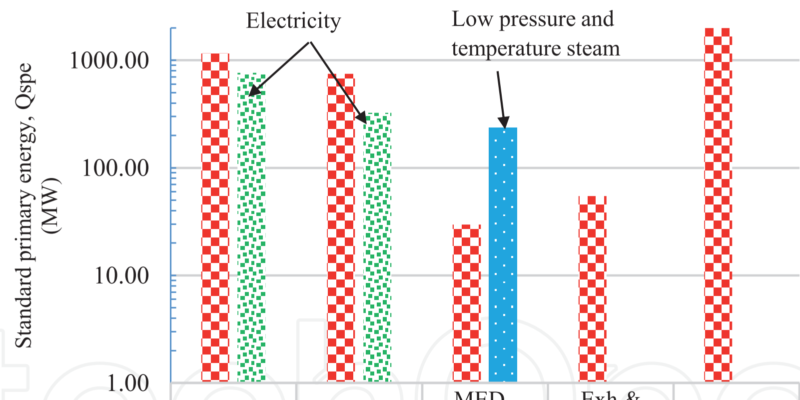
For clarity, a typical CCGT plant of nominal primary energy input of 2000 MW is considered as presented in **Figure 2**. By analyzing the heat transfer rates at the respective temperature reservoirs for each of the cascaded processes, the ideal or Carnot work can be determined with a selected common temperature platform, defined by the adiabatic flame and ambient temperatures. By summing all the standard primary energy ($Q_{\_SPE}$), as described by Eq. (4), it yields the equivalent primary energy of fuel or the fuel exergy supplied to the CCGT plant. In terms of the useful output, the total electricity generation from both turbines of CCGT amounts to 1094.37 MW_{elec} and a steam-powered multi-effect distillation (integrated MED_TVC) produces 5445 m^3/h potable water. To sustain the dissimilar derived energy, a steady heat rate of 2000 MW is needed by burning a fossil fuel such as the natural gas at the combustor of gas turbines (GT) cycle. The detailed thermodynamic states and the mass flow rates of working fluids operating in key components of CCGT, either the products of combustion or steam at all state points of key components, are presented in Appendix 1.

This procedure offers a means of apportionment of the Q_{spe} into fractions that generate all types of useful derived energy to power the assorted desalination plants, as summarized in **Figure 4**. Based on these fractions of primary energy dissipation, the appropriate conversion factors are derived which forms a basis for level platform to normalize the primary fuel to derived energy or vice versa. For example, the conversion factor for electricity is simply expressed as the ratio of $Q_{\_SPE}$ to the electricity generated or alternatively, it can also be determined from the Second Law and temperature ratios as shown below:

$$CF_{\text{elec}} = \frac{\left(Q_{SPE\_GT} + Q_{SPE\_ST}\right)}{\left(W_{SPE\_GT} + W_{SPE\_GT}\right)} = \frac{1}{\left(1 - \frac{T_o}{T_{adia}}\right) \eta_i^{''}} = 1.7328 \tag{7}$$

Similarly, the conversion factor for low-grade steam input to MED_TVC is expressed by the ratio Q_{spe} to the thermal energy input or it can also be determined from the appropriate temperature ratios:

$$CF_{\text{thermal}} = \frac{\left(Q_{SPE\ of\ bled\ steam}\right)}{\left(Q_{actual\ bled\ steamat\ low\ pressure}\right)} = \frac{1 - \frac{T_o}{T_{MED}}}{\left(1 - \frac{T_o}{T_{adia}}\right)} = 0.1250 \tag{8}$$



	GT	ST	MED_ TVC	Exh & Cond	Total
Q_spe (MW)	1165.00	750.00	29.75	54.93	1998.66
Derived energy (MW)	768.87	325.00	237.54	0.00	

Figure 4.
The consumption of standard primary energy and the production of useful derived energy by the major components of a combined cycle gas turbines (CCGT) power plant. The units of accompanying table are in MW.

The thermodynamic limit of 0.78 kWh_{spe}/m^3 is engaged to determine the Carnot work and the temperature reservoirs of the ideal states. Thus, the above calculations demonstrated that a common standard primary energy platform could resolve the long-held implicit misconception of equivalency that were assumed between different types of derived energy, namely that between electrical and thermal energy. Such a thermodynamic fallacy has unfortunately persisted in the desalination industry for over 5 decades.

Figure 4 present the standard primary energy consumptions and the production of useful derived energy by the major components of a CCGT power plant based on derived conversion factors.

It is noticed that at ideal conditions, the maximum potable water production per unit primary energy consumed is 1.282 m^3/kWh_{spe} or minimum specific energy consumption is 0.943 kWh_{spe}/m^3. Being an ideal process, no conversion of primary energy to derived energy is needed. However, a common misconception, often seen in literature where the graph of specific energy consumption for desalination processes is presented against the various recovery ratios. Conventionally, it showed a curve of gradual increase of the derived energy consumption with increasing recovery ratio (RR) from zero to more than 60%. This depiction of specific derived energy consumption has omitted the dissipative losses incurred by the conversion plants in producing the derived energy when the RR is other than zero. A similar concept is found in the Carnot efficiency of a heat engine when the actual work output is deemed zero at the ideal limit, although the available Carnot work from the cycle is at its highest. Using the proposed common platform of standard primary energy consumption for all desalination processes, the cross comparison of energy efficiency amongst all desalination methods can now be accurately resolved. **Figure 5** shows the energy efficacy from about 60 seawater desalination plants powered by assorted desalination methods, stretching from 1983 to the present [21].

For a fair comparison, all conventional specific derived energy consumption in these plants is transformed to their equivalent primary energy with the relevant conversion factors, where the embedded quantitative and qualitative aspects of the derived energy are now incorporated. It can be seen that SWRO is has a slightly better energy efficacy than MED and MSF, achieving around 13% of TL.

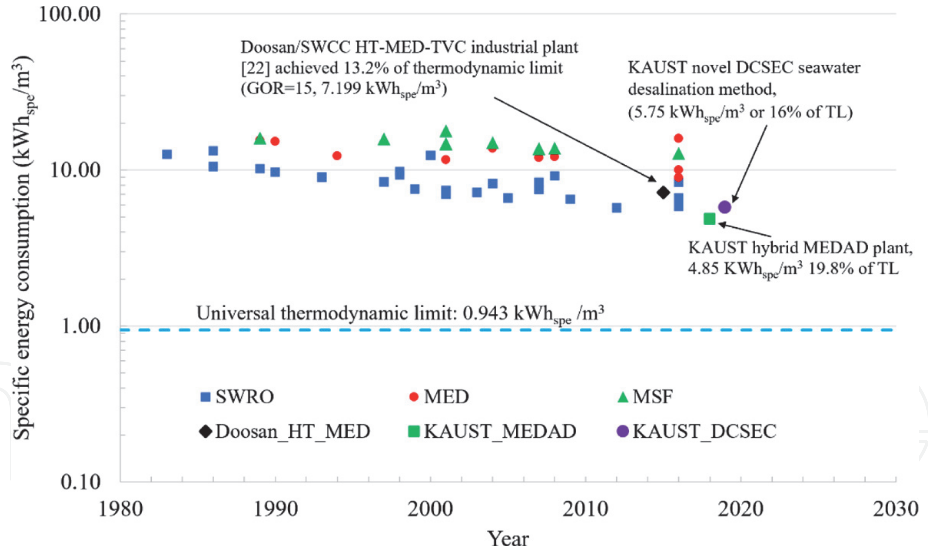


Figure 5.
Energy efficiency of seawater desalination processes based on standard primary energy. The MED-TVC shows a higher energy efficacy as compared to MSF and the SWRO.

Nevertheless, all practical methods available hitherto are still far below the TL, hovering less than 10–13% of the ideal.

The authors have conducted an experimental study at KAUST of a hybrid approach involving the well-proven heat driven MED-TVC processes with an adsorption (AD) cycle, arranged in a back-to-back manner [12, 22–31]. A quantum jump in the energy efficiency is achieved through the thermodynamic integration of two thermally-driven cycles with two salient consequences, namely (i) an increase in the available temperature differences between the top to bottom brine temperatures and hence more MED stages could be inserted, and (ii) an opportunity to scavenge more enthalpy from the seawater feed by liquid flashing in the lower stages of MED where the corresponding stage temperatures were below ambient. The recent pilot-scale experiments, conducted with hybrid design of MED-AD plant at KAUST, have attained a lowest brine temperature of 5°C. The vapor generation in these MED stages maximized both the effects from the thermally-driven film evaporation and the liquid flashing from the excess enthalpy embedded available in the feed spray [32–35]. Consequently, the thermodynamic synergy between MED-TVC and AD cycles have boosted distillate production by more than two folds with the same energy input to the top brine stage, attaining a specific energy consumption level of 4.85 kWh$_{spe}$/m^3 that shows a quantum jump in energy efficiency from current 13 to 20% of TL, as indicated in **Figure 5**.

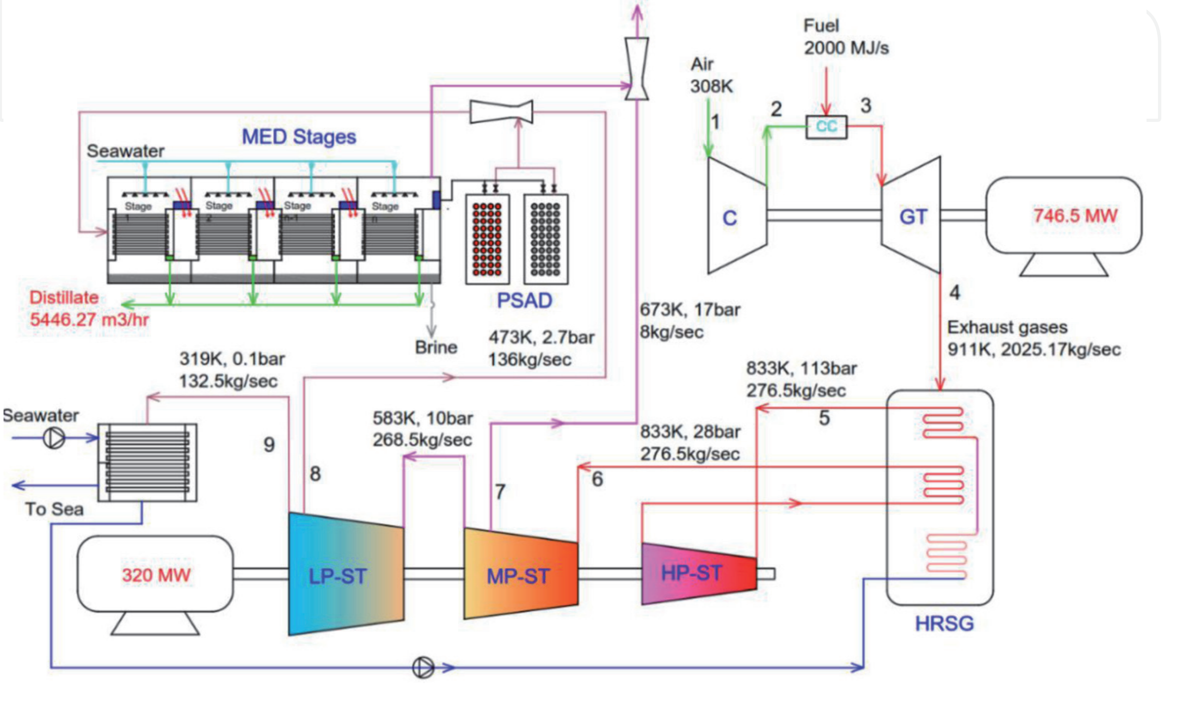
6. Summary

In summary, the common platform of standard primary energy consumption is thermodynamically the most rigorous method for the cross comparison of energy efficiency of assorted desalination processes. The outward acceptance of equivalency between electricity and low-grade thermal energy has led to a long-held indifference to the quality of derived energy supply to utilize more optimally. This attitude has afflicted the desalination industry for more than 5 decades. The consequence from such a fallacy has led to some inferior decisions by leaders of desalination industry particularly regarding the adoption of less energy efficient desalination processes and hence non-optimal energy consumption. Such poor selection has burdened the future economy of many water-stressed countries with higher unit water costs over the decade-long life-span of plants. In concluding it is noted, firstly that the energy efficiency of all practical desalination methods available hitherto have been shown, on a standard primary energy platform, to be far below the ideal limit, typically hovering between 10 and 13% of the TL. Secondly, the design experiences accrued by scientists and engineers have demonstrated, in some other disciplines, that a plausible energy efficiency target of an engine operating between 35 and 40% of ideal limit is tenable for the cascaded designs of assorted desalination plants. Only at these higher efficacy levels will the desalination processes be poised to meet the future goals of sustainable seawater desalination. Hence, there is motivation to strive for higher efficiency with better thermally-driven distillation techniques or thin-film composite membranes [36–40]. The caveat is that a common platform for energy efficacy comparison is desirable, and it is anchored to the best available conversion technology known. For example, in the past three decades, the CCGT has the highest conversion efficiency in the production of convenient derived energy that powers the desalination processes. In future when making appropriate comparison, the same thermodynamic-rigorous methodology of using a standard primary energy platform is equally valid.

Acknowledgements

Authors would like to thank Northumbria University, Newcastle Upon Tyne NE1 8ST, United Kingdom POC grant for Solar Water project awarded to Dr. Muhammad Wakil Shahzad, and King Abdullah University of Science and Technology, Saudi Arabia for the research support of this research. This work was also supported by the Engineering and Physical Sciences Research Council (EPSRC, UK) grant-EP/N007921.

Appendix 1: CCGT plant schematic and summary of state points



Thermodynamic states of air and steam of CCGT cycle under investigation.

State points	ṁ (kg/s)	T (K)	P (bar)	h (kJ/kg)	s (kJ/kg-K)
1	2021.64	305	1.0	305.6	6.88
2	2021.64	592	8.0	599.3	6.98
3	2056.00	1470	8.0	1559.1	8.30
4	2056.00	911	1.2	945.0	8.0
4a	2066.00	370	1.05	371.8	7.08
5	295.16	833	113	3514.3	6.7
5a	295.16	683	28	3360.0	7.0
6	295.16	833	28	3600.0	7.5
6a	287.16	703	10	3380.0	7.8
P1	8.0	768	17	3490.0	7.55
7	287.16	703	10	3380.0	7.8
7a	151.16	319	0.1	2590.0	8.16
P2	136.0	573	2.7	3090.0	7.75
8	151.16	308	0.1	189.0	0.639

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