Application of “Sink & Source” and “Stream wise” Methods for Exergy Analysis of Two MED Desalination Systems

Hossein Ahamdi Danesh-Ashtiani* and Hamid Abdollah-Zargar

Islamic Azad University of South Tehran Branch.

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Abstract

Utilization of fossil fuel for supplying of requires energy of desalination systems is common. On the other hand, solar energy is one of the high-grade energies in the world that can be found specifically in hot weather places. Therefore, utilization of solar energy for operation of desalination systems will reduce greenhouse gases and is a good alternative way. Common exergy analysis method (stream wise) uses input and output exergy of streams to calculate the efficiency and exergy loss. Another exergy analysis method, named “Sink & Source”, is illustrated in the present study. The Stream wise method usually computes efficiency of systems as higher than a reliable value. For example, the computed exergy efficiency of presented high capacity MED desalination system is 88.63%, while this value is estimated about 1.04% from the new method. The uselessness of the traditional method for analyzing presented low-capacity MED desalination system is also shown. For example, the computed exergy efficiency of a low-capacity desalination system was 97.51%, while a value of 42.57% was obtained from the new method. A solar field and a solar heating system are suggested for presented high capacity and low capacity MED, respectively. Furthermore, an economic analysis of afore said desalination system is presented.

Keywords

Exergy analysis method;
Solar energy;
MED desalination system;
Stream wise;
Sink & source.

1. Introduction

Today, the utilization of desalination systems is necessary because of water shortages [1]; on the other hand, desalination is the most intensive method among energy-consuming processes [2]. The pollution rate of terminable energy resources is also very high [3]. Renewable energies, e.g., solar energy, are clean and available around the world. Therefore, the use of solar energy along with a desalination system is inevitable [4]. Desalination processes are divided into two categories, phase change and non-phase change [5]. Multiple effect distillation (MED) is one phase changing process. Desalination and solar energy-producing systems reduce overall costs, since the desalination process is able to use low-grade energy rather than a primary energy source [6].

In other studies about the multiple effect distillation desalination plant, it has been shown that

* Corresponding Author.
E-mail:h_a_danesh@azad.ac.ir(H.AhmadiDanesh-Ashtiani)

utilization of steam for saltwater evaporation [8], the fresh water heat recovery [7], utilization of heat loss from other processes as an energy resource [9], increase in desalination stages, temperature difference reduction in pre–heaters, and increasing evaporator input steam temperature [10], are the ways of reducing exergy loss, enhancing exergetic efficiency, and reducing costs.

In this study, a new exergy analysis method for optimizing system operational parameters has been presented. Moreover, factors affecting on its efficiency has been determined by utilizing a traditional exergy analysis method for a solar energy consuming high-capacity MED. In addition, by means of the aforementioned exergy analysis methods, a low-capacity solar MED system has been analyzed. For every desalination system, an efficient solar heat production system has been suggested. The requisite capital cost and payment duration of these two desalination systems would specify by economic analyses.

2. Theoretical Background

2.1. Stream wise method

Exergy balance relation for a control region undergoing a steady-state process is thus [11, 12]:

$$\dot{E}_i - \dot{E}_Q = \dot{E}_e + \dot{W}_x + I_{sw} \quad (1)$$

where:

$$\dot{E}_i = \sum_{IN} \dot{m}\, \varepsilon \quad (2)$$

$$\dot{E}_e = \sum_{OUT} \dot{m}\, \varepsilon \quad (3)$$

$$\dot{E}_Q = \sum_r [\, \dot{Q}_r \frac{T_r - T_0}{T_r}] \quad (4)$$

The expression for specific exergy may be written as:

$$\varepsilon = (h - T_0 s) - (h_0 - T_0 s_0) + \dot{E}_{ch} + \frac{C^2}{2} + gz \quad (5)$$

$$\dot{E}_{ch} = \dot{m}\varepsilon^0 \mu \quad (6)$$

$$\dot{E}_{ph} = (h - T_0 s) - (h_0 - T_0 s_0) \quad (7)$$

ε^0 can be obtained from tables presented in [11,12].

2.1.1. Stream wise exergy efficiency

A general technique on the concept of exergy for formulating performance criteria is presented for a variety of thermal plants. Consider a steady or quasi-steady process. If the process is not completely dissipative, then:

$$\sum \Delta \dot{E}_{IN} = \sum \Delta \dot{E}_{OUT} + I_{sw} \quad (8)$$

where $\sum \Delta \dot{E}_{IN}$ is the sum of all exergy inputs, and $\sum \Delta \dot{E}_{OUT}$ is the sum of all exergy outputs. According to the second law of thermodynamics:

$$I_{sw} \geq 0 \quad (9)$$

then:

$$\frac{\sum \Delta \dot{E}_{OUT}}{\sum \Delta \dot{E}_{IN}} \leq 1 \quad (10)$$

The ratio of exergy output to exergy input is less than one for irreversible processes and is equal to one for reversible processes. This feature of the ratio assesses thermodynamic perfection of a process. This term is called as exergetic efficiency and is expressed in the following two equivalent formulas [11, 12]:

$$\eta_{Ex_{sw}} = \frac{\sum \Delta \dot{E}_{OUT}}{\sum \Delta \dot{E}_{IN}} \quad (11)$$

$$\eta_{Ex_{sw}} = 1 - \frac{I_{sw}}{\sum \Delta \dot{E}_{IN}} \quad (12)$$

2.2. Sink & source method

Through potential consumption, different systems import energy to each other. For example, assume that two masses have the same weight but different temperatures. The warmer one has higher potential and is capable of importing energy to the other one.

The sink & source method says potential Source is that part of a system that loses its potential and potential Sink is that part of a system which gains it. To compute the potential of a substance, a reference system is needed. In this method like stream wise method, environment is the reference system. There is no potential in this environment, and every non-zero potential substance is capable of doing work.

In this new method, exergy exists in different energies and is categorized as physical, chemical, kinetic, etc. Systems must simply be specified as that which has lost its potential, i.e. the "source" and that which has gained potential, i.e. the "sink". Then, by means of the exergy relations mentioned in the previous section (in the traditional exergy analysis method), the exergy values of sink and source are computed. Several systems may be present in a reaction where several sinks and sources are specified. There is another relation for the computation of irreversibility that utilizes the exergy balance relation for a specified control volume. The exergy balance equation in the Sink & Source exergy analysis method is:

$$I_{s\&s} = \left|\Delta\dot{E}_{Source}\right| - \left|\Delta\dot{E}_{Sink}\right| \quad (13)$$

ΔEx_{Source} Value is always negative.

2.2.1. Sink & source exergy efficiency

After computing ΔEx_{Source} and ΔEx_{Sink}, the exergetic efficiency of the sink & source method can be calculated from:

$$\eta_{Ex_{s\&s}} = \frac{|\Delta\dot{E}_{Sink}|}{|\Delta\dot{E}_{Source}|} \quad (14)$$

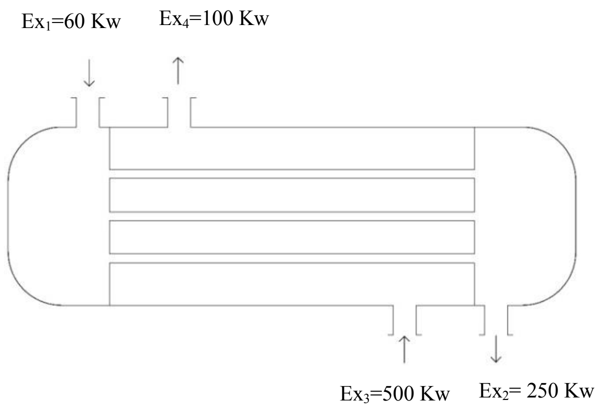

Figure 1. Schematic of a heat exchanger.

2.3. Contrast of stream wise and sink & source methods

If the potential difference between systems is too much, the results obtained from the Stream wise method will not be reliable. For example, consider a crosscurrent heat exchanger. One current enters with 60 Kw exergy and exits with 250 kW (Fig. 1). The other enters with 500 kW exergy and exits with 100 kW.

Using the Stream wise method, the exchanger exergetic efficiency is calculated as follows:

$$\eta_{Ex_{sw}} = \frac{\dot{E}_{OUT}}{\dot{E}_{IN}} = \frac{100 + 250}{60 + 500} = 62.5\%$$

And, for the sink & source method:

$$\eta_{Ex_{s\&s}} = \frac{\left|\Delta\dot{E}_{Sink}\right|}{\left|\Delta\dot{E}_{Source}\right|} = \frac{|250 - 60|}{|100 - 500|} = 47.5\%$$

Now, assume 106 kilowatts of exergy are added to the second current:

$$\eta_{Ex_{sw}} = \frac{\dot{E}_{OUT}}{\dot{E}_{IN}} = \frac{100 + 250 + 10^6}{60 + 500 + 10^6} \approx \frac{10^6}{10^6} = 100\%$$

$$\eta_{Ex_{s\&s}} = \frac{\left|\Delta\dot{E}_{Sink}\right|}{\left|\Delta\dot{E}_{Source}\right|} = \frac{|250 - 60|}{|100 - 500|} = 47.5\%$$

As can be seen, the calculation of exergetic efficiency by means of the traditional exergy analysis method is not reliable.

2.4. High-capacity MED

The schematic diagram of a multi-effect VTE (vertical tube) plant is shown in Fig. 2. Table 1 shows the stream characteristics of a 1-mgd plant. A single tube is shown in each effect to simplify the drawing, while a tube bundle containing many tubes would actually be used [14].

Stream 1 (seawater) at 180°C is fed to the plant. The feed water is screened to remove trash and debris before reaching the VTE plant. Steam 2 which contains approximately two-third of water is used for cooling in final condenser and for vacuum system condensers. After treating of feed water (stream 4), the brine passes through a series of pre-heaters (one for each effect) to the top of the tube bundle of the first effect by pressure increasing by means of a pump. At this point, the water temperature is approximately 121°C. The descending film of seawater is heated to its boiling temperature by steam condensing on the outside of tube. The heating steam comes from concentrating collectors. Heating of entire distillation process is supplied from this system steam and seawater mixture is exited from the bottom of the first effect tubes, and the water falls to the sump at the bottom of the effect.

The steam goes upward and passes through an entrainment separator to the shell side of the tube bundle of effect 2, where it condenses and yields its latent heat to slightly concentrated seawater that pumps from sump of effect 1. In preheated for feeding of first effect, a portion of steam is condensed. Steam of preceding effect vaporizes water of each effect similarly. As brine passes through the series of effects, it becomes more concentrated until it is discharged as blow down from the last effect. Temperature of brine decreases as it passes through each succeeding effect, it experiences pressure drop also. Therefore, its initial temperature always exceeds the boiling point for that pressure. Final effect steam is condensed in the final condenser, where it is used to preheat the incoming seawater. By condensation, most of heat is re-

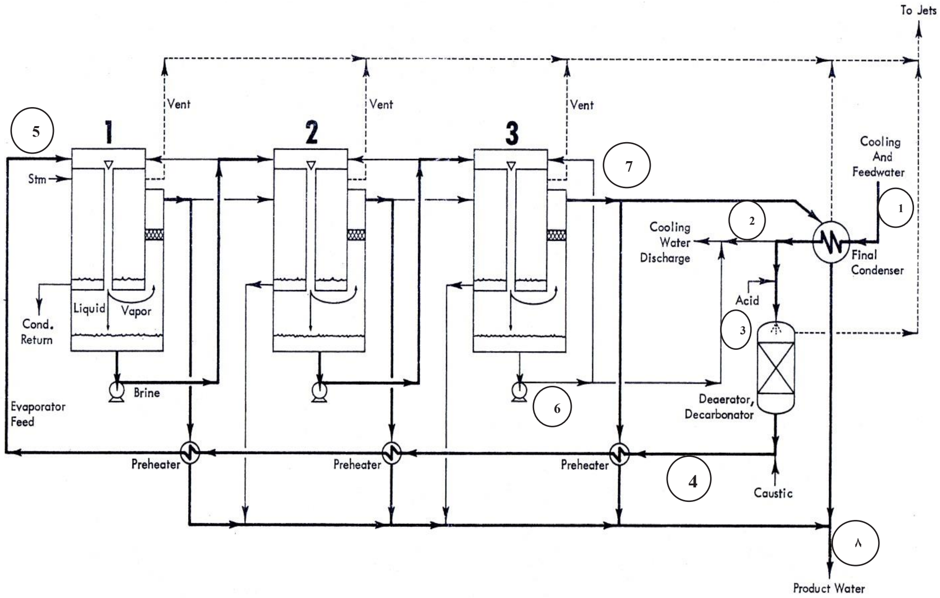

Figure 2. High capacity MED.

jected to the stream 2. Product water includes condensate water of all vertical tube bundles (except those in effect 1), pre-heaters and final condensations. It is pumped to storage or to a distribution system. This stream may be passed through a cooler in plants where its temperature is high enough. In cooler part of stream, sensible heat is used to warm the feed water [14].

Due to the perfect insulation of the units, there is no heat exchange between the environment and the MED. Therefore, the exergy of heat transfer is not involved in the exergy analysis of this unit. The schematic diagram of a multi-effect VTE (vertical tube) plant is shown in Fig. 2. Table 1 shows the stream characteristics of a 1-mgd plant. A simplified MED system is shown in Fig. 3. System control volume input and output flows are shown in Fig. 3(a). This control volume is associated with the stream wise method. Fig. 3(b) shows sink and source flows. The steam-to-liquid flow is called the source since it loses its exergy (As described earlier, source is attributed to that flow which has lost its own exergy). In Fig. 3, flow (4) is sink which is divided into three flows (2), (6) and (8).

Exergy analysis of a high capacity MED is carried out using equations (8), (11), (13), and (14):

$$\Delta\dot{E}_{Sink} = \dot{E}_{ph_2} + \dot{E}_{ch_2} + \dot{E}_{ph_6} + \dot{E}_{ch_6} + \dot{E}_{ph_8} + \dot{E}_{ch_8} - \dot{E}_{ph_1} - \dot{E}_{ch_1} \quad (15)$$

$$\Delta\dot{E}_{Source} = \dot{E}_{ph_{Liquid}} - \dot{E}_{ph_{Steam}} \quad (16)$$

Table 1. High capacity MED points characteristic.

Points and utilities	Temperature (°C)	Flow rate (kg/s)	Concentration (%)	Enthalpy (kJ/kg)	Entropy (kJ/kgK)	$\dot{E}_{ph}$ (kW)	$\dot{E}_{ch}$ (kW)
1	18.3	169.5	3.5	76.8	0.25	800.04	30299.82
2	36.6	102	3.5	152.33	0.51	279.48	18232.5
6	52.2	34.5	6.9	218.48	0.72	216.66	6347.30
8	26.1	34.7	0	109.46	0.37	55.86	6011.08
Steam	150	6.60	0	2746.44	6.83	4699.72	——
Liquid	150	6.60	0	632.18	1.84	587.59	——

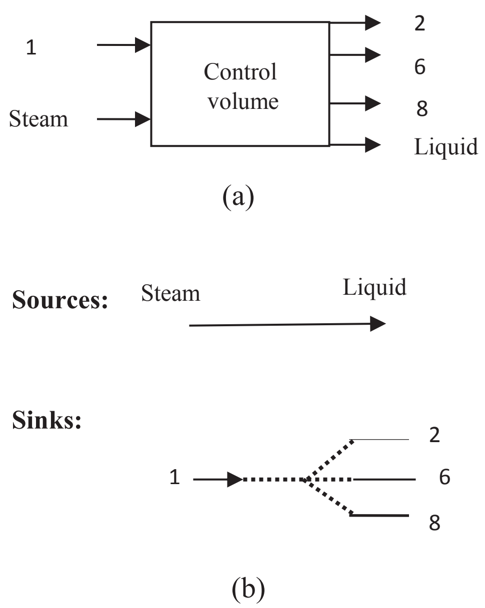

Figure 3. Simplified high capacity MED: a) System control volume; b) Sink & cource flows.

$$\sum \dot{E}_{IN} = \dot{E}_{ph_{Steam}} + \dot{E}_{ph_1} + \dot{E}_{ch_1} \quad (17)$$

$$\sum \dot{E}_{OUT} = \dot{E}_{ph_2} + \dot{E}_{ch_2} + \dot{E}_{ph_6} + \dot{E}_{ch_6} + \dot{E}_{ph_8} + \dot{E}_{ch_8} + \dot{E}_{ph_{Liquid}} \quad (18)$$

2.5. Impact of high temperature utility steam on system performance

To achieve this purpose, the operational parameters of the system should be modified, and then the positive and negative effects of these modifications on the performance criteria must be evaluated. Solar-produced utility steam temperature is one operational parameter. By utilizing two types of higher-than-usual operational steam, effect of this parameter on exergetic efficiency and irreversibility of the system with the two mentioned exergy analysis methods, is investigated. Steam properties are presented in Table 2.

2.6. Solar heat producing system for high capacity MED system

Two phase flow (water/steam) processes in parabolic trough collectors can be studied on the DISS loop. Subsystems of the DISS loop comprise a parabolic-trough collector solar field and the power-block. Concurrent to preheating, evaporation, and conversion to superheated steam, the feed water is circulated through absorber tubes of a 550-m-long row of parabolic trough collectors having a total solar collecting surface of 2,750 m^2. Flow rate, pressure, and steam temperature of this facility are 1kg/s, 100 bar, and 370˚C, respectively.

Superheated steam generated in the solar field is condensed in the power block and then processed and reused as feed water for the solar field (closed-circuit operation).

A simplified diagram of the DISS loop is shown in Fig. 4. In which the solar field consists of 11 north–south oriented parabolic-trough collectors in one row. Nine collectors are composed of 4 reflective parabolic-trough modules, while 2 collectors (Nos. 9 and 10) have only 2 modules. Module length and width are 12 m and 5.7 m, respectively. The solar field consists of 2 parts, the evaporating and the superheating sections. A recirculation pump and a water/steam separator which increases the operative flexibility of the system are devised at the end of the evaporating section [15].

2.6.1. Economic analysis of high capacity MED solar field

A high capacity MED needs solar concentrating collectors to supply the requisite solar energy.

JJR-CSP01 is a model of a parabolic trough collector from the JIAJIARE Company. Every 10 sets costs $1,000 USD. Due to the effects of steam flow rate and temperature on the quantity of concentrating collectors (parabolic trough), 3 model designs are needed for the 3 utilized kinds of steam.

Table 2. High capacity MED utility characteristics.

Utilities	Temperature (˚C)	Flow rate (kg/s)	Concentration (%)	Enthalpy (kJ/kg)	Entropy (kJ/kgK)	$\dot{E}_{ph}$ (kW)	$\dot{E}_{ch}$ (kW)
Input steam	200	7.19	0	2793.18	6.43	6313.32	———
Output liquid	200	7.19	0	852.43	2.33	1173.33	———
Input steam	250	8.13	0	2801.52	6.07	8079.18	———
Output liquid	250	8.13	0	1085.34	2.79	2105.26	———

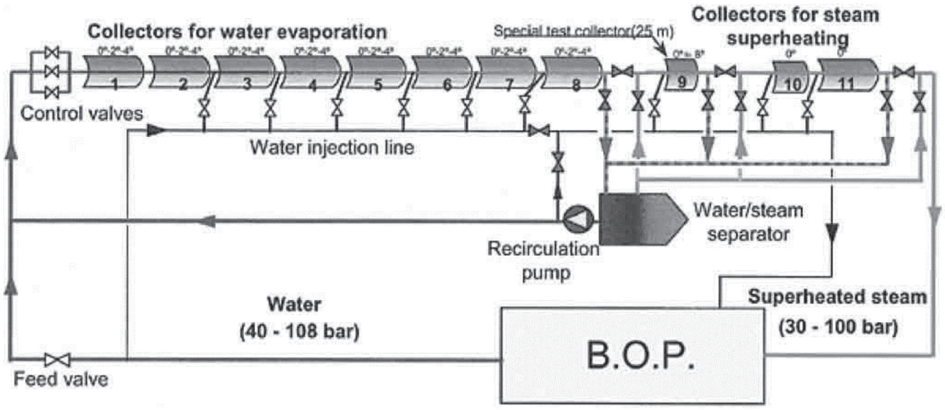

Figure 4. DISS loop schematic diagram, [13].

2.7. Low-capacity MED

Because there is no eagerness to invest in the manufacturing of concentrating collectors and since the technology for constructing these systems is lacking in Iran, by modification of performance parameters of the MED in the present paper, a low-capacity MED system is designed which make it more efficient and contractible. Furthermore, an economic analysis of this new system estimates capital cost and payment duration. Requisite equipment, heat energy production, and saltwater transfer costs are reduced in low-capacity MED and exergy efficiency is enhanced; therefore, a low capacity MED is suggested in the next section.

As shown in Table 3, phase of utility fluid is changed due to intention of using flat plate collectors for producing of needed temperature. Three different states are contemplated for input utility fluid temperature. Output temperature is gained by applying of energy equilibrium relation; the only variable is temperature of utility fluid, so mass flow rate of it is assumed constant in these three states.

Table 3. Low capacity MED various points characteristics.

Points and Utilities	Temperature (°C)	Flow rate (kg/s)	Concentration (%)	Enthalpy (kJ/kg)	Entropy (kJ/kgK)	$\dot{E}_{ph}$ (kW)	$\dot{E}_{ch}$ (kW)
1	21.3	0.9	3.5	89.28	0.3	2.06	160.87
2	33.6	0.55	3.5	140.78	0.46	3.35	98.31
6	49.2	0.17	6.9	205.93	0.67	1.46	31.27
8	23.1	0.18	0	96.89	0.32	0.70	31.18
First state input (liquid)	150	0.1	0	632.18	1.84	8.9	———
First state output (liquid)	65.86	0.1	0	275.79	0.89	1.29	———
Second state input (liquid)	200	0.1	0	852.43	2.33	16.31	———
Second state output (liquid)	118.20	0.1	0	496.4	1.5	5.16	———
Third state input (liquid)	250	0.1	0	1085.34	2.79	25.89	———
Third state output (liquid)	165.53	0.1	0	699	1.99	10.81	———

Input, output, source and sink flows in Fig. 5 are chosen according to their definitions.

Exergy of a low capacity MED is analyzed by utilizing relations (8), (11), (15), and (18):

$$\Delta\dot{E}_{Sink} = \dot{E}_{ph_2} + \dot{E}_{ch_2} + \dot{E}_{ph_6} + \dot{E}_{ch_6} + \dot{E}_{ph_8} + \dot{E}_{ch_8} - \dot{E}_{ph_1} - \dot{E}_{ch_1} \quad (19)$$

$$\Delta\dot{E}_{Source} = \dot{E}_{ph_{Liquid(warm)}} - \dot{E}_{ph_{Liquid(Hot)}} \quad (20)$$

$$\sum \dot{E}_{IN} = \dot{E}_{ph_{Liquid(Hot)}} + \dot{E}_{ph_1} + \dot{E}_{ch_1} \quad (21)$$

$$\sum \dot{E}_{OUT} = \dot{E}_{ph_2} + \dot{E}_{ch_2} + \dot{E}_{ph_6} + \dot{E}_{ch_6} + \dot{E}_{ph_8} + \dot{E}_{ch_8} + \dot{E}_{ph_{Liquid(warm)}} \quad (22)$$

2.7.1. Low capacity MED solar water heating system

Supplying the requisite solar energy for a low capacity MED needs a solar water heating system. The model was design according to the technical characteristics of an optimal model flat plate collector from solar polar company (appendix). For example, for the production of 150°C utility liquid, the required temperature and flow rate of the utility liquid are supplied by the parallel attachment of 2 collectors (Figure 6). This kind of Collector and generally all flat plate collectors existing in Iran are unable to produce 200°C or 250°C water. The reason for consideration of 200°C or 250°C for utility fluid and analysis of low capacity desalination system in these states is discussed in section 3.3.

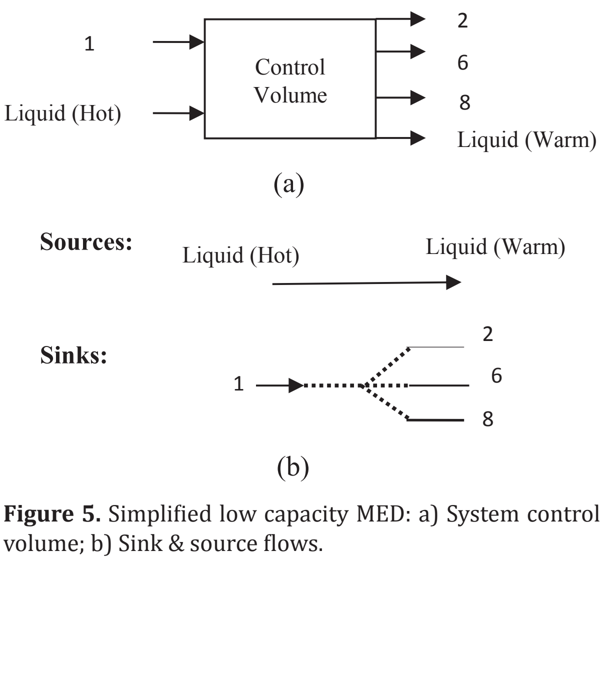

Figure 5. Simplified low capacity MED: a) System control volume; b) Sink & source flows.

2.7.2 Economic analysis of solar water heating system

As the price of such collectors is $400 USD and that of the side solar water heating equipment is $750 USD in year 2015, the capital cost of establishing solar water heating is calculated for each desalination system in the next part.

Computed costs of MED (whether in Iran or outside) is a function of flow rate of a system. Establishment and production costs of an MED in Iran are computed with consideration given to the cost of importing an MED .Due to value fluctuations in Iran's currency against the US currency, the costs of establishment and production of an MED is computed as a function of the US dollar. Payment duration is calculated according to 50% of the mineral water bottle price (3,500,000 bottles per day for a high-capacity MED and 14,000 bottles per day for a low capacity MED, with each bottle mean price being $1 USD) as net interest and production cost. Calculated capital includes solar collector's price. Every price is in terms of the United States dollar.

3. Results and Discussion

3.1. High capacity MED exergy analysis results

As can be seen from Table 4, both sink & source and Stream wise methods compute the irreversibility of the process equally; however, the efficiency value of sink and source is lower.

Computed exergy efficiency from SW method is extraordinary high because of used Computational technique. Stream 1 doesn't bring exergy in presented system practically, rather steam imports exergy and get the stream 1 exergy to rise up. As described in comparison of these two methods section, the stream wise method calculates the efficiency of a flow includes several–thousand-kilowatt energy, 100%.

For the presented MED system, if several thousand kilowatts of exergy are added to the steam–liquid flow, the computed exergy of the stream wise method would be 100%. This means SW mathematical technique is not correct in terms of physics; when interchanged exergies is too much, the exact amount of exergy loss is not gained and the system efficiency is computed high automatically.

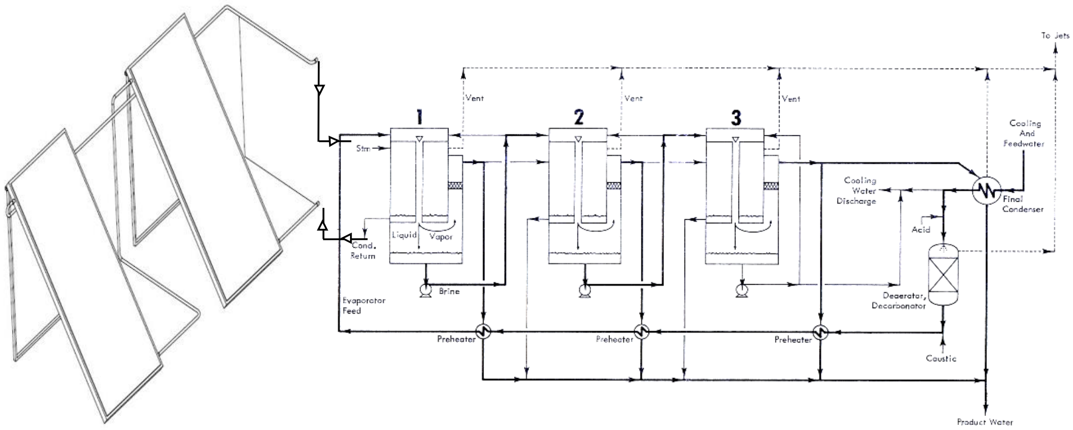

Figure 6. Solar water heating system of low capacity desalination system, input utility fluid temperature: 150°C.

3.2. Analyses results of investigation of impact of high temperature utility steam on system performance

By usage of relations of 15-18, we can reaches to Table 5. Table 5 shows that irreversibility values increase with increases in utility steam temperature, but exergy efficiency shows a reverse relation with utility steam temperature. The two methods calculate irreversibility values equally, but the efficiency value obtained with the Stream wise method is higher. Other purpose of this investigation is validation of reverse being of exergy efficiency and temperature of utility fluid theory by S&S method. As it is obvious from Fig. 7 and Fig. 8, S&S method validates that with increase of utility fluid temperature, exergy efficiency reduces.

Moreover, the required quantity of concentrating collector depends on steam temperature. Therefore, the capital cost and cost effectiveness of this system are influenced. Here, nonuse of lower steam temperatures is questionable. The concentrating collector's functional temperature range begins at 150°C, so it is not capable of producing lower temperatures.

3.3. Low capacity MED exergy analysis results

As can be seen from Table 6, the Stream wise method is also incapable of low-size plant analysis. The calculated efficiency of the Stream wise method is also illogically and consumedly high. Considerable increasing of exergy efficiency as a result of utility fluid phase change is the other significant point that can be seen in Fig. 9.

Changing of phase of utility fluid can be an effective parameter in increasing of exergy efficiency. By adding several thousand kilowatts of exergy to the presented low-capacity systems, the computed exergy efficiency of the Stream wise method be-

Table 4. High capacity MED exergy analysis results.

Utility	Sink & source method				Stream wise method			
	$\Delta\dot{E}x_{Sink}$(kW)	$\Delta\dot{E}x_{Source}$(kW)	$I_{s\&s}$(kW)	$\eta_{EX_{s\&s}}$(%)	$\sum\dot{E}_{IN}$(kW)	$\sum\dot{E}_{OUT}$(kW)	I_{sw}(kW)	$\eta_{EX_{sw}}$(%)
Steam 150°C	43.02	-4112.13	4069.11	1.04	35799.58	31730.47	4069.11	88.63

Table 5. High capacity MED exergy analysis results.

Utilities	Sink & Source method				Stream wise method			
	$\Delta\dot{E}x_{Sink}$(kW)	$\Delta\dot{E}x_{Source}$(kW)	$I_{s\&s}$(kW)	$\eta_{EX_{s\&s}}$(%)	$\sum\dot{E}_{IN}$(kW)	$\sum\dot{E}_{OUT}$(kW)	I_{sw}(kW)	$\eta_{EX_{sw}}$(%)
Steam 200°C	43.02	-5139.99	5069.96	0.83	37413.18	32316.21	5096.96	86.37
Steam 250°C	43.02	-5973.92	5930.9	0.72	39179.04	33248.14	5930.9	84.86

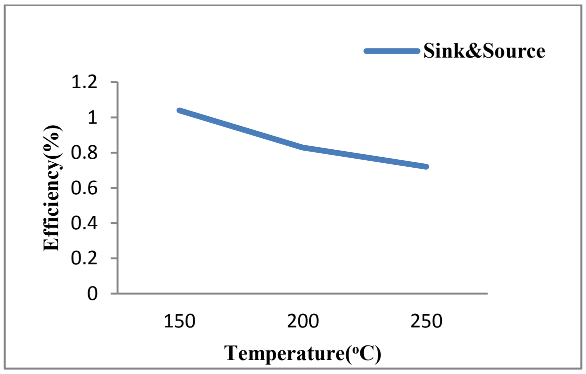

Figure 7. High capacity MED S&S analysis results.

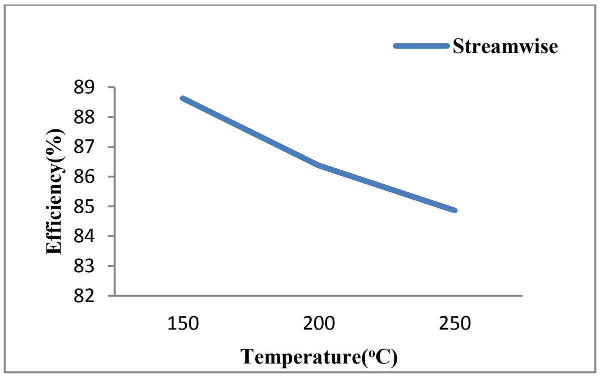

Figure 8. High capacity MED SW analysis results.

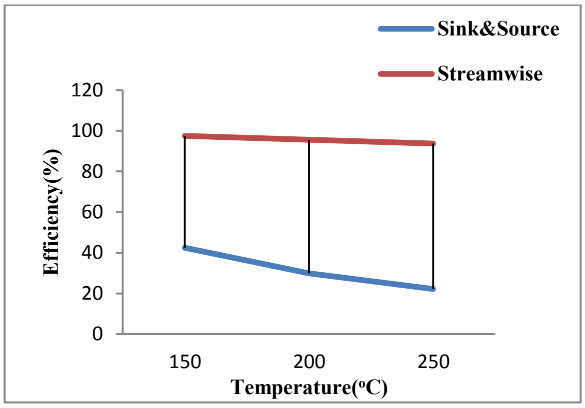

Figure 9. Low capacity MED S&S and SW analysis results.

comes 100% again. It is taken care that presented study has not just theatrical attributed by suggestion of low capacity system and it is tried to present a system that is capable of implementation in Iran practically and industrially.

Consideration of 200°C or 250°C for utility fluid temperature is not practical. Theoretical Illustration of reverse relation between utility fluid temperature and exergy efficiency of low capacity system is the reason for exergy analysis of low capacity desalination system in these states .

3.4. Economic analyses

The three solar field and water heating systems are analyzed economically (Tables 7 and 8). Number of collectors is specified according to required mass flow rate. In consideration of DISS loop mass flow rate (1kg/s), we need 70 collectors for supplying of required mass flow rate for solar field when temperature of utility fluid is 150°C. Total Capital and maintenance costs are brought from reference [14]. In section 2.6.1 and 2.7.2 are described how payment duration is calculated. Capital cost is decreased by changing of utility fluid phase and reduction of capacity of desalination system.

As it is shown, low capacity system implementation capability (in terms of economic and required facilities) is higher than high capacity system in Iran. On the other hand, calculated efficiency of low capacity system (by S&S) is much higher than high capacity system. Purpose of presenting of low capacity system and economic analyses of this system is suggestion of a small and high efficiency system for industrial production.

4. Conclusion

Stream wise mathematical technique is not correct in terms of physics; when interchanged exergies is too much, the exact amount of exergy loss is not gained and the system efficiency is computed high automatically. More efficiency for each of the two systems is obtained from the SW than

Table 6. Low capacity MED exergy analysis results.

Utilities	Sink & Source method				Stream wise method			
	$\Delta\dot{E}x_{Sink}$(kW)	$\Delta\dot{E}x_{Source}$(kW)	$I_{s\&s}$(kW)	$\eta_{EX_{s\&s}}$(%)	$\Sigma\dot{E}_{IN}$(kW)	$\Sigma\dot{E}_{OUT}$(kW)	I_{sw}(kW)	$\eta_{EX_{sw}}$(%)
First sate	3.34	-7.61	4.27	42.57	171.83	167.56	4.27	97.51
Second state	3.34	-11.15	7.91	29.90	179.24	171.43	7.91	95.64
Third state	3.34	-15.08	11.84	22.14	188.82	177.08	11.84	93.78

Table 7. High capacity solar MED economic analysis.

Phase	Temp. (˚C)	Solar field flow rate (Kg/s)	MED flow rate (Kg/s)	Collector's quantity (DISS) / loop's quantity	Total solar field area (m^2)	Solar field capital cost ($)	MED capital cost ($)	Total maintenance cost ($)	Total capital cost ($)	Payment duration
Steam	150	6.69	169.5	70/7	19,250	7,000	7,597,000	1,788,000	7,904,000	About 10 yrs.
Steam	200	7.19	169.5	70/7	19,250	7,000	7,597,000	1,788,000	7,904,000	About 10 yrs.
Steam	250	8.13	169.5	80/8	22,000	8,000	7,597,000	1,788,000	7,905,000	About 10 yrs.

Table 8. Low capacity solar MED economic analysis.

Phase	Temp. (˚C)	Solar field flow rate (Kg/s)	MED flow rate (Kg/s)	Collector's quantity (DISS) / loop's quantity	Total Solar water heating system area	Solar water heating system capital cost ($)	MED capital cost ($)	Total maintenance cost ($)	Total capital cost ($)	Payment duration
Steam	150	0.1	0.9	2	4	1,550	1,000	300	2,550	About 10 yrs.
Steam	200	0.1	0.9	4	8	2,500	1,000	300	3,500	About 10 yrs.
Steam	250	0.1	0.9	6	12	3,500	1,000	300	4,500	About 10 yrs.

from the Sink & Source exergy efficiencies. For the presented MED systems, if several thousand kilowatts of exergy are added to the steam–liquid flow, the computed exergy of the Stream wise method would be 100.

Reverse being of exergy efficiency and utility fluid temperature theory is validated by S&S.

Numerical results of efficiency and exergy loss of high -and low- capacity desalination systems show that the optimum condition of functional parameters occurs when the temperature of the heat carrier fluid is at its minimum. The optimum temperature of heat carrier fluid is 150˚C, because the minimum functional temperature of concentrating collectors is 150˚C.

By presenting of the low capacity system and economic analyses of two presented systems, it is concluded that it could be started up an efficient desalination system by low budget. It is shown that Stream wise method is not capable to calculate irreversibility and exergy efficiency according to computed results.

In the present study, an attempt is made to show that results of the stream wise method are inaccurate and deficient. The newly–offered, alternative method (sink & source) does not have the problems of the traditional method. Furthermore, it shows its efficiency under various conditions. Innovations of presented study are: 1. Presentation of a new and low defect method for exergy analysis of systems; 2. Improvement of reverse relation between utility fluid temperature and exergy efficiency by S&S method; 3. Illustration of disadvantages of stream wise method are; 4. Presentation of a low capacity MED desalination system which is able to be constructed in Iran; 5. Presentation of a system builds up of a low capacity desalination plant and a solar water heating equipment.

In future applications of the presented exergy analysis method, other thermodynamic and non-thermodynamics systems analyses would be investigated.

Nomenclature

C	*Flow speed relative to reference (ms^{-1})*
Ė	*Flow exergy (Kw)*
G	*The gravitational constant (m^{3}kgm$^-$2)*
h	*Flow enthalpy (Kjkg^{-1})*
I	*Irreversibility (Kw)*
ṁ	*Flow rate (kgs^{-1})*
Q˙	*Thermal energy (Kj)*
s	*Flow entropy (Kjkg^{-1}°K^{-1})*
T	*Temperature (°C)*
W˙	*Shaft work (Kw)*

Greek Symbols

ε	*Specific exergy (Kjkg^{-1})*
η	*Efficiency (%)*

Superscript

0	*Relative to standard chemical exergy*

Subscript

Ch	*Chemical*
e, Out	*Output*
i, IN	*Input*
Ph	*Physical*
Q	*Relative to thermal energy*
r	*Relative to reference*
S&S	*Sink & source*
SW	*Stream wise*
0	*Relative to environment*

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Appendix

Table A1. Solar polar collector type optimal specification (translated to English).

Row	Property	Dimension	Scale
1	Outer dimension	94*200	cm
2	Absorber area	1.57	m^2
3	Aperture area	1.78	m^2
4	Weight	42.9	Kg
5	Casing material	Extruded Al6063	
6	Thermal insulation material	Mineral wool	
7	Thermal insulation density	80	Kg/m^3
8	Thermal insulation thickness	50 (back of collector)	mm
9	Type of glass	Low Iron Wooded Glass	
10	Transmittance of glass	86 %	
11	Glass thickness	4	mm
12	Collector Capacity	1.5	Liter
13	Manifold (Cooper)	Diameter 22, Thickness 0.9	mm
14	Risers (Cooper)	Diameter 10, Thickness 0.9	mm
15	Absorber plate (sun strip)	Heat reflection factor: 7% Absorption factor: 96% Plate width: 143mm Coating method: vacuum ionized perfusion	
16	Standard test procedure (Iso 9060/9459 – I/II, En 12975-2)	Collector operating pressure(117.7 Psi)	
		Test of water penetration to collector	
		Inside heat shock	
		Standstill tempearture:180°C	
		Efficiency curve according to En – 12975 $Etta_0$ = 0.78 a1 = 1.4W/m^2.k , a_2 = 0.09W/$m^2.k^2$	
		Pressure loss curve according to En –*12975	

*Pressure loss for flow rate of 108Kg/s is 128.5 mbar.