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Techno-Economic Evaluation of 1200 m³/Day Seawater Desalination Plants: Comparative Analysis of RO, MSF, and MED Technologies

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ABSTRACT

Libya, like many arid countries, relies heavily on groundwater resources, which are increasingly scarce. With a 1950 km Mediterranean coastline offering an abundant but highly saline water source (35,000–38,000 ppm), seawater desalination is essential to meet national water demands. This study presents a techno-economic evaluation of three desalination technologies—Reverse Osmosis (RO), Multi-Stage Flash (MSF), and Multi-Effect Distillation (MED)—for a 1200 m³/day plant. RO design was conducted using ROSA software, while MSF and MED were modeled thermodynamically.RO requires significantly lower seawater intake (117 m³/h) compared to MSF (475.7 m³/h) and MED (200 m³/h), with corresponding plant efficiencies of 43%, 10.5%, and 25%. RO produces potable water (190 ppm TDS), while MSF and MED yield ultra-pure water (~50 ppm TDS), necessitating remineralization. RO operates without steam input, unlike MSF and MED (7.3 m³/h steam), and demands 235 kW of electrical power versus 245 kW (plus steam) for MSF and 50 kW (plus 7.5 m³/h steam) for MED. RO's high brine pressure (53.5 bar) enables energy recovery, whereas MSF and MED discharge warm brine at low pressure, posing environmental challenges. Economically, unit water costs are $0.37/m³ for RO, $1.52/m³ for MSF, and $1.21/m³ for MED. Overall, RO is the most technically and economically viable option for this capacity under Libyan conditions.

Keywords: Seawater desalination, Reverse Osmosis, Multi-Stage Flash, Multi-Effect Distillation.

التقييم التقني والاقتصادي لمحطات تحلية مياه البحر بطاقة 1200 متر مكعب/يوم: تحليل مقارن لتقنيات التناضح العكسي(RO) ، والتقطير الومضي متعدد المراحل(MSF) ، والتقطير متعدد التأثيرات(MED)

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ملخـــــــص البحـــــث

تعتمد ليبيا، كغيرها من الدول الجافة، بشكل كبير على الموارد الجوفية التي تشهد تناقصًا مستمرًا. ومع امتلاكها لساحل طويل على البحر الأبيض المتوسط يبلغ حوالي 1950 كم، فإنها تتمتع بمصدر مائي وفير ولكنه عالي الملوحة (35,000–38,000 جزء في المليون)، مما يجعل تحلية مياه البحر ضرورة لتلبية احتياجاتها المائية الحالية والمستقبلية. تقدم هذه الدراسة تقييمًا تقنيًا واقتصاديًا لثلاث تقنيات لتحلية مياه البحر: التناضح العكسي(RO) ، والتبخير الوميضي متعدد المراحل(MSF) ، والتقطير متعدد التأثيرات(MED) ، وذلك لمحطة بسعة 1200 م³/يوم. تم تصميم نظام التناضح العكسي باستخدام برنامج ROSA ، بينما تم نمذجة تقنيتي MSF و MEDباستخدام النمذجة الديناميكية الحرارية. من الناحية التقنية، يتطلب نظام RO كمية أقل بكثير من مياه البحر (117 م³/ساعة) مقارنةً بـ MSF (475.7 م³/ساعة) و MED (200 م³/ساعة)، بكفاءة تشغيلية تبلغ 43%، 10.5%، و25% على التوالي. ينتج نظام RO مياهًا صالحة للشرب 190) جزء في المليون(TDS ، بينما تنتج تقنيتا MSF و MED مياهًا فائقة النقاء 50~) جزء في المليون (TDS تتطلب إعادة تمعدن. كما أن نظام RO لا يحتاج إلى بخار، على عكس MSF و MED اللذين يستهلكان حوالي 7.3 م³/ساعة من البخار، ويتطلبان قدرة كهربائية تبلغ 245 كيلووات و50 كيلووات على التوالي، بالإضافة إلى البخار. يتميز نظام RO ضغط مرتفع لمياه الرجيع (53.5 بار)، مما يتيح إمكانية استرجاع الطاقة، في حين أن MSF و MED يفرغان مياهًا دافئة عند ضغط منخفض، مما يطرح تحديات بيئية حرارية. من الناحية الاقتصادية، تبلغ تكلفة إنتاج المتر المكعب الواحد من المياه 0.37 دولار لنظام RO، و1.52 دولار لنظامMSF ، و1.21 دولار لنظام .MED وتُظهر نتائج هذه الدراسة أن تقنية RO هي الخيار الأنسب من الناحيتين التقنية والاقتصادية لهذه السعة التشغيلية في ظل الظروف الليبية.

الكلمات المفتاحية :تحلية مياه البحر، التناضح العكسي، التقطير الومضي متعدد المراحل، التقطير متعدد التأثيرات.

1. INTRODUCTION

Libya's arid climate, limited freshwater resources, and growing population have intensified the demand for alternative water supply solutions. Coastal regions, despite their proximity to seawater, suffer from acute shortages due to aging infrastructure, over-reliance on groundwater, and limited investment in modern water treatment technologies. Seawater desalination presents a viable and increasingly necessary solution. However, the selection of desalination technology must be informed by a rigorous evaluation of technical performance, economic feasibility, and environmental sustainability [1].

Reverse Osmosis (RO), Multi-Stage Flash (MSF), and Multi-Effect Distillation (MED) being the most widely adopted. Each technology presents unique advantages and limitations in terms of energy efficiency, cost, scalability, and environmental impact. RO systems, driven by high-pressure pumps and semi-permeable membranes, are known for their modularity and relatively low energy consumption. MSF and MED, both thermal processes, are favoured in regions with abundant waste heat or low-cost steam but require more complex infrastructure and operational expertise [2].

While RO, MSF, and MED technologies are well-established globally, this study provides a localized techno-economic comparison tailored to Libya's coastal conditions and infrastructure. The use of ROSA software for site-specific RO design, combined with thermodynamic modeling for MSF and MED, offers practical insights for small-scale desalination planning in arid region.

2. METHODOLOGY

2.1 Design Basis

The study models a 1200 m³/day seawater desalination plant using three technologies. RO design is conducted using ROSA software, while MSF and MED are evaluated using thermodynamic principles and empirical data. All systems are assessed under identical feedwater conditions and operational targets The intake location and storage tank of product water are existent in project site, so it's not including in this technical and economical evaluation for three plants. The Open intake system of Tajoura desalination plant consists of raw seawater feed pipes and raw seawater basin [3].

2.2 Evaluation Criteria

- Technical performance: recovery rate, energy consumption, chemical dosing, system complexity
- Economic feasibility: capital cost, operating cost, cost per m³
- Environmental impact: energy source, brine disposal

2.3 Data Sources

Technical parameters are derived from manufacturer specifications, software simulations, and published literature. Economic data includes vendor quotes, operational benchmarks, and amortization models over a 20-year plant life. Environmental metrics are based on lifecycle assessments and carbon footprint estimations [4-10].

3. THE SEA WATER DESALINATION SYSTEMS

3.1 Multi-Stage Flash (MSF)

As illustrated in Figure 1, a certain portion of seawater is diverted behind the seawater pump for supply of the evacuation unit. The main portion is treated with anti-scale and - in case of becoming necessary - with antifoam chemical and is then fed into the condenser of evaporation stage 12. In addition, a sodium-bisulfite dosing station is provided for eliminating residual as chlorine in the feed water.

Due to the considered summer/winter fluctuations of the seawater temperature (min 14°C / max 28 °C), controlled by resistance thermometer, the evaporator is equipped with an automatic remixing device which keeps the inlet temperature of the seawater into the evaporator always constant at 28 °C. By this way the whole process is stabilized, and together with this control at the evaporator's cold end, a certain adjusted brine top temperature and seawater flow creates always the same water production temperature of the seawater into the evaporator always constant at 28 °C. By this way the whole process is stabilized, and together with this control at the evaporator's cold end, a certain adjusted brine top temperature and seawater flow creates always the same water production.

The treated seawater (make-up) is flowing through 12 condensers and is heated stepwise up to the brine heater inlet temperature (98.6°C) by recovering the heat of condensation of the vapours released in the flash stages. In the brine heater it is heated up to the brine top temperature (108 °C) by condensing heating steam at a temperature of 115 °C. The heating steam supplied to the brine heater has a pressure of max. 9 bar / min. 8 bar and saturation temperature (approx. 180 °C).

The steam is passing a fast-closing steam valve which automatically closes the steam supply in case of power failure of other dangerous events in the plant. The steam pressure is then reduced to 3 bar in a pressure reduction valve. The heated seawater is entering via an integrated spray pipe the first flashing chamber. As the brine is superheated, spontaneous boiling takes place and vapor is released until the brine has reached its saturation temperature. This procedure takes place in all following stages at decreasing temperature and pressure. The brine is flowing from stage to stage by specially designed inter-stage brine flow devices; being designed for optimum flexibility in operation and minimized stage-to-stage vapor leakages. The residual concentrated brine is discharged to the blow down pump, while controlling the brine level in stage. The distillates forming in each stage are collected in an external distillate pipe in parallel to the evaporator Stage to stage [11]. Table 1 and Table 2 show the steam data Operating Parameters for MSF, respectively.

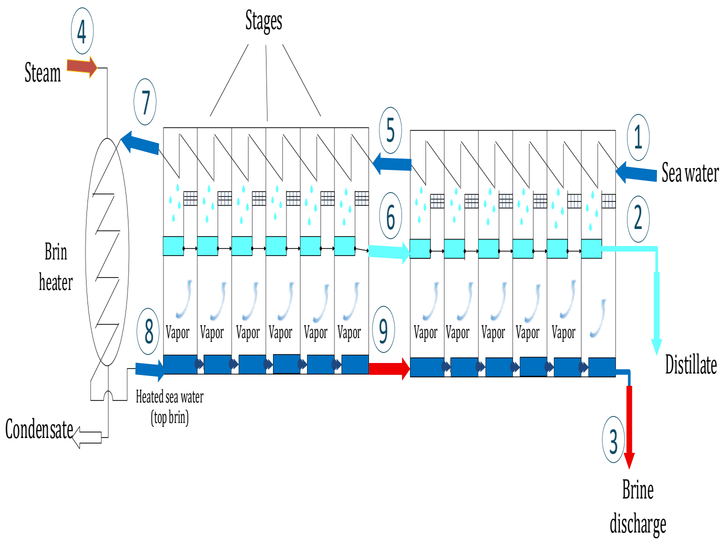

Fig 1. Flow diagram of MSF plant [11].

Table 1. Stream data for Figure 1.

Stream	Medium	Flow rate (m^3/d)	Operating P (bar)	Operating T (°C)
1	Seawater	475.7	1	28
2	Distilled	50	3	36.2
3	Brine	393.2	1.8	37.5
4	Steam inlet	7.3	10	180
5	Outlet Seawater from Evaporator 7-6	443.2	-	62
6	Distilled pipe from stage 6-7	27.3	-	70.5
7	Outlet Seawater from Evaporator 1	443.2	-	98.6
8	Inlet water to stage 1	443.2	-	108
9	Brian pipe from stage 6-7	415.9	-	71.4

Table 2. Process Data of MSF plant.

Type	MSF- Once-Through with 12 flash
Nominal capacity	1200 m^3/d
Brine Top Temperature	108 °C
Type of chemical dosing	Antiscale approx. 0.93 kg/h Antifoam approx. 0.14 kg/h
Sea Water inlet	
Flow	475.7 m^3/h
Temperature	Max. 28°C Min. 14 °C
Pressure	1 bar
Heating steam inlet	
heat transfer capacity	4566 kW
Flow	7.30 m^3/h
Temperature	180 °C
Pressure	Max. 9 bar Min. 8 bar
Steam supply to brine heater	
Temperature	180°C
Pressure.	Max. 9 bar Min. 8 bar
Distillate outlet	
Flow	50 m^3/h
Temperature	36,2 °C
Pressure	3 bar
Conductivity	20 µS/cm
Blow Down (Brine)	
Flow	393.2 m^3/h
Pressure	1.8 bar
Temperature	37.5 °C
Electricity	
Power consumption	245 kW 400V / 3Ph / 50Hz
Conductivity	20 µS/cm

3.2 Multi-Effect Distillation (MED)

MED plant consists of evaporator includes two successive cells at decreasing temperature from cell (1) to cell (2) as in shown Figure 2. The vapor introduced at 0.31 bar. In cell (1) is condensed at 70°C in a tube bundle externally sprayed by raw water. The vapor condensation heat allows part of this raw water to evaporate at a lower temperature / pressure (66°C/0.26 bar). The vapor produced then goes through cell (2) where it is condensed, thus evaporating part of cell (2) raw water at a temperature / pressure of (62°C/0.22 bar). [11]

Part of the vapor produced in cell (2) is drawn up by the thermos compressor, in order to feed cell (1) with vapor. The remaining goes to the raw water cooled condenser where it is condensed.

The water condensed in the first cell goes through a U-shape tube to the second cell and finally to the condenser. The water is extracted from cell (2) by means of the distilled water pump. In a similar way, the part of the sprayed raw water which has not been evaporated in cell (1) goes through a U-shape tube to the cell (2) to be finally blown down by means of the brine pump. Steam data and Operating Parameters for MSF are represented in Table 3 and 4, respectively.

Table 3. Stream Data for Figure 2.

Stream	**Medium**	**Flow rate (m^3/d)**	**Operating P (bar)**	**Operating T (C^0)**
1	Seawater (summer)	200	3.5	28
	Seawater (winter)	160	3.5	16
2	Seawater (summer)	200	3	38
	Seawater (winter)	160	3	31
5	Seawater	100	0.2	58
6	Seawater	100	0.1	60
7	Brine	140	0.7	62.3
8	Brine	150	0.1	62.3
9	Steam inlet	7.5	20	214.8
10	Steam	7.3	19	212
11	steam	0.2	19	212
12	steam	-	0.69	70
13	Distilled	57.5	2.7	61
14	Distilled	7.5	1.8	38
15	Distilled	50	1.8	38
16	Antiscalent	0.002	3.5	

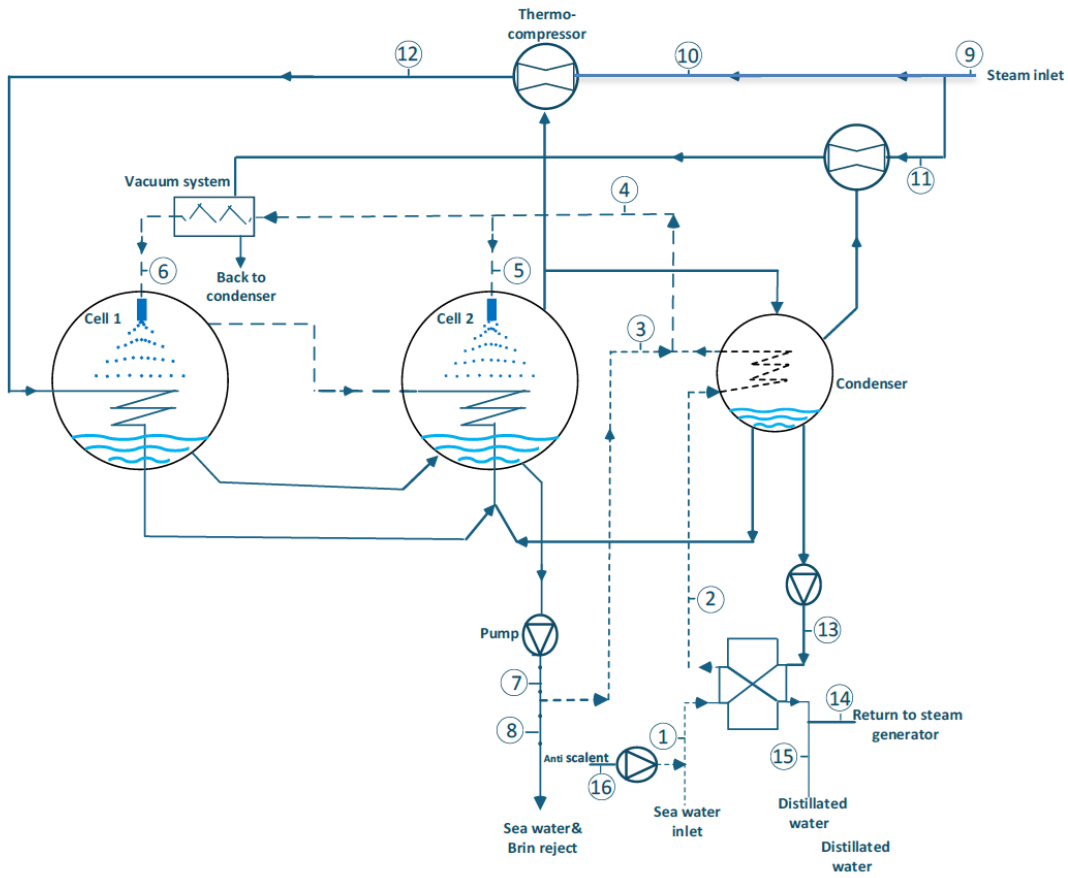

Fig 2. Process flow diagram of MED Plant [11].

Table 4. Process Data of MED plant [11].

Number of units	**1**
Number of cells	**2**
Distillate output	
Flow (daily)	1200 m^3/d
Flow (hourly)	50 m^3/h
Distillate out put pressure	1.8 bars
Temperature	Less than 38°C
NaCl content	20 ppm or less
Piping design pressure	5 bars
Steam inlet	
Flow	7.5 m^3/h
Pressure	20 bars
Temperature	215°C
Design pressure	17 bars
Sea water inlet/unit	
Required flow	200 m^3/h
Temperature	28°C or less
Piping design pressure	3.5 bars

3.3 Reverse Osmosis (RO)

The seawater reverse osmosis (RO) systems are designed to produce potable water from Mediterranean seawater the source water of Tajura Desalination Plant (Tripoli, Libya) was used as feed water for the (RO) systems. The intake head was placed at a distance of 1.3 km into the sea 7m below the sea level and 6m above the sea bottom. From the intake head seawater by gravity goes through two submersed pipelines into a seawater basin with a design capacity of 1920 m^3. Raw water characteristics are presented in Table 5.

Spiral wound membrane by the Dow chemical Company for Filmtec elements 8" were selected in the design used "FilmTec ROSA software, Version (8.3) to calculate of Membrane elements unit. RO systems are capable of producing up to 50 (m^3/hr) of permeate at a recovery of 45%. RO system includes six (96) Dow FilmTec SW30XLE-440i offers medium salinity and medium temperature feed waters an advanced combination of high productivity and high rejection through extra-low energy consumption and single-pass design are shown in figure 3 Tables 6 and 7 summarize the SWRO design parameters and predicted results obtained using ROSA Software for Dow Membranes Company.

Table 5. Tajura Raw seawater analysis [12].

Components	Sweater composition (mg/l)
Calcium Ca^{++}	455
Magnesium Mg^{++}	1427
Sodium Na^{+}	11600
Potassium K^{+}	419
Silica Si^{+}	2
Sulphate SO_4^{-}	2915
Chloride Cl^{-}	20987
Bicarbonates HCO_3^{-}	33
Nitrate NO_3^{-}	0

TDS	37938	(mg/l)
PH	8.0	
Temperature T	20	°C

Table 6. Design results of a membrane system.

Raw Water Flow to System	111.11	m³/h
Feed Pressure	55.5	bar
Flow Factor	0.85	
Chem. Dose (100% H2SO4)	138.47	mg/l
Total Active Area	3924.1	M²
Permeate Flow	50	m³/h
Recovery	45	%
Feed Temperature	20	C
Feed TDS	37964.31	mg/l
Number of Elements	96	
Average Flux	12.74	lmh
Power	214.25	kW
Specific Energy	4.28	kWh/m³

Osmotic Pressure:		
Feed	26.35	bar
Concentrate	49.31	bar
Average	37.83	bar

Table 7. the results for permeate and brain analysis.

Name	Feed	Adjusted Feed	Concentrate	Permeate
K	419.19	419.19	759.87	2.81
Na	11605.28	11605.47	21045.57	68.02
Mg	1427.65	1427.65	2594.23	1.89
Ca	455.21	455.21	827.18	0.6
CO3	18.17	0	0.02	0
HCO3	162.93	27.97	50.37	2.02
Cl	20977.49	20977.5	38049.37	112.7
SO4	2913.68	3049.32	5542.99	1.62
SiO2	2	2	3.62	0.02
CO2	0.9	111.53	111.7	110.26
TDS	37981.61	37964.31	68873.24	189.68
pH	8	5.14	5.47	4.45
P(bar)	55.5		53.5	2
CO2	0.9	111.53	111.7	110.26

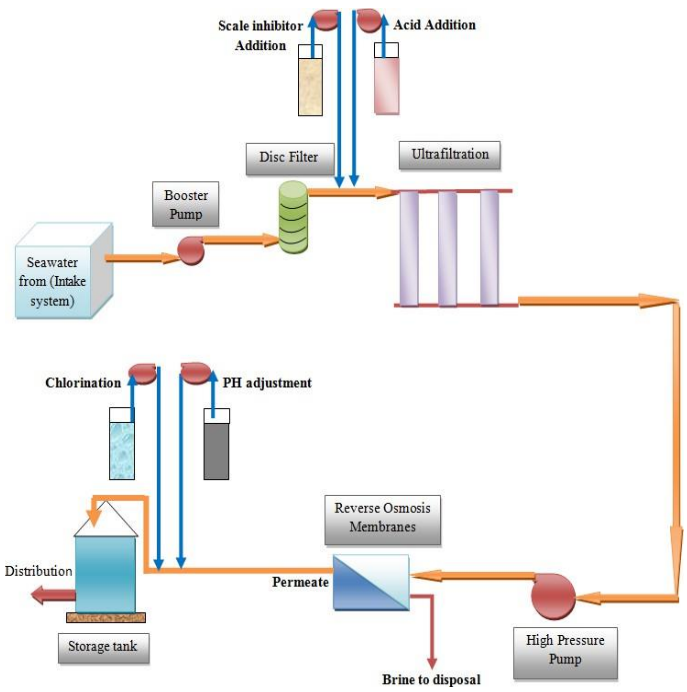

Fig 3. RO plant Design of Single Stage System with capacity of 1200 m³/day.

4. Technical evaluation:

Table 8 presents a comparative technical evaluation of three seawater desalination technologies: Multi-Stage Flash (MSF), Multi-Effect Distillation (MED), and Reverse Osmosis (RO)—for a plant capacity of 1200 m³/day. The seawater inlet flow rate for the RO plant is 111 m³/h, significantly lower than that of the MSF (475.7 m³/h) and MED (200 m³/h) systems. This variation reflects the differences in operating efficiencies: RO achieves 43%, compared to 10.5% for MSF and 25% for MED. The lower intake requirement for RO results in reduced capital costs (smaller high-pressure pumps) and lower operating costs due to reduced pumping energy.

The brine outlet pressure for the RO plant is 53.5 bar, substantially higher than that of MSF (1.8 bar) and MED (0.1 bar). This high-pressure discharge is advantageous, as it facilitates the integration of energy recovery systems that can assist the high-pressure feed pump. This is because the RO process requires a feed pressure of approximately 55.5 bar to drive seawater through the membranes.

Regarding product water quality, the RO system produces permeate with a total dissolved solids (TDS) concentration of about 190 ppm, while MSF and MED generate ultra-pure distillate (~50 ppm TDS). Although the latter appears superior, MSF and MED distillate typically require remineralization to meet potable water standards, adding complexity and cost to post-treatment. These differences in TDS are inherent to the membrane-based (RO) and thermal distillation (MSF and MED) processes.

Chemical dosing requirements also differ among the technologies: RO uses two chemical additives (acid and antiscalant), MSF employs antiscalant and antifoam, and MED uses only antiscalant. Overall chemical consumption is comparable between RO and MED, whereas MSF requires approximately 50% more chemicals. Both MSF and MED depend on heating steam at a flow rate of 7.3 m³/h, while RO operates without steam, resulting in lower operating costs and improved environmental sustainability.

The electrical power consumption of the RO plant is 235 kW, slightly lower than that of MSF (245 kW) and higher than that of MED (50 kW). However, the additional fuel required for steam generation in MSF and MED must be accounted for in the overall energy balance, further increasing their operational costs.

Overall, RO demonstrates superior technical performance in terms of efficiency (43%), reduced intake flow, potential for energy recovery, and lower environmental impact, making it the most favourable option under the evaluated conditions.

Table 8. Technical evaluation summary for MSF, MED and RO plants with capacity of 1200 m3/day.

	RO	**MSF**	**MED**
Seawater inlet			
Flow	117 m³/h	475.7 m³/h	200 m³/h
Temperature	28°C	28°C	28°C
Pressure	1 bar	1 bar	3.5 bar
Distillate outlet			
Flow	50 m³/h	50 m³/h	50 m³/h
Temperature	20 °C	36.2 °C	Less than 38°C
Pressure	1.5 bar	3 bar	1.8 bar
Brine			
Flow	67 m³/h	393.2m³/h	150 m³/h
Temperature	20 °C	37.5 °C	62.3°C
Pressure	53.5 bar	1.8 bar	0.1 bar
Product quality TDS			
	190 ppm	50 ppm	50 ppm
Type of feed chemical dosing			
	Sulfuric acid 2.7 kg/h Antiscalent 0.55 kg/h	Antiscalent 0.93 kg/h Antifoam 0.14 kg/h	Antiscalent 2.7 kg/h
Forms of energy input			
	Electrical Motors	steam	Steam
Energy requirement			
	Low	Medium	Low – medium
Heating steam			
Flow	-	7.30 m³/h	7.5 m³/h
Temperature	-	180 °C	215°C
Pressure	-	Max 9 bar Min 8 bar	20 bar
Electrical consumption			
	235 kW	245 kW	50 kW
Efficiency of plants			
	43 %	10.5 %	25 %

5. Economic evaluation

The economic evaluation of desalination technologies was performed for MSF, MED, and RO plants, each with a design capacity of 1200 m³/day, combining capital investment with annual operating costs are shown in table 9. Capital costs for the thermal systems (MSF and MED) were estimated using an exponential scaling relation:

$$j = C \cdot m^2 \qquad (1)$$

where j is the capital cost, $m$is the plant capacity, and $C$is a constant derived from reference plant data. For MSF, using a reference plant of 4000 m³/day with an investment of \$6.6 × 10⁶, the constant $C$was calculated as 26,192, resulting in a capital cost of \$2.96 × 10⁶ for 1200 m³/day. Similarly, for MED, a reference cost of \$5.3 × 10⁶ yielded $C = 20{,}636$, giving a capital cost of \$2.3 × 10⁶. In contrast, the capital cost for the RO system was obtained directly from vendor quotations, totaling \$4.0 × 10⁵.

Annual operating costs (A_t) were calculated by summing fixed charges, energy consumption, chemical usage, labor, steam (for thermal plants), membrane replacement (for RO), and maintenance:

$$A_t = A_1 + A_2 + A_3 + A_4 + A_5 + A_6 \qquad (2)$$

Fixed charges (A_1) were determined using:

$$A_1 = a \cdot DC \qquad (3)$$

where $DC$is the capital cost and $a$is the amortization factor, defined as:

$$a = \frac{i(1+i)^n}{(1+i)^n - 1} \qquad (4)$$

Assuming an interest rate $i = 5\%$, plant life $n = 20$years, and availability factor $f = 0.9$, the unit product cost (A_s) was calculated as:

$$A_s = \frac{A_t}{f \cdot m \cdot 365} \qquad (5)$$

Maintenance costs were estimated based on industry averages: 1.5% of capital cost for RO, 3% for MSF, and 4% for MED, reflecting the higher complexity and thermal stress in multi-effect systems compared to membrane-based units. Substituting the design and cost parameters, the annual operating costs were found to be $\$6.1\times10^4$for MSF, $\$5.1\times10^4$ for MED, and $\$14.5\times10^4$ for RO. These correspond to unit water costs of \$1.52/m³ for MSF, \$1.21/m³ for MED, and \$0.37/m³ for RO. The results clearly demonstrate that RO is the most economical option for small to medium-scale desalination plants due to its low capital investment and reduced energy requirements. Among thermal technologies, MED is more cost-effective than MSF, primarily due to its lower capital and operating costs.

Table 9. Economic comparison of desalination technologies (1200 m³/day).

Plant	Capital Cost (USD)	Annual Operating cost (\$/year)	Uint cost (\$/m³)
RO	4.0×10^5	1.429×10^5	0.37
MSF	2.3×10^6	5.98×10^5	1.52
MED	$2.69 \times 10^{6/}$	4.78×10^5	1.21

6. Environmental and Operation Implications

The environmental and operational characteristics of desalination technologies play a critical role in determining their long-term sustainability and feasibility. Reverse Osmosis (RO) demonstrates clear environmental advantages over thermal processes such as MSF and MED. RO systems operate without the need for steam generation, thereby eliminating fuel combustion and associated greenhouse gas emissions. In contrast, both MSF and MED require continuous steam input, typically produced by fossil-fueled boilers, which contributes to higher carbon footprints and thermal pollution. Additionally, RO systems discharge high-pressure brine (53.5 bar), which can be harnessed through energy recovery devices to reduce overall power consumption. Thermal systems, however, release warm brine at low pressure, posing greater challenges for heat dissipation and marine ecosystem impact. From an operational standpoint, RO offers higher efficiency (43%) and lower seawater intake (111 m^3/h), reducing both pumping energy and intake infrastructure requirements. Moreover, the absence of steam handling simplifies plant operation and maintenance. Although RO requires chemical dosing (acid and antiscalant), its overall chemical footprint is comparable to MED and lower than MSF, which also uses antifoam. The need for remineralization in MSF and MED due to ultra-pure distillate (TDS ~50 ppm) adds complexity to post-treatment, whereas RO permeate (TDS ~190 ppm) typically meets potable standards. According to life-cycle assessment (LCA) studies, RO desalination emits approximately 1.5–2.0 kg CO_2/m^3, which is 40–60% lower than the 4–6 kg CO_2/m^3 reported for thermal desalination systems. These findings confirm that RO is generally the more energy-efficient and environmentally favourable option under comparable operating conditions.

7. Limitations and Future Work

This study is primarily based on modeled data and vendor specifications for a 1,200 m^3/day desalination plant. The findings may vary under different feedwater compositions, plant capacities, or operational conditions. Therefore, future work should include pilot-scale validation to verify the technical and economic performance under real Libyan coastal environments.

8. Conclusion

For a small size capacity of 1200 m^3/day, the study concluded that the RO desalination unit is the most cost-effective compared to MSF and MED units. RO technology also proves to be less complex to operate and more environmentally favourable due to its lower energy demand and absence of steam requirements. While RO, MSF, and MED technologies are well-established globally, this study provides a localized techno-economic comparison tailored to Libya's coastal conditions and infrastructure. The use of ROSA software for site-specific RO design, combined with thermodynamic modeling for MSF and MED, offers practical insights for small-scale desalination planning in arid regions.

ROSA Software is a powerful tool to select between different designs. The main result items are the number of RO elements, percent recovery (R), and inlet feed pressure. Therefore, this software is strongly recommended in the design of RO units.

The economic evaluation indicated that the unit product cost for the MSF plant was 1.52 $/m³ and for the MED plant was 1.21 $/m³, both higher than the 0.37 $/m³ for the RO plant. As a result, the RO plant for this capacity of 1200 m^3/day is technically superior and economically the most viable option under the evaluated conditions.

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