ME 4315, Section A

Prof. Simmons

Project 2 Report

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Abstract

Freshwater scarcity is intensifying due to climate change and industrial expansion. Large scale seawater desalination offers one potential solution to this. Nuclear desalination is a promising path forward in this area, however, conventional nuclear desalination plants often have a large parasitic draw on the electric power generated by the plant. The project investigates two potential low temperature desalination technologies that run on the waste heat of a nuclear power plant. The two methods modeled are multi-effect desalination (MED) and spray assisted low temperature desalination (STLD). The nuclear power plant model was based on the diablo canyon power plant to provide reference environmental and operating conditions for an existing plant in arid coastal region. The systems were modeled using steady state thermodynamic analysis, accounting for boiling point elevation (BPE) of the water based on its salinity, and comparing performance based on the gained output ratio (GOR) and the second-law efficiency. With the waste heat from this plant, MED was able to chain together 15 effects, producing 10,263 kg/s of fresh water at a mass gain output ratio of 4.33 and a second law efficiency of 47%. MED outperformed SLTD in every comparison metric. This was largely due to the fact that each effect in the MED system is operating on the waste heat of the previous stage, while SLTD rejects heat at each stage without any recovery system. Economic analysis of this system shows that the system offers a reasonable levelized cost of water (LCOW) of 0.62 USD/m^3. This is roughly 25% lower than an RO plan of a similar capacity. These results show that MED technology offers a high capacity, low carbon, economically competitive method of desalination able to be retrofitted onto existing nuclear infrastructure.

Introduction

Freshwater scarcity is a mounting issue driven by climate change and industrial expansion. Although the Earth is mostly covered by water, only 3% of it is freshwater suitable for human consumption. Desalination is recognized as a vital solution to address the imbalance between freshwater supply and demand. Currently, desalination predominantly relies on fossil fuels, contributing to greenhouse gas emissions and unsustainable energy use. Nuclear desalination emerges as an environmentally friendly alternative, offering high energy density, zero emissions, and reliability. Integrating nuclear energy with desalination could contribute significantly to net-zero emission goals while providing stable, large-scale freshwater supplies.

Conventional nuclear desalination often extracts steam from the nuclear power cycle to drive thermal desalination processes, which reduces the electricity output of the plant. Common desalination technologies include multi-stage flash (MSF) and reverse osmosis (RO). While RO dominates the market for its lower energy cost, it faces challenges with water quality and membrane fouling. MSF delivers higher-quality freshwater but requires more energy, a high heat source temperature, and has poor efficiency.

This project focuses on a more efficient approach: utilizing waste heat rejected from the nuclear power plant condenser to drive low-temperature desalination technologies, specifically, multi-effect desalination (MED) and spray-assisted low-temperature desalination (SLTD).

Overall Design

This model will use a simplified nuclear power plant (NPP) design with a pressurized water reactor (PWR), shown in Figure 1, to simulate the waste heat supplied to the desalination plant. There are three main components of the design. First, is the reactor cooling water loop, which runs through the reactor itself, followed by the steam generator. This is followed by the secondary loop, also known as the steam loop, which powers the turbine, producing electricity, and then goes through the condenser to turn the working fluid back to a saturated liquid. Whereas in a normal NPP this waste heat from the condenser would be ejected to the environment, this design uses it as the heat source for the last segment, a thermal desalination plant. This desalination plant takes in seawater, and outputs freshwater, which is the desired product, and a high-salinity brine, a byproduct. The NPP design is simplified as it is not the focus of the project, but is modeled rather to see how different variables of the NPP affect the desalination plant's capabilities.

This overall design demonstrates two important aspects: the ability to retrofit existing NPPs with desalination, and protection from radiation danger. As the desalination plant only connects to the NNP's condenser, and does not have any parasitic draw on the steam cycle, construction on existing NPPs can be done without any negative effects, or the need to build completely new purpose-built NPPs for desalination. Furthermore, with regards to safety, there are two barriers between the water flowing through the radioactive reactor and the drinking water produced, in the form of the steam generator and condenser heat exchangers. These physical barriers are important, as the primary concern, tritium, a radioactive isotope of hydrogen, reacts with water to form tritiated water. Tritium causes cancer, and drinking it is 25,000 times more hazardous than breathing it. Tritium cannot be filtered out, however, it can be easily detected with liquid scintillation counters at the end product's output to ensure it satisfies the EPA's maximum contaminant level for tritium in drinking water of 20,000 picocuries per liter (pCi/L).

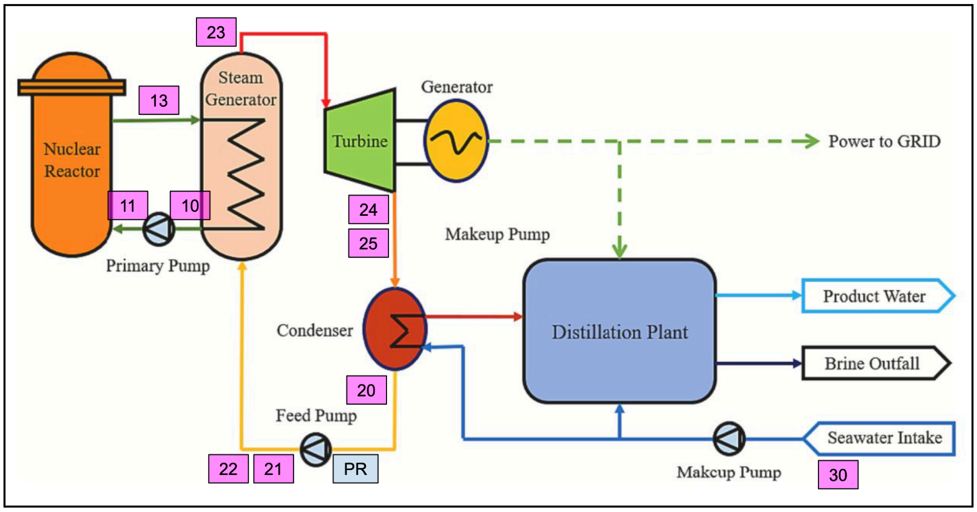


Figure 1: Overall Design

Modeling Methods

The following assumptions were used for the model: (1) The systems work in a steady state; (2) There is no heat loss to the surrounding environment; (3) The fluid properties are identical in each effect, and they are calculated from the state parameters, including pressure, temperature, and salinity.

Ambient conditions and plant capacity were based on the Diablo Canyon Power Plant in San Luis Obispo, CA. Based on this location, ambient seawater conditions of 20 °C and a salinity of 35 g/kg were used, as well as an allowable brine salinity of 85 g/kg. The plant's capacity is 1138 MW, from which, a NPP mass flow rate of ~2300 kg/s was derived.

Saltwater has a higher boiling point than pure water because dissolved salt lowers water's vapor pressure, so the liquid must be heated to a higher temperature before its vapor pressure can match the surrounding pressure and form stable bubbles. Thus, for modeling the evaporation chambers and the produced brine, the boiling point elevation (BPE), ΔT_b, must be calculated and applied to the model. For this, the BPE equation is used, which is a function of salinity, S [g/kg].

$$\Delta T_b = S \cdot i \cdot K_B / M$$

$i = 1.9$ [-], van't Hoff factor for seawater
$K_B = 0.512$ [C·kg/mol], ebullioscopic constant for water
$M = 58.44$ [g/mol], molar mass of NaCl

As can be seen in Figure 2, this model closely estimates the actual experimental data for saltwater's BPE, although it does slightly overestimate as salinity increases.

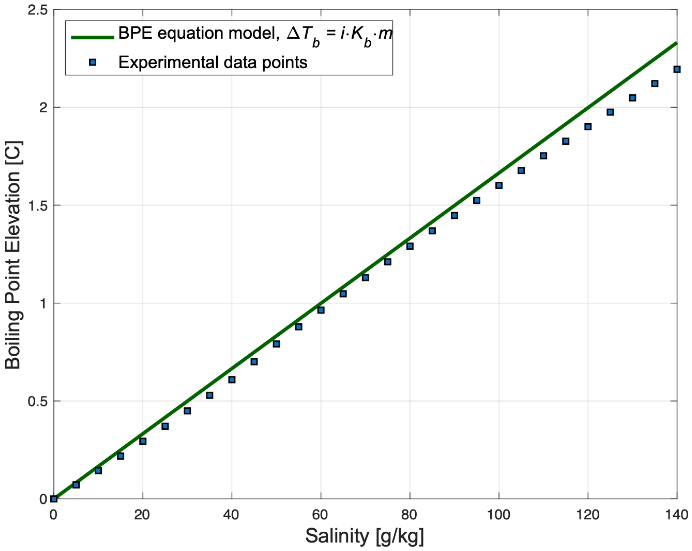


Figure 2: Boiling Point Elevation (BPE) equation model

In order to evaluate the performance of the desalination plant, the metrics of Gained Output Ratio (GOR) and 2nd Law Efficiency (η_{II}) are used. The GOR can be calculated through two different methods. The first method is through mass (GOR_{mass}), where the mass flow rate of the total distilled water is divided by the mass of the NPP steam powering the desalination. The second method is through enthalpy of evaporation (GOR_{hv}), where the evaporation enthalpy rate of the distilled water is divided by the waste heat rate provided by the NPP. The η_{II} is calculated by dividing the exergy recovered by the exergy supplied (E_{in}) by the NPP's waste heat. Since the exergy recovered can be difficult to quantify directly in a distillation plant, it is instead calculated by subtracting the exergy destroyed (E_d) from the exergy supplied.

$$GOR_{mass} = \frac{Mass\ flow\ rate\ of\ distilled\ water}{Mass\ flow\ rate\ of\ NPP\ steam} = \frac{\dot{m}_D}{\dot{m}_{NPP}}$$

$$GOR_{hv} = \frac{Evaporation\ enthalpy\ rate\ of\ distilled\ water}{Waste\ heat\ rate\ of\ NPP} = \frac{\dot{H}_{vap}}{\dot{Q}_{NPP}}$$

$$\eta_{II} = \frac{Exergy\ recovered}{Exergy\ supplied} = \frac{\dot{E}_{in} - \dot{E}_d}{\dot{E}_{in}}$$

MED Design

The Multi-Effect Distillation (MED) design, shown in Figure 3, uses a series of evaporation chambers, called "effects", whereby the enthalpy of the distilled water steam produced in one chamber is used for powering the evaporation in the subsequent chamber. The evaporation process occurs in a two-stage counterflow process, where the seawater first gets heated up to saturation temperature in the economizer, and then gets evaporated in the falling-film evaporator. The effects conclude with a final condenser at the end.

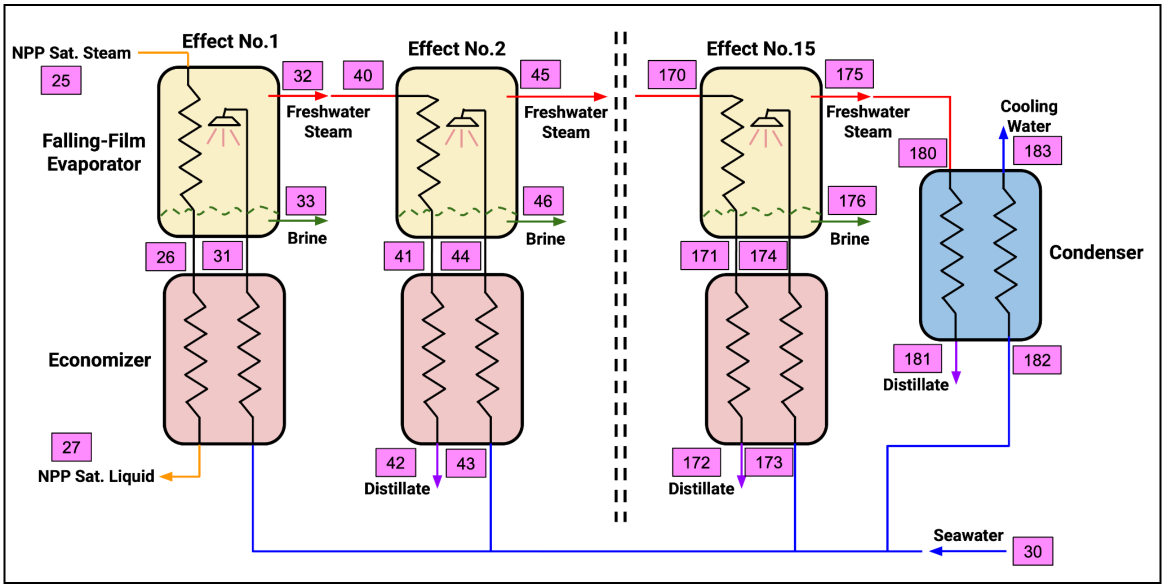


Figure 3: Multi-Effect Desalination (MED) design

The desalination effects can continue until ambient temperature is reached, and thus, the maximum number of possible effects is determined by the lower pressure of the NPP steam cycle (P_L) and the minimum heat exchanger temperature difference (ΔT_{HX}). Since the P_L is the pressure of the NPP steam leaving the turbine, it determines the enthalpy of the source of the waste heat used to fuel the desalination process. More specifically, since the steam is at saturation temperature, the pressure P_L determines the steam's temperature, which then sets the temperature that the first desalination effect can start at. The greater the P_L, the greater the maximum number of effects. From there, the ΔT_{HX} determines how many effects can be fit between that starting temperature and the ambient temperature. The lower the ΔT_{HX}, the greater the maximum number of effects. This relationship can be seen in Figure 4 below.

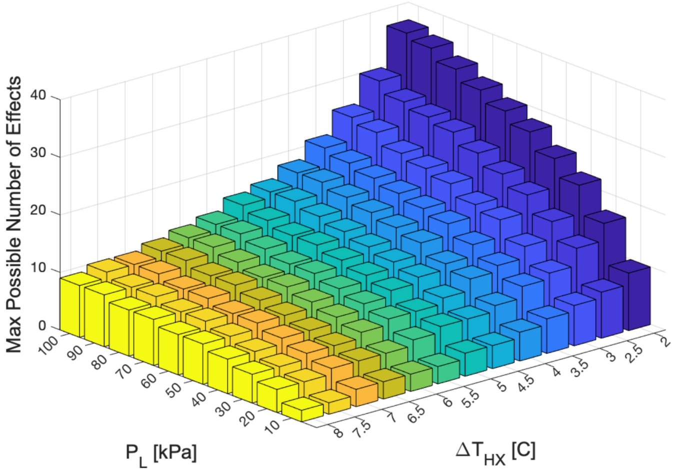


Figure 4: Max possible number of effects for each design NPP lower pressure (P_L) and heat exchanger temperature difference (ΔT_{HX}).

For this design, based on the Diablo Power Plant, a P_L of atmospheric pressure (101 kPa) will be used, as well as a ΔT_{HX} of 5 °C, which allows for 15 effects in the MED. The ΔT_{HX} required depends on the design of the heat exchanger, its effectiveness, and the margin of error deemed acceptable, however, that is beyond the scope of this project.

In each effect, the ratio of the distilled water flow rate (m_D) and the brine flow rate (m_B) is determined by the ambient salinity (S_0) and the maximum allowed brine salinity (S_B), using the conservation of salinity below:

$$\dot{m}_{in} \cdot S_{in} = \dot{m}_{out} \cdot S_{out}$$

$$(\dot{m}_D + \dot{m}_B) \cdot S_0 = \dot{m}_B \cdot S_B$$

Thus, the greater the maximum allowed brine salinity, and the lower the ambient salinity, the greater the mass flow rate of the distilled water. This relationship will also be shown in parameterization later.

Across the effects, the temperature decreases linearly, as can be seen in Figure 5, with a drop according to ΔT_{HX} in each step. The pressure, which is determined based on this temperature and the fact that it's a saturated steam, decreases nonlinearly, as can be seen in Figure 6, with decreasing pressure drops across each effect, nearing a vacuum towards the end.

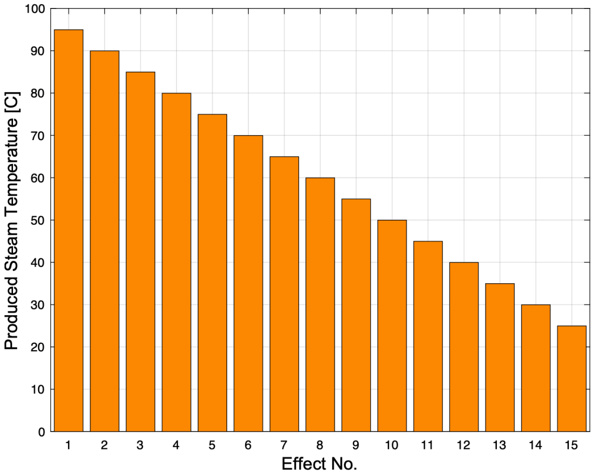


Figure 5: Produced steam temperature in each effect.

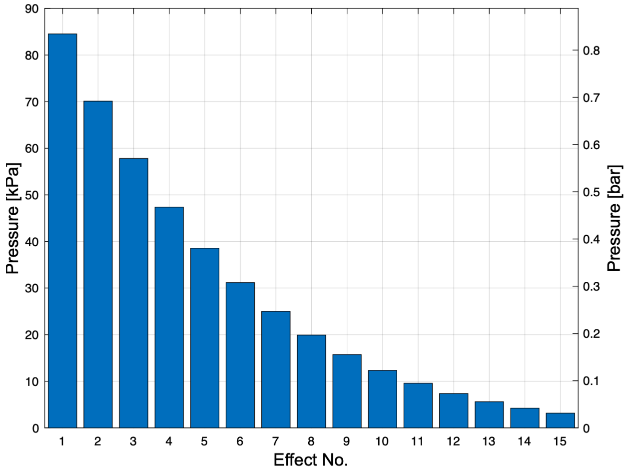


Figure 6: Pressure in each effect.

MED Results

The distilled water produced decreases with each passing effect, shown Figure 7. This means that each additional installed effect results in diminishing returns. In fact, over half of the total distilled water produced is done so in the first 5 effects. Furthermore, it appears that the production approaches a minimum value, settling around 15% of the NPP flowrate.

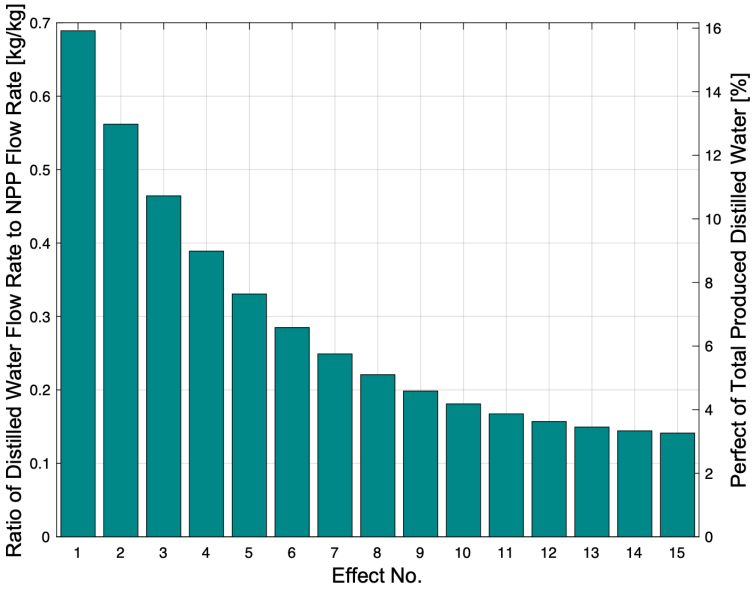


Figure 7: Produced distilled water flowrate across effects.

The exergy destruction has a similar trend, with decreasing exergy destruction in passing effects per kg of NPP water. However, unlike the mass flowrate, it doesn't have a minimum value, but rather approaches zero, shown in Figure 8. More interestingly, brine ejection is a source for the vast majority, 65%, of exergy destruction, as the heated up brine absorbs enthalpy and is then rejected back to the environment. The condenser, which is the last step of the MED, makes up 33% of exergy destruction, and heat exchange causes only 2%.

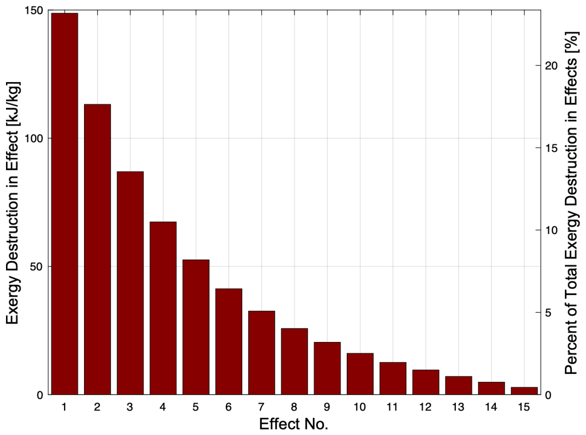


Figure 8: Exergy destruction across effects.

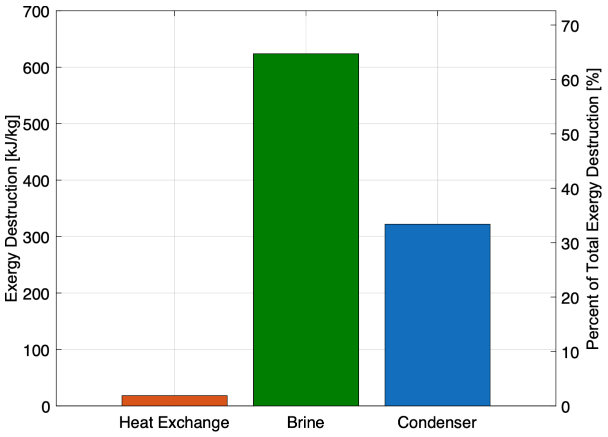


Figure 9: Sources of exergy destruction.

SLTD Design

Spray-assisted Low Temperature Distillation (SLTD) works by utilising nozzles that spray the seawater out in the form of tiny droplets into a chamber with lower pressure than the seawater had prior, inducing flash evaporation. A key simplification of this model is that the flash evaporation can be characterized as change from a quality of 0 to 0.1. The spray evaporators are characterized in the paper as siphoning a small portion of the brine as steam in each evaporator, since a static pressure drop results in unreasonable amounts of distillate being produced in each effect. This siphoning results in the brine increasing in salinity following the same conservation of salinity equation MED follows, except that the input salinity is the prior evaporator's output salinity. The steam distillate that forms is siphoned off into a condenser that is cooled with seawater in counterflow starting with the last evaporator in the arrangement, as seen in Figure 10 below.

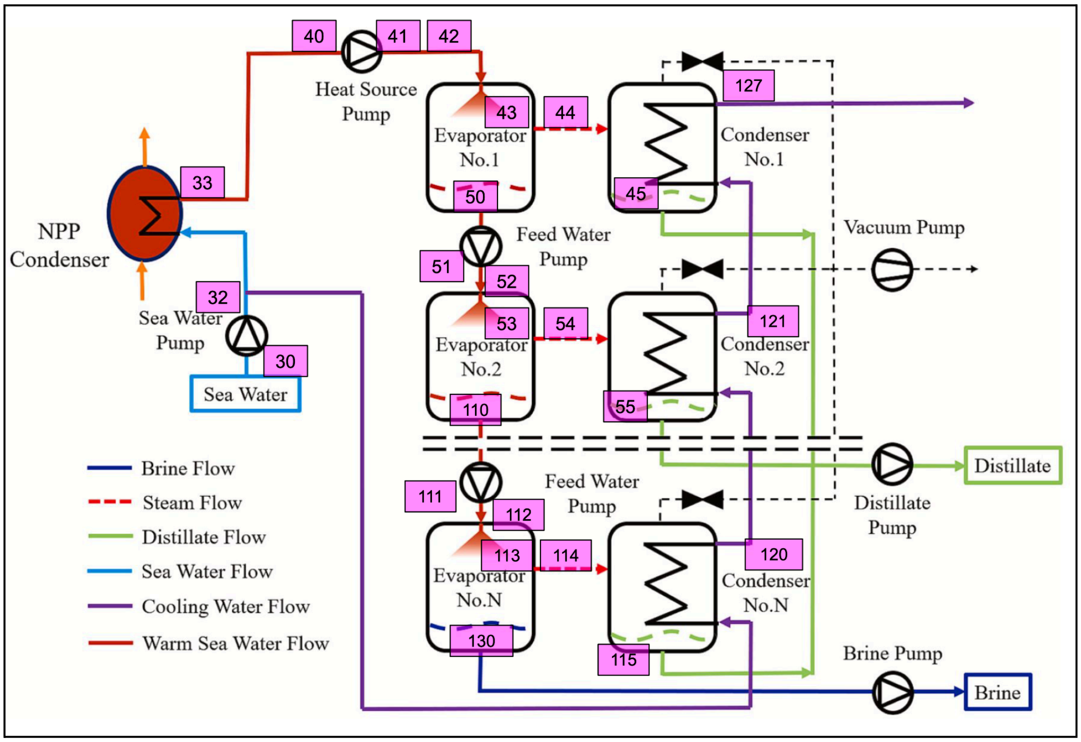


Figure 10: SLTD Model with Labeled State Points.

The key difference from MED aside from the actual mechanics of desalination is that the brine is continuously moved into further chambers, which means that the maximum allowable brine salinity is what drives the number of evaporators that are feasible, rather than the enthalpy of the heated seawater. This relationship is characterized to the right in Figure 11.

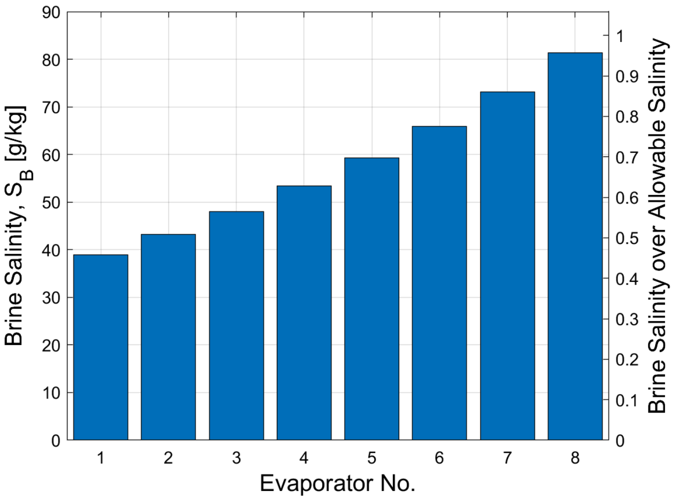


Figure 11: Brine salinity in each evaporator.

The brine salinity is 38.31 g/kg through the first evaporator, and after moving through 8 evaporators the final salinity is 81.31 g/kg. The salinity change is nonlinear as more steam is siphoned off, implying that an additional evaporator would push the brine salinity over the allowable salinity of 85 g/kg. Although the salinity through each evaporator is the driving factor behind how many are possible to utilize, another important factor in the general design is the temperature change through each evaporator, as seen below in Figure 12.

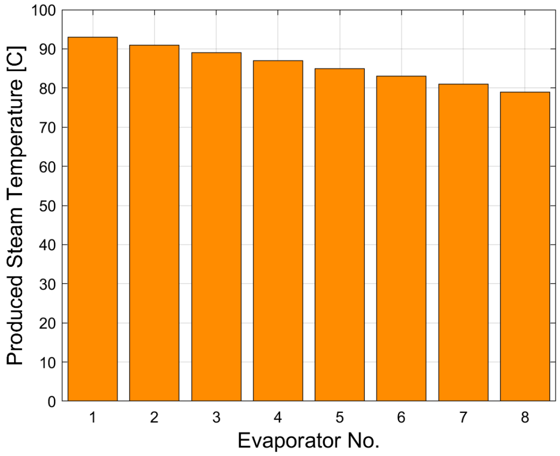


Figure 12: Temperature in each evaporator.

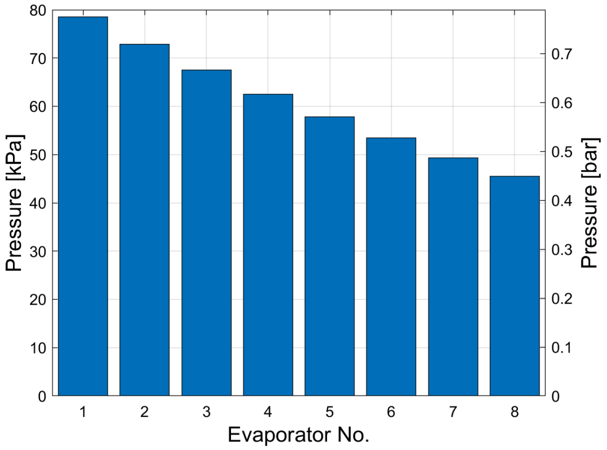


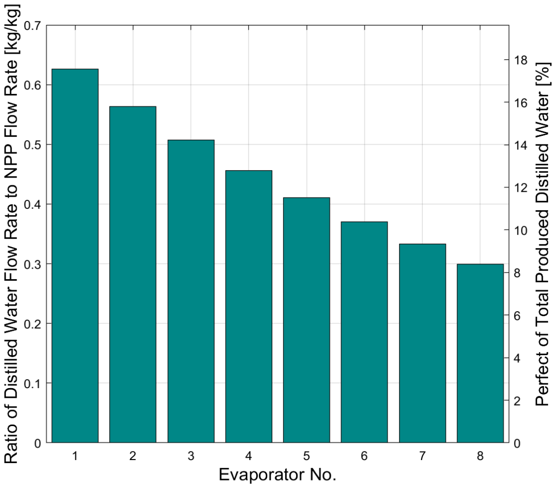
Figure 13: Pressure in each evaporator.

The temperature drop follows a linear trend. The temperature is only 2 C between evaporators because the method of evaporation works entirely through drops in pressure rather than heat exchange. This temperature drop does explain the reason for the cooling water flowing into the condensers in the reverse direction is because of this temperature drop, since the lowest temperature brine is in the last evaporator, which would bottleneck the system if the cooling water flowed in parallel with the evaporators.

The pressure in each evaporator, shown in Figure 13, does not follow a linear relationship as each evaporator causes smaller drops in pressure than the one before. The largest drop in pressure occurs as the seawater goes into the first evaporator, as the pressure drops from 101.325 kPa to 78.5 kPa, and none of the proceeding pressure drops exceed 10 kPa. The final evaporator has a pressure of 45.5 kPa. The salinity of the seawater has a minimal effect on the pressure drops, as it needs to be greater than 120 g/kg to change the brine saturation pressure by 1-2 kPa.

SLTD Results

Similar to the MED, the sequential evaporators have diminishing returns of distilled water flow rate, with the first three evaporators accounting for half of total production. This change is nonlinear, as can be seen in Figure 14 to the right.



The exergy destruction in each comes from the small brine temperature drop and cooling the freshwater steam back to a liquid. The destroyed exergy falls through the evaporators, primarily due to the falling mass flow rate through the evaporators. The specific exergy destroyed is nearly identical between each evaporator, changing from 207.1 kJ/kg to 210 kJ/kg through the eight evaporators. At first glance, this indicates that having less evaporators would result in a more efficient system, but the waste brine would simply become hotter, which does not change the amount of destroyed exergy as it eventually returns to ambient upon being pumped out to sea.

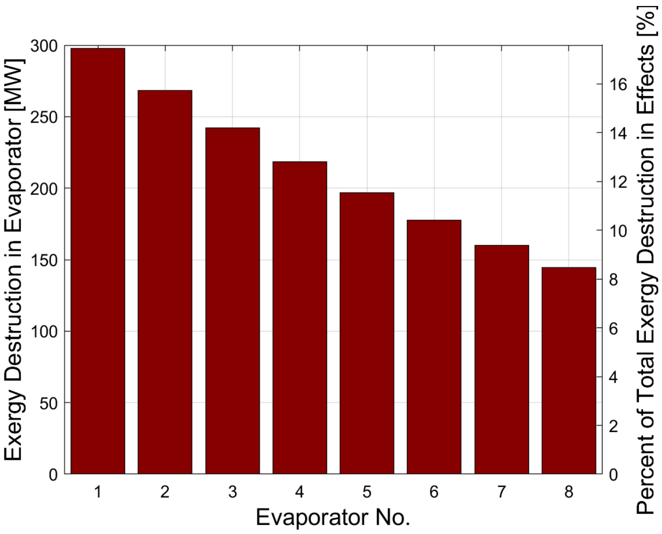


Figure 15: Exergy destruction across evaporators.

MED vs. SLTD Performance

Performance Metric	MED	SLTD
GOR_{mass} [kg/kg]	4.33	3.57
GOR_{hv} [kJ/kJ]	5.21	4.10
η_{II} [-]	0.474	0.458
Production, m_D [kg/s]	10,263	8,190

MED is a better choice for desalination than SLTD by every metric. MED has a higher GOR on a mass and enthalpy basis, a higher 2nd Law Efficiency, and a higher distilled water mass flow rate. The main reason behind the higher GOR and 2nd law efficiency is that the MED uses the produced freshwater steam from each effect to heat the seawater going into the next stage, while SLTD requires an additional flow of seawater used only to cool off the steam produced by each evaporator, leading to exergy destruction.

The mass flow rate required to cool the steam in SLTD is a startling 65,917 kg/s, due to the high enthalpy of the steam and that the condensers are placed in a series, requiring a single input to cool all of the distillate. This required cooling water flow rate falls drastically as the number of evaporators falls, but removing evaporators lowers the mass flow rate of the distilled water and the final brine salinity. MED is much more widely applicable due to these limitations affecting SLTD, as the brine salinity can be maintained even with fewer effects. Thus, MED will be used as the chosen design, and analyzed in subsequent parameterizations and cost analysis.

Parameterization

In order to see the effects of changing conditions on the performance of the MED desalination plant, the following were parameterized: ambient temperature, ambient salinity, and allowed brine salinity. Figure 16 shows that the GOR decreases with ambient temperature, as the plant has to spend more energy heating it up to saturation temperature in the economizers. However, the η_{II} actually slightly increases with colder ambient temperatures, which most likely is just a result of the reference temperature used to calculate exergy decreasing as a result. Regardless, with both GOR and η_{II}, the ambient temperature does not have a large effect.

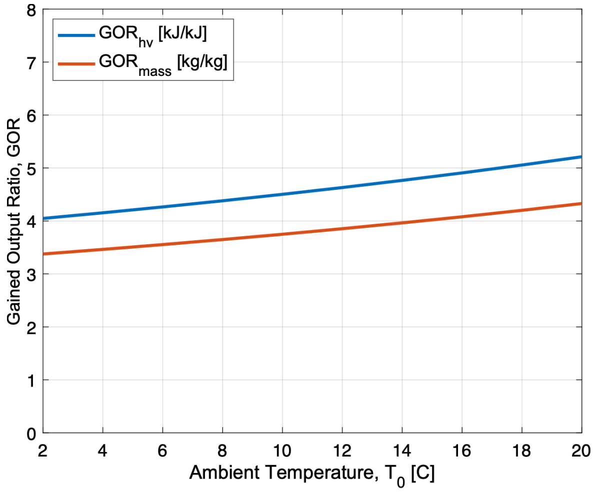


Figure 16: GOR across ambient temperatures.

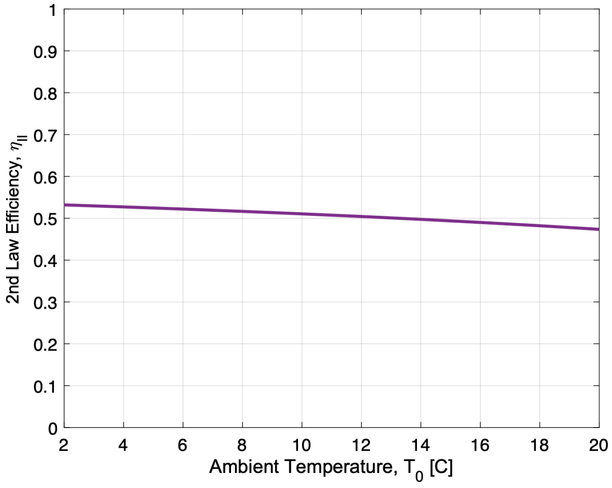


Figure 17: η_{II} across ambient temperatures.

By comparison, the ambient seawater salinity has a much larger effect. Increasing the seawater salinity from 5 g/kg to 50 g/kg causes the GOR to halve. The η_{II} also experiences a significant drop. These show that the desalination plant is less efficient and less viable in places of the world with high salinities, such as the Persian Gulf.

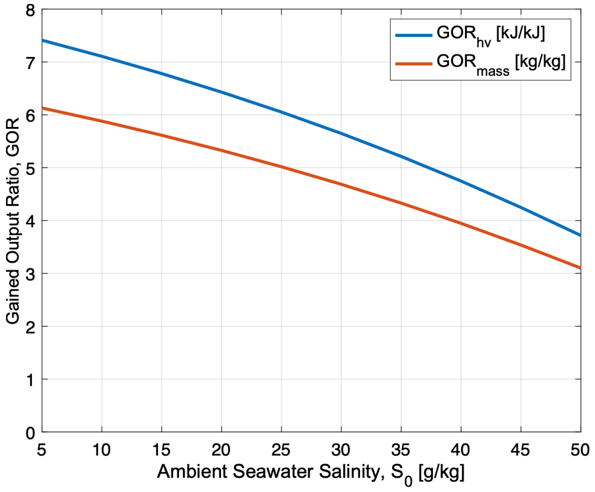


Figure 18: GOR across ambient seawater salinity.

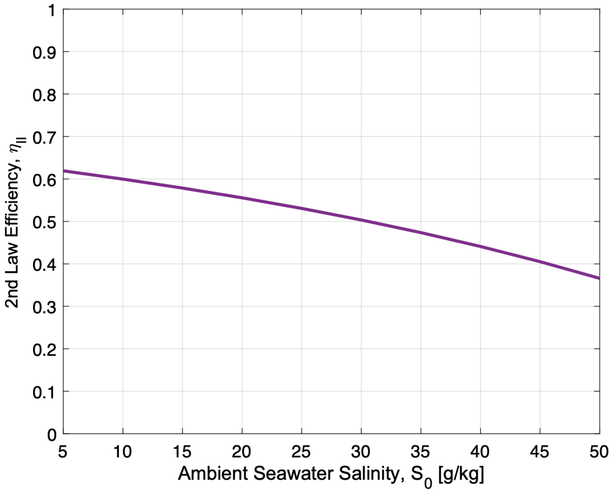


Figure 19: η_{II} across ambient seawater salinity.

Lastly, increasing the brine salinity from 50 g/kg to 140 g/kg causes the GOR to more than double, and the η_{II} to significantly improve. This is because higher brine salinities allow for less brine flow, which in turn decreases the largest source of exergy destruction, brine ejection. Thus, to optimize efficiency, the desalination plant should make the brine salinity as high as within local government and environmental restrictions. However, Figures 20 and 21 demonstrate that there are diminishing returns in performance as brine salinity gets really high, with both metrics beginning to stagnant past 130 g/kg. This is because less brine flow also means greater distillation flow, which requires large amounts of energy for the enthalpy of vaporization. Taken to the extreme, completely boiling off the water to leave salt crystals will make for easier disposal, however, it would require levels of energy too large for waste heat applications.

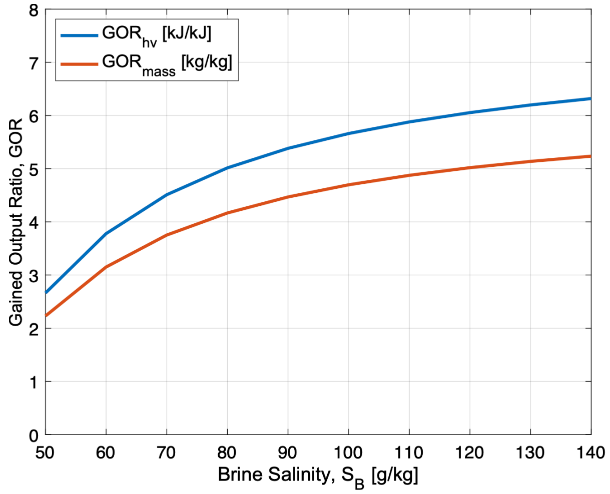


Figure 20: GOR across allowed brine salinity.

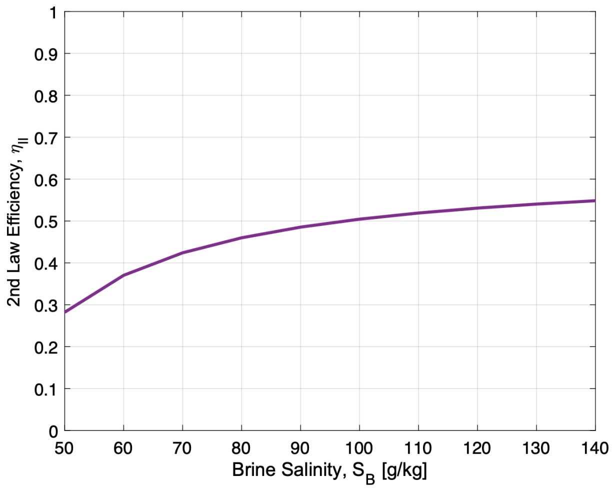


Figure 21: η_{II} across allowed brine salinity.

Seawater Intake and Brine Removal

Two important factors to consider when implementing MED are the pump specifications for intaking seawater and removing brine. Seawater is pulled from the surface of the sea at a distance of 250 meters from shore to avoid disrupting the ecosystem in shallower water. The pipe length (L) is determined to be 300 meters from this, under the assumptions that the plant itself is located some distance from the shoreline and that the endpoint of the intake pump is at sea level. The pipe material is concrete, because concrete is very resistant to corrosion and fouling. The desired volumetric flow rate (Q) in m^3/s is determined from the following equation:

$$Q = \dot{m}_{in}/\rho$$

Where $\dot{m}_{in}$ is the mass flow rate in kg/s and ρ is the density of seawater in kg/m^3. Q is determined to be 16.47 m^3/s, for which a pipe diameter (D) of 3.4 meters is sufficient. This results in a flow velocity (v) of 1.814 m/s, which is low enough to not disrupt sea life. Using these characteristics and the formula for Reynolds number:

$$Re = \rho \cdot v \cdot D / \mu$$

Where Re is Reynolds number, and μ is the viscosity in Pa·s. The resulting Reynolds number is 5,805,000, and with an equivalent roughness of 0.001 m for concrete, consulting a moody diagram results in a friction factor (*f*) of 0.019. We are then able to use the pump head equation:

$$H = P_1 - P_2 + \rho(\frac{v_1^2 - v_2^2}{2} - \frac{f\rho v_1^2}{2D} - \frac{kv_1^2}{2})$$

Where H is the pump head in Pa, P_1 and P_2 refer to the pressure in Pa at the inlet and outlet, and k refers to the minor loss coefficient alongside previously stated variables. There is no minor loss in the intake pump, and using the equation results in a pressure difference of 2,829 Pa or 0.289 meters of water. The pump power can then be calculated using the equation:

$$Power = vH/\eta$$

In this equation, pump power is in units of watts and η is the pump efficiency, which is assumed to be 0.8. This results in a power draw of 58 kW.

Disposing of brine requires a diffuser to raise the pressure of the outcoming brine so that it properly diffuses into the surface water once it is disposed of. The brine mass flow rate is 6957 kg/s. However, this total brine flow is split amongst the 15 effects, and was assumed to be combined into a single flow with a temperature of 75 C and a pressure of 84.53 kPa. Additionally, the outflow pipe is 400 meters long with one 90° bend so that the brine waste does not affect the intake seawater. Once again, the pipe is made of concrete to avoid issues with fouling. The diffuser is placed at the end of the piping to save on construction costs, and the pipe diameter is chosen to be 1 meter and the ending diameter is set to be 3.5 meters. Using these parameters, the outlet pressure is found according to the following equation:

$$\frac{\rho v_1^2}{2} + P_1 = \frac{\rho v_2^2}{2} + P_2$$

Using this equation, the outlet pressure, P_2, is found to be 122.51 kPa. The volumetric flow rate is 6.781 m^3/s according to the prior equation, and the flow velocity before the diffuser is 8.633 m/s. The flow velocity at the end of the diffuser is found to be 0.705 m/s. The Reynolds number of the brine flow is 8,127,000, and using the moody diagram with the roughness of concrete results in a friction factor of 0.019 again. Using these values in the pump head equation gives a pump head of 380.46 kPa or 38.8 meters of water. The required pump power is then calculated to be 3225 kW according to the prior equation.

These values show that there is a large benefit to avoiding large amounts of pump head where possible in the system, as introducing changes in height to the pumps will result in very large power draws due to the high mass flow rates in both the seawater intake and brine disposal.

Cost Analysis – LCOW Metric and Framework

For the economic comparison we use the Levelized Cost of Water (LCOW), defined in analogy to the levelized cost of electricity. LCOW represents the total annualized cost of the desalination system divided by the annual volume of product water, and is reported in $/m³. This single metric allows a direct comparison between different technologies at the same water output.

In our model, the annualized cost includes five components:

1. Capital cost amortized over the plant lifetime,
2. fixed operation and maintenance (fixed O&M),
3. variable non-energy operation and maintenance (variable O&M),
4. electricity cost, and
5. thermal energy cost (which is zero in our MED + waste-heat case).

$$LCOW = \frac{(Annualized\ CAPEX + Fixed\ O\&M + Variable\ O\&M + Electricity\ Cost + Thermal\ Energy\ Cost)}{Annual\ Water\ Production}$$

For both the MED + nuclear waste-heat system and the reference RO plant, we compute each cost term using a discounted-cash-flow approach in Excel and apply this LCOW expression. Capital costs are annualized using a capital recovery factor (CRF) based on a 25-year lifetime and 7% discount rate; the full CRF expression and numerical evaluation are provided in Appendix A.3. The detailed input values used to evaluate LCOW (technical performance and cost assumptions) are summarized in Appendix A.1.

Cost Analysis – Key Inputs and Assumptions

The MED state-point model gives a base capacity of ≈ 0.9×10^6 m³/day, or about 2.9×10^8 m³/year at 90% capacity factor, with an effective GOR ≈5. For electricity we assume 1.5 kWh/m³ for MED and 3.5 kWh/m³ for RO, consistent with reported ranges, while the MED thermal requirement (≈ 120 kWh_{th}/m³) is supplied by nuclear condenser waste heat. Economically, both systems are evaluated over 25 years at a 7% real discount rate. We assume MED CAPEX of 800 MUSD (≈ 900 USD/(m³/day)) and RO specific CAPEX of 1200 USD/(m³/day), 3%/yr fixed O&M, variable non-energy O&M of 0.20 USD/m³ (MED) and 0.15 USD/m³ (RO), and an electricity price of 0.07 USD/kWh. The full input list and literature ranges are summarized in Appendix A.1.

Cost Analysis – MED + Waste Heat vs RO

Using the inputs summarized in the previous section, the LCOW_Base sheet evaluates the cost of the MED + nuclear waste-heat configuration. At a design capacity of approximately 0.89×10^6 m³/day and 90% capacity factor, the MED system produces about 2.91×10^8 m³/year of product water. At the base capacity, MED annualized CAPEX, fixed O&M, variable O&M, and electricity costs are 68.6, 24.0, 58.3, and 30.6 MUSD/yr, which correspond to about 0.24, 0.08, 0.20, and 0.11 USD/m³ respectively, for a total LCOW of 0.62 USD/m³, with no additional charge for thermal input because condenser heat from the nuclear plant is treated as free waste heat. The full numeric breakdown is provided in Appendix A.2.

For the reference seawater RO plant, the LCOW_RO sheet uses the same annual water production but a higher specific CAPEX and electricity use. At 1200 USD/(m³/day) specific CAPEX and 3.5 kWh/m³ electricity consumption, the corresponding annual cost components are 91.3, 31.9, 43.7, and 71.4 MUSD/yr, or roughly 0.31, 0.11, 0.15, and 0.25 USD/m³, yielding an LCOW of 0.82 USD/m³. Again, the detailed numbers are listed in Appendix A.2.

Figure 22 shows the resulting LCOW breakdown for both technologies. The MED + waste-heat design is roughly 25% cheaper per cubic meter than the RO reference (0.62 vs 0.82 USD/m³). The stacked bars make clear that electricity is the dominant difference: RO spends on the order of 0.25 USD/m³ on electrical power for high-pressure pumps, whereas MED spends about 0.11 USD/m³ and pays nothing for thermal input in this scenario. CAPEX and non-energy O&M are of comparable magnitude between the two options, so the lower LCOW for MED primarily reflects its ability to substitute free nuclear waste heat for electricity. To test how robust this comparison is, we next examine how LCOW changes when MED performance and plant size vary.

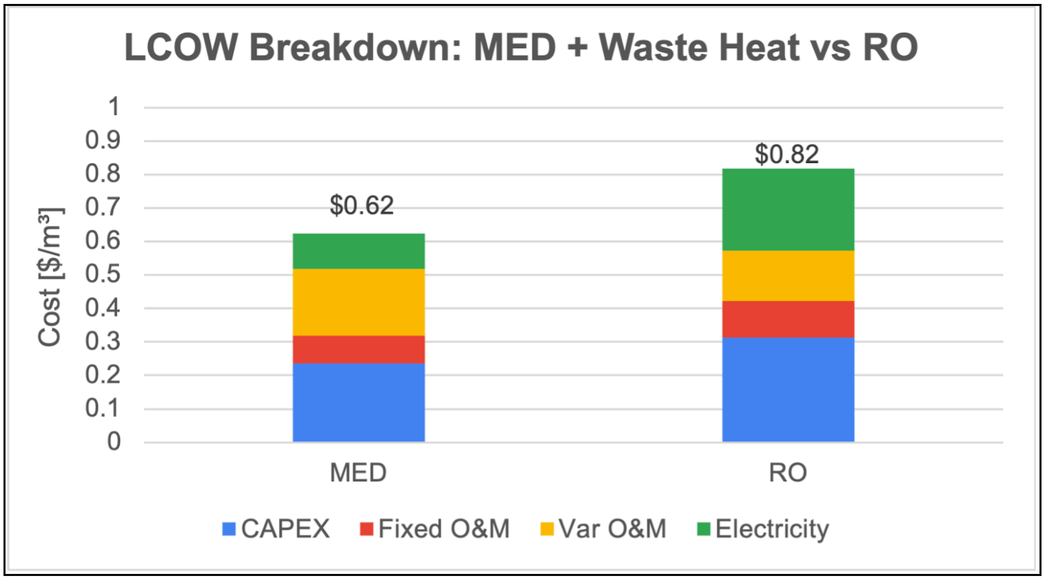


Figure 22: Levelized cost of water (LCOW) breakdown by cost category for the MED + nuclear waste-heat configuration and the reference seawater RO plant at equal capacity and capacity factor.

Cost Analysis – Parametric Sensitivity

To test sensitivity, we used the MED parameterization to vary cooling-water temperature T_0 from 20 to 2 °C, which changes distillate flow and thus plant capacity. For each point we convert $\dot{m}_D$ to annual water production and rescale MED CAPEX using a standard cost-to-capacity exponent of 0.7. In other words, if capacity changes by a factor $R = \frac{capacity}{base\ capacity}$, then the scaled CAPEX used for parameterization is:

$$CAPEX(R) = CAPEX_{base} \cdot R^{0.7}.$$

Fixed O&M, variable O&M, and electricity are then recomputed with the same assumptions as in the base case. Figure Y shows LCOW versus T_0. Across this range, LCOW stays in a narrow band of ≈0.62–0.65 USD/m³. In this parameterization, the coldest case (T_0 = 2 °C) has the highest LCOW (~0.65 $/m³) because lower T_0 slightly reduces capacity and raises specific CAPEX, while the warmest case (T_0 = 20 °C) has the lowest LCOW (~0.63 $/m³). Overall, LCOW only shifts by a few cents per cubic meter, indicating that our conclusions are not very sensitive to moderate changes in MED performance or scale. Detailed parametric values are listed in Appendix A.4.

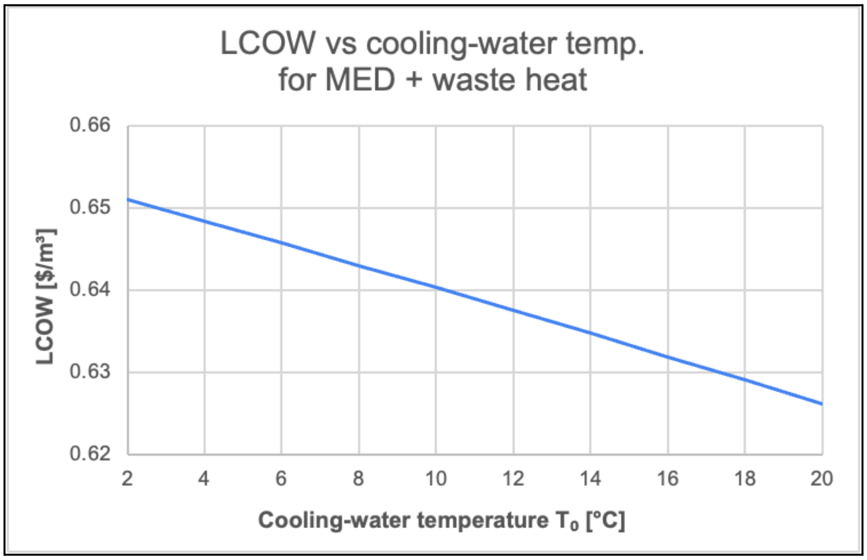


Figure 23: Parametric LCOW for the MED + nuclear waste-heat system as a function of cooling-water temperature T_0, based on MED – Parameterization and LCOW_Param_MED sheets.

The key implication is that our economic conclusion is not highly sensitive to moderate variations in MED performance or plant capacity within the modeled range. The dominant factor in the LCOW comparison remains the choice of technology and energy source—MED driven by essentially free nuclear waste heat versus RO driven entirely by electricity—rather than fine-tuning of MED operating conditions. Detailed numerical values for each parametric point are provided in Appendix A.4.

Cost Analysis – Discussion and Limitations

The LCOW comparison in this section should be interpreted as an order-of-magnitude, scenario-based analysis rather than a site-specific cost estimate. The main qualitative result—that a large MED system driven by nuclear condenser waste heat can achieve a lower LCOW than a similarly sized seawater RO plant—is robust within our modeling assumptions, but several limitations should be emphasized.

CAPEX values (800 MUSD for MED and 1200 USD/(m^3/day) for RO) are chosen within published ranges, but we lack vendor quotes and detailed integration costs, so the absolute LCOW numbers (0.62 and 0.82 USD/m^3) should be treated as indicative rather than precise. Moderate CAPEX changes for both technologies shift LCOW similarly and do not remove MED's advantage when waste heat is free.

The energy and process assumptions are also simplified. We assume MED and RO electricity uses of 1.5 and 3.5 kWh/m^3 within reported ranges, treat MED's ~120 kWh_{th}/m^3 thermal demand as free condenser waste heat, and use a fixed high-GOR (15-effect) MED design and a generic large RO plant without detailed intake/brine costs. Sensitivity runs show that varying MED electricity and thermal assumptions within plausible bounds only changes LCOW by a few cents per cubic meter, so the main conclusion remains that, under reasonable large-plant assumptions, MED coupled to nuclear waste heat can compete with or undercut seawater RO on a cost-per-m^3 basis.

Conclusion

This study shows that desalination powered by nuclear waste heat is a viable option for large scale freshwater production. Among the examined low-temperature thermal desalination methods, Multi-Effect Distillation (MED) outperforms Spray-assisted Low Temperature Distillation (SLTD) in 2nd Law Efficiency, Gained Output Ratio, and distilled water production. This design harnesses the nuclear power plant's condenser waste heat without impacting the nuclear plant's electricity production cycle, requiring minimal additional pumping power.

Economic analysis reveals that the MED system offers a competitive levelized cost of water (LCOW), approximately 25% lower than a comparable reverse osmosis plant, primarily by substituting free thermal energy from nuclear waste heat for electrical energy consumption. Sensitivity studies indicate that this economic advantage remains robust across variable ambient and operational conditions. Consequently, MED powered by nuclear waste heat presents a sustainable, cost-effective, and scalable solution to freshwater scarcity, especially suited for integration with existing nuclear infrastructure.

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Appendix

A.1 Technical and Economic Inputs for LCOW Model

Category	Parameter	Value (units)	Source / Notes
Technical (MED)	Base distillate mass flow	10,263 kg/s	From MED state-point model
	Design capacity	~0.89×10^6 m³/day	From $\dot{m}_D$ assuming $\rho \approx 1000$ kg/m³
	Capacity factor	0.9	Assumed
	Annual water production	2.91×10^8 m³/year	Capacity × CF × 365
	Distillate production per heat	0.00231 kg/kJ	From MED/SLTD calculations
	Heat per kg water	433 kJ/kg	= 1 / (0.00231 kg/kJ)
	Specific thermal energy (MED)	120 kWh_{th}/m^3	Convert 433 kJ/kg to kWh/m³
	Effective GOR (for interpretation	≈ 5	2250 kJ/kg latent heat ÷ 433 kJ/kg
	Specific electricity	1.5 kWh/m³	Assumed, low end of reported MED range
Technical (RO)	Specific electricity	3.5 kWh/m³	Assumed, typical seawater RO
Economic / Financial	Plant lifetime	25 years	Assumed
	Discount rate	7%	Real discount rate
	Total CAPEX (MED)	$800 million	Assumed install cost for MED + integration
	Specific CAPEX (MED)	≈ $900 /(m³/day)	$800 M ÷ 0.89×10^6 m³/day
	Specific CAPEX (RO)	$1200 /(m³/day)	Assumed, within researched range for large SWRO
	Fixed O&M fraction	3% of CAPEX/year	Applied to both technologies
	Variable O&M (MED, non-energy)	0.20 USD/m³	Assumed

	Variable O&M (RO, non-energy)	0.15 USD/m³	Assumed
	Electricity price	0.07 USD/kWh	Assumed industrial / wholesale rate
	Thermal energy price (MED)	0 USD/kWh$_{th}$	Condenser waste heat treated as free

A.2 Cost-Breakdown Tables

LCOW cost components for MED + nuclear waste heat (base case)

Component	Annual cost [$/year]	Cost per m³ [$/m³]
Annualized CAPEX	68,648,414	0.24
Fixed O&M	24,000,000	0.08
Variable non-energy O&M	58,259,417	0.20
Electricity	30,586,194	0.11
Thermal Energy	0	0.00
Total	181,494,024	0.62

LCOW cost components for reference seawater RO plant

Component	Annual cost [$/year]	Cost per m³ [$/m³]
Annualized CAPEX	91,310,882	0.31
Fixed O&M	31,922,968	0.11
Variable non-energy O&M	43,694,563	0.15
Electricity	71,367,786	0.25
Thermal Energy	0	0.00
Total	238,296,199	0.82

A.3 CRF derivation and formulas

To convert the one-time capital expenditure (CAPEX) into an equivalent annual cost, we use the standard capital recovery factor (CRF) from discounted-cash-flow analysis. For a real discount rate i and plant lifetime n (in years), the CRF is

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

In this project we assume a real discount rate of 7% and a plant lifetime for $25\ years$, so

$$i = 0.07,\ n = 25$$

And the resulting CRF is

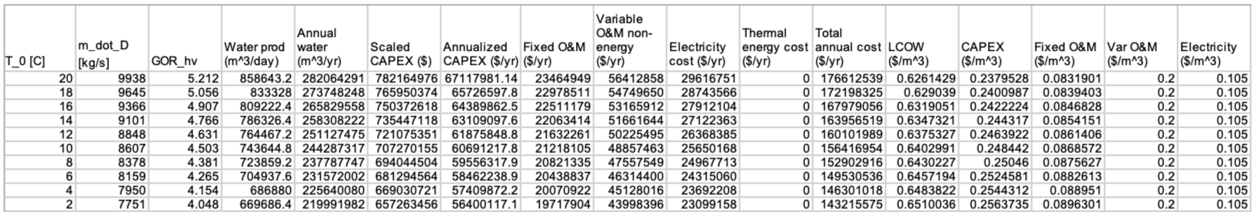
$$CRF \approx 0.0858$$

The annualized capital cost for each technology is then computed as

$$Annualized\ CAPEX = CRF \times CAPEX$$

This annualized cost term $Annualized\ CAPEX$ appears in the LCOW numerator for both the MED + waste heat system and the reference RO plant.

A.4 Parametric LCOW results for MED + nuclear waste heat



T_0 [C]	m_dot_D [kg/s]	GOR_hv	Water prod (m^3/day)	Annual water (m^3/yr)	Scaled CAPEX ($)	Annualized CAPEX ($/yr)	Fixed O&M ($/yr)	Variable O&M non-energy ($/yr)	Electricity cost ($/yr)	Thermal energy cost ($/yr)	Total annual cost ($/yr)	LCOW ($/m^3)	CAPEX ($/m^3)	Fixed O&M ($/m^3)	Var O&M ($/m^3)	Electricity ($/m^3)
20	9938	5.212	858643.2	282064291	782164976	67117981.14	23464949	56412858	29616751	0	176612539	0.6261429	0.2379528	0.0831901	0.2	0.105
18	9645	5.056	833328	273748248	765950374	65726597.8	22978511	54749650	28743566	0	172198325	0.629039	0.2400987	0.0839403	0.2	0.105
16	9366	4.907	809222.4	265829558	750372618	64389862.5	22511179	53165912	27912104	0	167979056	0.6319051	0.2422224	0.0846828	0.2	0.105
14	9101	4.766	786326.4	258308222	735447118	63109097.6	22063414	51661644	27122363	0	163956519	0.6347321	0.244317	0.0854151	0.2	0.105
12	8848	4.631	764467.2	251127475	721075351	61875848.8	21632261	50225495	26368385	0	160101989	0.6375327	0.2463922	0.0861406	0.2	0.105
10	8607	4.503	743644.8	244287317	707270155	60691217.8	21218105	48857463	25650168	0	156416954	0.6402991	0.248442	0.0868572	0.2	0.105
8	8378	4.381	723859.2	237787747	694044504	59556317.9	20821335	47557549	24967713	0	152902916	0.6430227	0.25046	0.0875627	0.2	0.105
6	8159	4.265	704937.6	231572002	681294564	58462238.9	20438837	46314400	24315060	0	149530536	0.6457194	0.2524581	0.0882613	0.2	0.105
4	7950	4.154	686880	225640080	669030721	57409872.2	20070922	45128016	23692208	0	146301018	0.6483822	0.2544312	0.088951	0.2	0.105
2	7751	4.048	669686.4	219991982	657263456	56400117.1	19717904	43998396	23099158	0	143215575	0.6510036	0.2563735	0.0896301	0.2	0.105

State Points: Nuclear reactor and interloop steam cycle

Region	Description	State Point	T [C]	P [kPa]	s [kJ/kg]	h [kJ/kg]	φ [kJ/kg]	x [-]
Nuclear Reactor	Reactor-side leaving steam gen	10	275	15000	2.995	1208	1070	
	Primary pump, Ideal	11	275.2	15750	2.995	1209	1071	
	Primary pump, Real	12	275.3	15750	2.995	1209	1071	
	Reactor-side entering steam gen	13	320	15750	3.422	1453	1306	
Interloop (electricity generation)	Interloop-side leaving condenser	20	99.97	101.3	1.307	419.1	314.8	0
	Feed pump, Ideal	21	100.1	2533	1.307	421.6	317.4	
	Feed pump, Ideal	22	100.2	2533	1.308	422	317.8	
	Interloop-side leaving steam gen	23	239.7	2533	6.345	2849	2645	
	Turbine, Ideal	24	99.97	101.3	6.345	2299	2094	0.833
	Turbine, Real	25	99.97	101.3	6.492	2354	2146	0.8574

State Points: MED

Region	Description	State Point	T [C]	P [kPa]	s [kJ/kg]	h [kJ/kg]	φ [kJ/kg]	x [-]	Salinity [g/kg]
Effect No.1	Evaporator, Hot In (NPP-side)	25	99.97	101.3	6.492	2354	2146	0.8574	
	Evaporator, Hot Out (NPP-side)	26	99.97	101.3	2.293	786.9	663	0.163	
	Economizer, Hot Out (NPP-side)	27	99.97	101.3	1.307	419.1	314.8	0	
	Seawater Intake	30	20	101.3	0.2965	84.01	0		35
	Economizer, Cold Out	31	94.97	101.3	1.25	398	294.9		35
	Evaporator, Freshwater Steam Out	32	94.97	84.53	7.415	2668	2441	1	0
	Evaporator, Brine Out	33	96.39	84.53	1.266	403.9	300.5	0	85
Effect No.1	Evaporator, Hot In	40	94.97	84.53	7.415	2668	2441	1	0
	Evaporator, Hot Out	41	94.97	84.53	2.353	803.9	678.7	0.1788	0
	Economizer, Hot Out	42	94.97	84.53	1.25	398	294.9	0	0
	Economizer, Cold In	43	20	101.3	0.2965	84.01	0		35
	Economizer, Cold Out	44	89.97	101.3	1.193	377	275		35
	Evaporator, Freshwater Steam Out	45	89.97	70.11	7.478	2660	2432	1	0
	Evaporator, Brine Out	46	91.39	70.11	1.209	382.9	280.6	0	85
Effect No.3	Evaporator, Hot In	50	89.97	70.11	7.478	2660	2432	1	0
	Evaporator, Hot Out	51	89.97	70.11	2.245	759	636	0.1674	0
	Economizer, Hot Out	52	89.97	70.11	1.193	376.9	275	0	0
	Economizer, Cold In	53	20	101.3	0.2965	84.01	0		35
	Economizer, Cold Out	54	84.97	101.3	1.134	355.9	255.2		35
	Evaporator, Freshwater Steam Out	55	84.97	57.81	7.544	2651	2422	1	0
	Evaporator, Brine Out	56	86.39	57.81	1.151	361.9	260.8	0	85
Effect No.4	Evaporator, Hot In	60	84.97	57.81	7.544	2651	2422	1	0
	Evaporator, Hot Out	61	84.97	57.81	2.133	713.4	592.7	0.1558	0
	Economizer, Hot Out	62	84.97	57.81	1.134	355.9	255.1	0	0
	Economizer, Cold In	63	20	101.3	0.2965	84.01	0		35
	Economizer, Cold Out	64	79.97	101.3	1.075	334.9	235.4		35
	Evaporator, Freshwater Steam Out	65	79.97	47.37	7.611	2643	2413	1	0
	Evaporator, Brine Out	66	81.39	47.37	1.092	340.8	240.9	0	85
Effect No.5	Evaporator, Hot In	70	79.97	47.37	7.611	2643	2413	1	0
	Evaporator, Hot Out	71	79.97	47.37	2.016	667.2	548.8	0.144	0
	Economizer, Hot Out	72	79.97	47.37	1.075	334.9	235.3	0	0
	Economizer, Cold In	73	20	101.3	0.2965	84.01	0		35
	Economizer, Cold Out	74	74.97	101.3	1.015	314	215.6		35
	Evaporator, Freshwater Steam Out	75	74.97	38.56	7.682	2635	2403	1	0
	Evaporator, Brine Out	76	76.39	38.56	1.032	319.9	221.1	0	85
Effect No.6	Evaporator, Hot In	80	74.97	38.56	7.682	2635	2403	1	0
	Evaporator, Hot Out	81	74.97	38.56	1.895	620.2	504.2	0.132	0
	Economizer, Hot Out	82	74.97	38.56	1.015	313.9	215.5	0	0
	Economizer, Cold In	83	20	101.3	0.2965	84.01	0		35
	Economizer, Cold Out	84	69.97	101.3	0.9548	293	195.8		35
	Evaporator, Freshwater Steam Out	85	69.97	31.17	7.754	2626	2393	1	0
	Evaporator, Brine Out	86	71.39	31.17	0.9721	298.9	201.4	0	85
Effect No.7	Evaporator, Hot In	90	69.97	31.17	7.754	2626	2393	1	0
	Evaporator, Hot Out	91	69.97	31.17	1.769	572.4	458.9	0.1198	0
	Economizer, Hot Out	92	69.97	31.17	0.9548	293	195.8	0	0
	Economizer, Cold In	93	20	101.3	0.2965	84.01	0		35
	Economizer, Cold Out	94	64.97	101.3	0.8933	272.1	176.1		35
	Evaporator, Freshwater Steam Out	95	64.97	25.01	7.83	2617	2383	1	0
	Evaporator, Brine Out	96	66.39	25.01	0.9108	277.9	181.6	0	85
Effect No.8	Evaporator, Hot In	100	64.97	25.01	7.83	2617	2383	1	0
	Evaporator, Hot Out	101	64.97	25.01	1.638	523.9	413	0.1074	0
	Economizer, Hot Out	102	64.97	25.01	0.8933	272	176.1	0	0
	Economizer, Cold In	103	20	101.3	0.2965	84.01	0		35
	Economizer, Cold Out	104	59.97	101.3	0.8309	251.1	156.4		35
	Evaporator, Freshwater Steam Out	105	59.97	19.92	7.909	2609	2373	1	0
	Evaporator, Brine Out	106	61.39	19.92	0.8487	257	161.9	0	85
Effect No.9	Evaporator, Hot In	110	59.97	19.92	7.909	2609	2373	1	0
	Evaporator, Hot Out	111	59.97	19.92	1.502	474.5	366.4	0.09478	0
	Economizer, Hot Out	112	59.97	19.92	0.831	251.1	156.4	0	0
	Economizer, Cold In	113	20	101.3	0.2965	84.01	0		35
	Economizer, Cold Out	114	54.97	101.3	0.7677	230.2	136.8		35
	Evaporator, Freshwater Steam Out	115	54.97	15.74	7.99	2600	2362	1	0
	Evaporator, Brine Out	116	56.39	15.74	0.7857	236.1	142.3	0	85
Effect No.10	Evaporator, Hot In	120	54.97	15.74	7.99	2600	2362	1	0
	Evaporator, Hot Out	121	54.97	15.74	1.36	424.4	319.1	0.08196	0
	Economizer, Hot Out	122	54.97	15.74	0.7677	230.2	136.7	0	0
	Economizer, Cold In	123	20	101.3	0.2965	84.01	0		35
	Economizer, Cold Out	124	49.97	101.3	0.7034	209.3	117.2		35
	Evaporator, Freshwater Steam Out	125	49.97	12.34	8.075	2591	2352	1	0
	Evaporator, Brine Out	126	51.39	12.34	0.7218	215.2	122.6	0	85
	Evaporator, Hot In	130	49.97	12.34	8.075	2591	2352	1	0
	Evaporator, Hot Out	131	49.97	12.34	1.211	373.4	271.1	0.06891	0

Effect No.11	Economizer, Hot Out	132	49.97	12.34	0.7035	209.2	117.1	0	0
	Economizer, Cold In	133	20	101.3	0.2965	84.01	0		35
	Economizer, Cold Out	134	44.97	101.3	0.6382	188.4	97.56		35
	Evaporator, Freshwater Steam Out	135	44.97	9.583	8.164	2582	2341	1	0
	Evaporator, Brine Out	136	46.39	9.583	0.6568	194.2	103	0	85
Effect No.12	Evaporator, Hot In	140	44.97	9.583	8.164	2582	2341	1	0
	Evaporator, Hot Out	141	44.97	9.583	1.057	321.5	222.3	0.05562	0
	Economizer, Hot Out	142	44.97	9.583	0.6383	188.3	97.49	0	0
	Economizer, Cold In	143	20	101.3	0.2965	84.01	0		35
	Economizer, Cold Out	144	39.97	101.3	0.572	167.5	77.99		35
	Evaporator, Freshwater Steam Out	145	39.97	7.375	8.256	2573	2330	1	0
	Evaporator, Brine Out	146	41.39	7.375	0.5909	173.3	83.45	0	85
Effect No.13	Evaporator, Hot In	150	39.97	7.375	8.256	2573	2330	1	0
	Evaporator, Hot Out	151	39.97	7.375	0.8955	268.7	172.7	0.04209	0
	Economizer, Hot Out	152	39.97	7.375	0.5721	167.4	77.91	0	0
	Economizer, Cold In	153	20	101.3	0.2965	84.01	0		35
	Economizer, Cold Out	154	34.97	101.3	0.5047	146.6	58.44		35
	Evaporator, Freshwater Steam Out	155	34.97	5.621	8.352	2565	2319	1	0
	Evaporator, Brine Out	156	36.39	5.621	0.5239	152.4	63.88	0	85
Effect No.14	Evaporator, Hot In	160	34.97	5.621	8.352	2565	2319	1	0
	Evaporator, Hot Out	161	34.97	5.621	0.7269	215	122.4	0.02831	0
	Economizer, Hot Out	162	34.97	5.621	0.5048	146.5	58.35	0	0
	Economizer, Cold In	163	20	101.3	0.2965	84.01	0		35
	Economizer, Cold Out	164	29.97	101.3	0.4364	125.7	38.91		35
	Evaporator, Freshwater Steam Out	165	29.97	4.241	8.453	2555	2308	1	0
	Evaporator, Brine Out	166	31.39	4.241	0.4559	131.5	44.35	0	85
Effect No.15	Evaporator, Hot In	170	29.97	4.241	8.453	2555	2308	1	0
	Evaporator, Hot Out	171	29.97	4.241	0.5507	160.3	71.17	0.01426	0
	Economizer, Hot Out	172	29.97	4.241	0.4364	125.6	38.82	0	0
	Economizer, Cold In	173	20	101.3	0.2965	84.01	0		35
	Economizer, Cold Out	174	24.97	101.3	0.3668	104.8	19.4		35
	Evaporator, Freshwater Steam Out	175	24.97	3.165	8.557	2546	2297	1	0
	Evaporator, Brine Out	176	26.39	3.165	0.3867	110.6	24.83	0	85
Condenser	Condenser, Hot In	180	24.97	3.165	8.557	2546	2297	1	0
	Condenser, Hot Out	181	24.97	3.165	0.3669	104.7	19.31	0	0
	Condenser, Cold In	182	20	101.3	0.2965	84.01	0		35
	Condenser, Cold Out	183	21.97	101.3	0.3245	92.27	7.698		35

State Points: SLTD

Region	Description	State Point	T [C]	P [kPa]	s [kJ/kg]	h [kJ/kg]	φ [kJ/kg]	x [-]	Salinity [g/kg]
Evaporator No. 1	Spray Evaporator, Brine In	40	94.97	101.3	1.25	398	0	-	35
	Spray Evaporator, Pump Ideal	41	94.97	106.4	1.25	398	0.005266	-	35
	Spray Evaporator, Pump Real	42	94.97	106.4	1.25	617	0.006145	-	35
	Liquid Brine Out	43	92.97	78.49	1.849	617	207.1	0.1	38.89
	Freshwater Steam Out	44	92.97	78.49	7.44	2664	1935	1	0
	Condensed Freshwater	45	92.97	78.49	1.227	389.6	-2151	0	0
Evaporator No. 2	Spray Evaporator, Brine In	50	92.97	78.49	1.227	389.6	0	0	38.89
	Spray Evaporator, Pump Ideal	51	92.98	82.42	1.227	389.6	0.004066	-	38.89
	Spray Evaporator, Pump Real	52	92.98	82.42	1.227	389.6	0.004745	-	38.89
	Liquid Brine Out	53	90.98	72.82	1.83	609.1	207.5	0.1	43.21
	Freshwater Steam Out	54	90.98	72.82	7.466	2661	1939	1	0
	Condensed Freshwater	55	90.98	72.82	1.204	381.1	-2155	0	0
Evaporator No. 3	Spray Evaporator, Brine In	60	90.98	72.82	1.204	381.1	0	0	43.21
	Spray Evaporator, Pump Ideal	61	90.98	76.47	1.204	381.2	0.003766	-	43.21
	Spray Evaporator, Pump Real	62	90.98	76.47	1.204	381.2	0.004395	-	43.21
	Liquid Brine Out	63	88.98	67.5	1.812	601.3	207.9	0.1	48.01
	Freshwater Steam Out	64	88.98	67.5	7.491	2658	1943	1	0
	Condensed Freshwater	65	88.98	67.5	1.181	372.7	-2159	0	0
Evaporator No. 4	Spray Evaporator, Brine In	70	88.98	67.5	1.181	372.7	0	0	48.01
	Spray Evaporator, Pump Ideal	71	88.98	70.87	1.181	372.7	0.003486	-	48.01
	Spray Evaporator, Pump Real	72	88.98	70.87	1.181	372.7	0.004067	-	48.01
	Liquid Brine Out	73	86.98	62.5	1.794	593.4	208.4	0.1	53.35
	Freshwater Steam Out	74	86.98	62.5	7.517	2655	1947	1	0
	Condensed Freshwater	75	86.98	62.5	1.158	364.3	-2163	0	0
Evaporator No. 5	Spray Evaporator, Brine In	80	86.98	62.5	1.158	364.3	0	0	53.35
	Spray Evaporator, Pump Ideal	81	86.98	65.63	1.158	364.3	0.003222	-	53.35
	Spray Evaporator, Pump Real	82	86.98	65.63	1.158	364.3	0.00376	-	53.35
	Liquid Brine Out	83	84.98	57.82	1.775	585.5	208.8	0.1	59.27
	Freshwater Steam Out	84	84.98	57.82	7.544	2651	1950	1	0
	Condensed Freshwater	85	84.98	57.82	1.134	355.9	-2167	0	0
Evaporator No. 6	Spray Evaporator, Brine In	90	84.98	57.82	1.134	355.9	0	0	59.27
	Spray Evaporator, Pump Ideal	91	84.98	60.71	1.134	355.9	0.002976	-	59.27
	Spray Evaporator, Pump Real	92	84.98	60.71	1.134	355.9	0.003473	-	59.27
	Liquid Brine Out	93	82.98	53.43	1.757	577.6	209.2	0.1	65.86
	Freshwater Steam Out	94	82.98	53.43	7.57	2648	1954	1	0
	Condensed Freshwater	95	82.98	53.43	1.111	347.5	-2171	0	0
Evaporator No. 7	Spray Evaporator, Brine In	100	82.98	53.43	1.111	347.5	0	0	65.86
	Spray Evaporator, Pump Ideal	101	82.98	56.11	1.111	347.5	0.002746		65.86
	Spray Evaporator, Pump Real	102	82.98	56.11	1.111	347.5	0.003204		65.86
	Liquid Brine Out	103	80.98	49.33	1.738	569.7	209.6	0.1	73.18
	Freshwater Steam Out	104	80.98	49.33	7.598	2645	1958	1	0
	Condensed Freshwater	105	80.98	49.33	1.087	339.1	-2175	0	0

Evaporator No. 8	Spray Evaporator, Brine In	110	80.98	49.33	1.087	339.1		0	73.18
	Spray Evaporator, Pump Ideal	111	80.98	51.8	1.087	339.1	0.002531	-	73.18
	Spray Evaporator, Pump Real	112	80.98	51.8	1.087	339.1	0.002953	-	73.18
	Liquid Brine Out	113	78.98	45.49	1.72	561.8	210	0.1	81.31
	Freshwater Steam Out	114	78.98	45.49	7.625	2641	1961	1	0
	Condensed Freshwater	115	78.98	45.49	1.063	330.7	-2179	0	0
Condenser Series	Condenser No. 1	120	25.76	101.3	0.3779	108.1	-	0	0
	Condenser No. 2	121	32.16	101.3	0.4664	134.8	-	0	0
	Condenser No. 3	122	39.25	101.3	0.5623	164.5	-	0	0
	Condenser No. 4	123	47.11	101.3	0.6662	197.3	-	0	0
	Condenser No. 5	124	55.82	101.3	0.7784	233.8	-	0	0
	Condenser No. 6	125	65.47	101.3	0.8994	274.1	-	0	0
	Condenser No. 7	126	76.15	101.3	1.03	318.9	-	0	0
	Condenser No. 8	127	87.97	101.3	0.3779	368.5	-	0	0
Brine Outflow	Outlet	130	78.98	45.49	1.72	561.8	-	0	81.31

```
"=============================================================================="
"                              ME4315 - Project 2 - MED                        "
"=============================================================================="


FUNCTION BPE_Seawater(z)
"Boiling Point Elevation for Seawater as a function of salinity"
"Input: z = salinity [g/kg of water]"
"Output: BPE = boiling point elevation [°C]"

   i = 1.9 [-]                 "van 't Hoff factor for seawater"
   K_b = 0.512 [C*kg/mol]   "ebullioscopic constant for water"
   M = 58.44 [g/mol]          "molar mass of NaCl"

   BPE_Seawater = (i * K_b / M) * z   "boiling point elevation [C]"
END


"Ambient Conditions"
T_0 = 20 [C]
P_0 = Po#
h_0 = Enthalpy(Water, T=T_0, P=P_0)
s_0 = Entropy(Water, T=T_0, P=P_0)
z_0 = 35 [g/kg]

"Conservation of mass"
m_dot_f1 = m_dot_D1 + m_dot_B1   "Effect No.1"
m_dot_f2 = m_dot_D2 + m_dot_B2   "Effect No.2"
m_dot_f3 = m_dot_D3 + m_dot_B3   "Effect No.3"
m_dot_f4 = m_dot_D4 + m_dot_B4   "Effect No.4"
m_dot_f5 = m_dot_D5 + m_dot_B5   "Effect No.5"
m_dot_f6 = m_dot_D6 + m_dot_B6   "Effect No.6"
m_dot_f7 = m_dot_D7 + m_dot_B7   "Effect No.7"
m_dot_f8 = m_dot_D8 + m_dot_B8   "Effect No.8"
m_dot_f9 = m_dot_D9 + m_dot_B9   "Effect No.9"
m_dot_f10 = m_dot_D10 + m_dot_B10   "Effect No.10"
m_dot_f11 = m_dot_D11 + m_dot_B11   "Effect No.11"
m_dot_f12 = m_dot_D12 + m_dot_B12   "Effect No.12"
m_dot_f13 = m_dot_D13 + m_dot_B13   "Effect No.13"
m_dot_f14 = m_dot_D14 + m_dot_B14   "Effect No.14"
m_dot_f15 = m_dot_D15 + m_dot_B15   "Effect No.15"

"Total Mass Flow"
m_dot_f = m_dot_D + m_dot_B  "Total seawater flowrate"
m_dot_D = m_dot_D1 + m_dot_D2 + m_dot_D3 + m_dot_D4 + m_dot_D5 + m_dot_D6 + m_dot_D7 + m_dot_D8 +
m_dot_D9 + m_dot_D10 + m_dot_D11 + m_dot_D12 + m_dot_D13 + m_dot_D14 + m_dot_D15 "Total distallate flowrate"
m_dot_B = m_dot_B1 + m_dot_B2 + m_dot_B3 + m_dot_B4 + m_dot_B5 + m_dot_B6 + m_dot_B7 + m_dot_B8 + m_dot_B9
+ m_dot_B10 + m_dot_B11 + m_dot_B12 + m_dot_B13 + m_dot_B14 + m_dot_B15 "Total brine flowrate"

"Allowable Brine Salinity"
z_B = 85 [g/kg]

"Heat Exchanger Temperature Parameters"
DELTAT_HX = 5 [C]  "Heat transfer temperature difference"

"Isentropic Effiencies"
eta_rpp = 0.85        "Reactor Primary Pump"
eta_fp = 0.85         "Feed Water Pump"
eta_t = 0.90          "Steam Turbine"

"Pressure Ratios"
PR_rpp =  1.05
```

```
PR_fp = 25


"================================================================================"
"                                                              Outputs                                                                                     "
"================================================================================"

"NPP Turbine Power"
Power_out = 1138 * (10^3) [kW]

"Reactor Metrics"
q_reactor = h[13] - h[12]
w_reactor = h[12] - h[10]

"Secondary/Steam Metrics"
w_t = h[23] - h[25]
w_c = h[22] - h[20]
q_in = h[23] - h[22]
q_out = h[25] - h[20]

"Mass Flow Rates"
m_dot_npp = Power_out / w_t                    "Nuclear powerplant flowrate"
m_dot_rcw = m_dot_npp * q_in / q_reactor   "Reactor cooling water flowrate"


"================================================================================"
"                                                            Cycle Efficiencies                                                                        "
"================================================================================"

"Gained Output Ratio, Steam Mass Flow Rate"
GOR_steam = m_dot_D / m_dot_npp

"Gained Output Raito, Latent Heat of Vaporization"
Q_dot_npp = m_dot_npp * q_out
GOR_hv = DELTAh_vap / Q_dot_npp

"2nd Law Effiiency"
"eta_II = (m_dot_D * w_min) / E_in"
E_in = m_dot_npp*(e[25] - e[27]) + W_dot_p
eta_II = (E_in - psi_D) / E_in
"w_min = 2.99 [kJ/kg]"
"E_in = Q_dot_npp*(1 - ConvertTemp(C,K,T_0) / ConvertTemp(C,K,T[25]) ) + W_dot_p"


"================================================================================"
"                                                            Exergy Destruction                                                                      "
"================================================================================"

"Total Exergy Destruction"
psi_D = psi_D_E + psi_D_B + psi_D_C

"Exergy Destruction in Heat Transfer of each Effect"
psi_D_E1 = m_dot_npp*(e[25] - e[27]) - m_dot_D1*(e[32] - e[30]) - m_dot_B1*(e[33] - e[30])
psi_D_E2 = m_dot_D1*(e[40] - e[42]) - m_dot_D2*(e[45] - e[43]) - m_dot_B2*(e[46] - e[43])
psi_D_E3 = m_dot_D2*(e[50] - e[52]) - m_dot_D3*(e[55] - e[53]) - m_dot_B3*(e[56] - e[53])
psi_D_E4 = m_dot_D3*(e[60] - e[62]) - m_dot_D4*(e[65] - e[63]) - m_dot_B4*(e[66] - e[63])
psi_D_E5  = m_dot_D4*(e[70] - e[72]) - m_dot_D5*(e[75] - e[73]) - m_dot_B5*(e[76] - e[73])
psi_D_E6  = m_dot_D5*(e[80] - e[82]) - m_dot_D6*(e[85] - e[83]) - m_dot_B6*(e[86] - e[83])
psi_D_E7  = m_dot_D6*(e[90] - e[92]) - m_dot_D7*(e[95] - e[93]) - m_dot_B7*(e[96] - e[93])
psi_D_E8  = m_dot_D7*(e[100] - e[102]) - m_dot_D8*(e[105] - e[103]) - m_dot_B8*(e[106] - e[103])
psi_D_E9  = m_dot_D8*(e[110] - e[112]) - m_dot_D9*(e[115] - e[113]) - m_dot_B9*(e[116] - e[113])
psi_D_E10 = m_dot_D9*(e[120] - e[122]) - m_dot_D10*(e[125] - e[123]) - m_dot_B10*(e[126] - e[123])
psi_D_E11 = m_dot_D10*(e[130] - e[132]) - m_dot_D11*(e[135] - e[133]) - m_dot_B11*(e[136] - e[133])
```

```
psi_D_E12 = m_dot_D11*(e[140] - e[142]) - m_dot_D12*(e[145] - e[143]) - m_dot_B12*(e[146] - e[143])
psi_D_E13 = m_dot_D12*(e[150] - e[152]) - m_dot_D13*(e[155] - e[153]) - m_dot_B13*(e[156] - e[153])
psi_D_E14 = m_dot_D13*(e[160] - e[162]) - m_dot_D14*(e[165] - e[163]) - m_dot_B14*(e[166] - e[163])
psi_D_E15 = m_dot_D14*(e[170] - e[172]) - m_dot_D15*(e[175] - e[173]) - m_dot_B15*(e[176] - e[173])
psi_D_E = psi_D_E1 + psi_D_E2 + psi_D_E3 + psi_D_E4 + psi_D_E5 + psi_D_E6 + psi_D_E7 + psi_D_E8 + psi_D_E9 +
psi_D_E10 + psi_D_E11 + psi_D_E12 + psi_D_E13 + psi_D_E14 + psi_D_E15

"Exergy Destruction in released Brine"
psi_D_B1 = m_dot_B1*(e[33] - e[30])
psi_D_B2 = m_dot_B2*(e[46] - e[43])
psi_D_B3 = m_dot_B3*(e[56] - e[53])
psi_D_B4 = m_dot_B4*(e[66] - e[63])
psi_D_B5 = m_dot_B5*(e[76] - e[73])
psi_D_B6 = m_dot_B6*(e[86] - e[83])
psi_D_B7 = m_dot_B7*(e[96] - e[93])
psi_D_B8 = m_dot_B8*(e[106] - e[103])
psi_D_B9 = m_dot_B9*(e[116] - e[113])
psi_D_B10 = m_dot_B10*(e[126] - e[123])
psi_D_B11 = m_dot_B11*(e[136] - e[133])
psi_D_B12 = m_dot_B12*(e[146] - e[143])
psi_D_B13 = m_dot_B13*(e[156] - e[153])
psi_D_B14 = m_dot_B14*(e[166] - e[163])
psi_D_B15 = m_dot_B15*(e[176] - e[173])
psi_D_B = psi_D_B1 + psi_D_B2 + psi_D_B3 + psi_D_B4 + psi_D_B5 + psi_D_B6 + psi_D_B7 + psi_D_B8 + psi_D_B9 +
psi_D_B10 + psi_D_B11 + psi_D_B12 + psi_D_B13 + psi_D_B14 + psi_D_B15

"Exergy Destruction in Condenser"
psi_D_C = m_dot_D15*(e[180] - e[181])


"==========================================================================="
"                                Vaporization Heat                          "
"==========================================================================="

"Latent Heat of Vaporization"
DELTAh_vap_1 = m_dot_D1 * Enthalpy_Vaporization(Water,T=T[32])
DELTAh_vap_2 = m_dot_D2 * Enthalpy_Vaporization(Water,T=T[45])
DELTAh_vap_3 = m_dot_D3 * Enthalpy_Vaporization(Water,T=T[55])
DELTAh_vap_4 = m_dot_D4 * Enthalpy_Vaporization(Water,T=T[65])
DELTAh_vap_5 = m_dot_D5 * Enthalpy_Vaporization(Water,T=T[75])
DELTAh_vap_6 = m_dot_D6 * Enthalpy_Vaporization(Water,T=T[85])
DELTAh_vap_7 = m_dot_D7 * Enthalpy_Vaporization(Water,T=T[95])
DELTAh_vap_8 = m_dot_D8 * Enthalpy_Vaporization(Water,T=T[105])
DELTAh_vap_9 = m_dot_D9 * Enthalpy_Vaporization(Water,T=T[115])
DELTAh_vap_10 = m_dot_D10 * Enthalpy_Vaporization(Water,T=T[125])
DELTAh_vap_11 = m_dot_D11 * Enthalpy_Vaporization(Water,T=T[135])
DELTAh_vap_12 = m_dot_D12 * Enthalpy_Vaporization(Water,T=T[145])
DELTAh_vap_13 = m_dot_D13 * Enthalpy_Vaporization(Water,T=T[155])
DELTAh_vap_14 = m_dot_D14 * Enthalpy_Vaporization(Water,T=T[165])
DELTAh_vap_15 = m_dot_D15 * Enthalpy_Vaporization(Water,T=T[175])
DELTAh_vap = DELTAh_vap_1 + DELTAh_vap_2 + DELTAh_vap_3 + DELTAh_vap_4 + DELTAh_vap_5 + DELTAh_vap_6 +
 DELTAh_vap_7 + DELTAh_vap_8 + DELTAh_vap_9 + DELTAh_vap_10 + DELTAh_vap_11 + DELTAh_vap_12 +
DELTAh_vap_13 + DELTAh_vap_14 + DELTAh_vap_15


"==========================================================================="
"                           Desalination Pump Input Work                    "
"==========================================================================="

"Specific Volume of Water"
rho_w = Density(Water, T=T_0, P=P_0)
v_w = 1 / rho_w
```

```
"Pump Work in each Effect"
W_dot_1 = m_dot_D1 * v_w * (P_0 - P[32])
W_dot_2 = m_dot_D2 * v_w * (P_0 - P[45])
W_dot_3 = m_dot_D3 * v_w * (P_0 - P[55])
W_dot_4 = m_dot_D4 * v_w * (P_0 - P[65])
W_dot_5 = m_dot_D5 * v_w * (P_0 - P[75])
W_dot_6 = m_dot_D6 * v_w * (P_0 - P[85])
W_dot_7 = m_dot_D7 * v_w * (P_0 - P[95])
W_dot_8 = m_dot_D8 * v_w * (P_0 - P[105])
W_dot_9 = m_dot_D9 * v_w * (P_0 - P[115])
W_dot_10 = m_dot_D10 * v_w * (P_0 - P[125])
W_dot_11 = m_dot_D11 * v_w * (P_0 - P[135])
W_dot_12 = m_dot_D12 * v_w * (P_0 - P[145])
W_dot_13 = m_dot_D13 * v_w * (P_0 - P[155])
W_dot_14 = m_dot_D14 * v_w * (P_0 - P[165])
W_dot_15 = m_dot_D15 * v_w * (P_0 - P[175])

"Total Effect Pump Work"
W_dot_p = W_dot_1 + W_dot_2 + W_dot_3 + W_dot_4 + W_dot_5 + W_dot_6 + W_dot_7 + W_dot_8 + W_dot_9 +
W_dot_10 + W_dot_11 + W_dot_12 + W_dot_13 + W_dot_14 + W_dot_15


"===================================================================================="
"                                       Reactor                                      "
"===================================================================================="

"State 10 - Reactor Side, After Steam Generator"
T[10] = 275 [C]
P[10] = 15000 [kPa]
s[10] = Entropy(Water, T=T[10], P=P[10])
h[10] = Enthalpy(Water, T=T[10], P=P[10])
e[10] = (h[10] - h_0) - T_0*(s[10] - s_0)

"State 11 - Reactor Primary Pump, Ideal"
T[11] = Temperature(Water, s=s[11], P=P[11])
P[11] = P[10] * PR_rpp
s[11] = s[10]
h[11] = Enthalpy(Water, T=T[11], P=P[11])
e[11] = (h[11] - h_0) - T_0*(s[11] - s_0)

"State 12 - Reactor Primary Pump, Real"
T[12] = Temperature(Water, h=h[12], P=P[12])
P[12] = P[11]
s[12] = Entropy(Water, T=T[12], P=P[12])
h[12] = h[10] + (h[11] - h[10])/eta_rpp
e[12] = (h[12] - h_0) - T_0*(s[12] - s_0)

"State 13 - After Reactor"
T[13] = 320 [C]
P[13] = P[12]
s[13] = Entropy(Water, T=T[13], P=P[13])
h[13] = Enthalpy(Water, T=T[13], P=P[13])
e[13] = (h[13] - h_0) - T_0*(s[13] - s_0)


"===================================================================================="
"                                Secondary/Steam Cycle                               "
"===================================================================================="

"State 20 - Interloop-side, After NPP Condenser"
T[20] = Temperature(Water, P=P[20], x=x[20])
```

```
P[20] = P_0
s[20] = Entropy(Water, x=x[20], P=P[20])
h[20] = Enthalpy(Water, x=x[20], P=P[20])
e[20] = (h[20] - h_0) - T_0*(s[20] - s_0)
x[20] = 0

"State 21 - Feed Pump, Ideal"
T[21] = Temperature(Water, s=s[21], P=P[21])
P[21] = P[20] * PR_fp
s[21] = s[20]
h[21] = Enthalpy(Water, T=T[21], P=P[21])
e[21] = (h[21] - h_0) - T_0*(s[21] - s_0)

"State 22 - Feed Pump, Real"
T[22] = Temperature(Water, h=h[22], P=P[22])
P[22] = P[21]
s[22] = Entropy(Water, T=T[22], P=P[22])
h[22] = h[20] + (h[21] - h[20])/eta_fp
e[22] = (h[22] - h_0) - T_0*(s[22] - s_0)

"State 23 - Interloop-side, After Steam Generator"
T[23] = Temperature(Water, x=1, P=P[23]) + 15 [C]
P[23] = P[22]
s[23] = Entropy(Water, T=T[23], P=P[23])
h[23] = Enthalpy(Water, T=T[23], P=P[23])
e[23] = (h[23] - h_0) - T_0*(s[23] - s_0)

"State 24 - Turbine, Ideal"
T[24] = Temperature(Water, s=s[24], P=P[24])
P[24] = P[23] / PR_fp
s[24] = s[23]
h[24] = Enthalpy(Water, T=T[24], s=s[24])
e[24] = (h[24] - h_0) - T_0*(s[24] - s_0)
x[24] = Quality(Water, s=s[24], P=P[24])

"State 25 - Turbine, Real"
T[25] = Temperature(Water, h=h[25], P=P[25])
P[25] = P[24]
s[25] = Entropy(Water, T=T[25], h=h[25])
h[25] = h[23] - eta_t*(h[23] - h[24])
e[25] = (h[25] - h_0) - T_0*(s[25] - s_0)
x[25] = Quality(Water,  h=h[25], P=P[25])


"================================================================================="
"                                              Effect No. 1                                              "
"================================================================================="

"State 26 - Effect No.1, Evaporator, Hot Out"
T[26] = Temperature(Water, P=P[26], h=h[26])
P[26] = P[25]
s[26] = Entropy(Water, P=P[26], h=h[26])
h[26] = h[25] - (m_dot_D1 / m_dot_npp)*(h[32] - h[31]) - (m_dot_B1 / m_dot_npp)*(h[33] - h[31])
e[26] = (h[26] - h_0) - T_0*(s[26] - s_0)
x[26] = Quality(Water, h=h[26], P=P[26])

"State 27 - Effect No.1, Economizer, Hot Out"
T[27] = Temperature(Water, P=P[27], x=x[27])
P[27] = P[26]
s[27] = Entropy(Water, P=P[27], h=h[27])
h[27] = h[26] - (m_dot_f1 / m_dot_npp)*(h[31] - h[30])
```

```
h[27] = Enthalpy(Water, P=P[27], x=x[27])
e[27] = (h[27] - h_0) - T_0*(s[27] - s_0)
x[27] = 0

"State 30 - Seawater Inlet"
T[30] = T_0
P[30] = P_0
s[30] = s_0
h[30] = h_0
z[30] = z_0
e[30] = (h[30] - h_0) - T_0*(s[30] - s_0)

"State 31 - Effect No.1, Economizer, Cold Out"
T[31] = T[27] - DELTAT_HX
P[31] = P[30]
s[31] = Entropy(Water, P=P[31], T=T[31])
h[31] = Enthalpy(Water, P=P[31], T=T[31])
z[31] = z_0
e[31] = (h[31] - h_0) - T_0*(s[31] - s_0)

"State 32 - Effect No.1, Evaporator, Distillate Out"
T[32] = T[31]
P[32] = Pressure(Water, T=T[32], x=x[32])
s[32] = Entropy(Water, T=T[32], x=x[32])
h[32] = Enthalpy(Water, T=T[32], x=x[32])
z[32] = 0
x[32] = 1
e[32] = (h[32] - h_0) - T_0*(s[32] - s_0)

"State 33 - Effect No.2, Evaporator, Brine Out"
T[33] = T[32] + BPE_Seawater(z[33])
P[33] = P[32]
s[33] = Entropy(Water, T=T[33], x=x[33])
h[33] = Enthalpy(Water, T=T[33], x=x[33])
z[33] = z[31] * (m_dot_f1 / m_dot_B1)
z[33] = z_B
x[33] = 0
e[33] = (h[33] - h_0) - T_0*(s[33] - s_0)


"==================================================================================="
"                                   Effect No. 2                                    "
"==================================================================================="

"State 40 - Effect No.2, Hot In"
T[40] = T[32]
P[40] = P[32]
s[40] = s[32]
h[40] = h[32]
z[40] = z[32]
x[40] = x[32]
e[40] = e[32]

"State 41 - Effect No.2, Evaporator, Hot Out"
T[41] = Temperature(Water, P=P[41], h=h[41])
P[41] = P[40]
s[41] = Entropy(Water, P=P[41], h=h[41])
h[41] = h[40] - (m_dot_D2 / m_dot_D1)*(h[45] - h[44]) - (m_dot_B2 / m_dot_D1)*(h[46] - h[44])
z[41] = z[40]
x[41] = Quality(Water, P=P[41], h=h[41])
e[41] = (h[41] - h_0) - T_0*(s[41] - s_0)
```

```
"State 42 - Effect No.2, Economizer, Hot Out"
T[42] = Temperature(Water, P=P[42], x=x[42])
P[42] = P[41]
s[42] = Entropy(Water, P=P[42], x=x[42])
h[42] = Enthalpy(Water, P=P[42], x=x[42])
h[42] = h[41] - (m_dot_f2 / m_dot_D1)*(h[44] - h[43])
z[42] = z[41]
x[42] = 0
e[42] = (h[42] - h_0) - T_0*(s[42] - s_0)

"State 43 - Effect No.2, Cold In"
T[43] = T[30]
P[43] = P[30]
s[43] = s[30]
h[43] = h[30]
z[43] = z[30]
e[43] = e[30]

"State 44 - Effect No.2, Economizer, Cold Out"
T[44] = T[42] - DELTAT_HX
P[44] = P[43]
s[44] = Entropy(Water, T=T[44], P=P[44])
h[44] = Enthalpy(Water, T=T[44], P=P[44])
z[44] = z[43]
e[44] = (h[44] - h_0) - T_0*(s[44] - s_0)

"State 45 - Effect No.2, Evaporator, Distillate Out"
T[45] = T[44]
P[45] = Pressure(Water, T=T[45], x=x[45])
s[45] = Entropy(Water, T=T[45], x=x[45])
h[45] = Enthalpy(Water, T=T[45], x=x[45])
z[45] = 0
x[45] = 1
e[45] = (h[45] - h_0) - T_0*(s[45] - s_0)

"State 46 - Effect No.2, Evaporator, Brine Out"
T[46] = T[45] + BPE_Seawater(z[46])
P[46] = P[45]
s[46] = Entropy(Water, T=T[46], x=x[46])
h[46] = Enthalpy(Water, T=T[46], x=x[46])
z[46] = z[44] * (m_dot_f2 / m_dot_B2)
z[46] = z_B
x[46] = 0
e[46] = (h[46] - h_0) - T_0*(s[46] - s_0)


"================================================================================"
"                                   Effect No. 3                                 "
"================================================================================"

"State 50 - Effect No.3, Hot In"
T[50] = T[45]
P[50] = P[45]
s[50] = s[45]
h[50] = h[45]
z[50] = z[45]
x[50] = x[45]
e[50] = e[45]

"State 51 - Effect No.3, Evaporator, Hot Out"
```

```
T[51] = Temperature(Water, P=P[51], h=h[51])
P[51] = P[50]
s[51] = Entropy(Water, P=P[51], h=h[51])
h[51] = h[50] - (m_dot_D3 / m_dot_D2)*(h[55] - h[54]) - (m_dot_B3 / m_dot_D2)*(h[56] - h[54])
z[51] = z[50]
x[51] = Quality(Water, P=P[51], h=h[51])
e[51] = (h[51] - h_0) - T_0*(s[51] - s_0)

"State 52 - Effect No.3, Economizer, Hot Out"
T[52] = Temperature(Water, P=P[52], x=x[52])
P[52] = P[51]
s[52] = Entropy(Water, P=P[52], x=x[52])
h[52] = Enthalpy(Water, P=P[52], x=x[52])
h[52] = h[51] - (m_dot_f3 / m_dot_D2)*(h[54] - h[53])
z[52] = z[51]
x[52] = 0
e[52] = (h[52] - h_0) - T_0*(s[52] - s_0)

"State 53 - Effect No.3, Cold In"
T[53] = T[30]
P[53] = P[30]
s[53] = s[30]
h[53] = h[30]
z[53] = z[30]
e[53] = e[30]

"State 54 - Effect No.3, Economizer, Cold Out"
T[54] = T[52] - DELTAT_HX
P[54] = P[53]
s[54] = Entropy(Water, T=T[54], P=P[54])
h[54] = Enthalpy(Water, T=T[54], P=P[54])
z[54] = z[53]
e[54] = (h[54] - h_0) - T_0*(s[54] - s_0)

"State 55 - Effect No.3, Evaporator, Distillate Out"
T[55] = T[54]
P[55] = Pressure(Water, T=T[55], x=x[55])
s[55] = Entropy(Water, T=T[55], x=x[55])
h[55] = Enthalpy(Water, T=T[55], x=x[55])
z[55] = 0
x[55] = 1
e[55] = (h[55] - h_0) - T_0*(s[55] - s_0)

"State 56 - Effect No.3, Evaporator, Brine Out"
T[56] = T[55] + BPE_Seawater(z[56])
P[56] = P[55]
s[56] = Entropy(Water, T=T[56], x=x[56])
h[56] = Enthalpy(Water, T=T[56], x=x[56])
z[56] = z[54] * (m_dot_f3 / m_dot_B3)
z[56] = z_B
x[56] = 0
e[56] = (h[56] - h_0) - T_0*(s[56] - s_0)


"==============================================================================="
"                                   Effect No. 4                                  "
"==============================================================================="

"State 60 - Effect No.4, Hot In"
T[60] = T[55]
```

```
P[60] = P[55]
s[60] = s[55]
h[60] = h[55]
z[60] = z[55]
x[60] = x[55]
e[60] = e[55]

"State 61 - Effect No.4, Evaporator, Hot Out"
T[61] = Temperature(Water, P=P[61], h=h[61])
P[61] = P[60]
s[61] = Entropy(Water, P=P[61], h=h[61])
h[61] = h[60] - (m_dot_D4 / m_dot_D3)*(h[65] - h[64]) - (m_dot_B4 / m_dot_D3)*(h[66] - h[64])
z[61] = z[60]
x[61] = Quality(Water, P=P[61], h=h[61])
e[61] = (h[61] - h_0) - T_0*(s[61] - s_0)

"State 62 - Effect No.4, Economizer, Hot Out"
T[62] = Temperature(Water, P=P[62], x=x[62])
P[62] = P[61]
s[62] = Entropy(Water, P=P[62], x=x[62])
h[62] = Enthalpy(Water, P=P[62], x=x[62])
h[62] = h[61] - (m_dot_f4 / m_dot_D3)*(h[64] - h[63])
z[62] = z[61]
x[62] = 0
e[62] = (h[62] - h_0) - T_0*(s[62] - s_0)

"State 63 - Effect No.4, Cold In"
T[63] = T[30]
P[63] = P[30]
s[63] = s[30]
h[63] = h[30]
z[63] = z[30]
e[63] = e[30]

"State 64 - Effect No.4, Economizer, Cold Out"
T[64] = T[62] - DELTAT_HX
P[64] = P[63]
s[64] = Entropy(Water, T=T[64], P=P[64])
h[64] = Enthalpy(Water, T=T[64], P=P[64])
z[64] = z[63]
e[64] = (h[64] - h_0) - T_0*(s[64] - s_0)

"State 65 - Effect No.4, Evaporator, Distillate Out"
T[65] = T[64]
P[65] = Pressure(Water, T=T[65], x=x[65])
s[65] = Entropy(Water, T=T[65], x=x[65])
h[65] = Enthalpy(Water, T=T[65], x=x[65])
z[65] = 0
x[65] = 1
e[65] = (h[65] - h_0) - T_0*(s[65] - s_0)

"State 66 - Effect No.4, Evaporator, Brine Out"
T[66] = T[65] + BPE_Seawater(z[66])
P[66] = P[65]
s[66] = Entropy(Water, T=T[66], x=x[66])
h[66] = Enthalpy(Water, T=T[66], x=x[66])
z[66] = z[64] * (m_dot_f4 / m_dot_B4)
z[66] = z_B
x[66] = 0
e[66] = (h[66] - h_0) - T_0*(s[66] - s_0)
```

```
"=========================================================================================="
"                                        Effect No. 5                                     "
"=========================================================================================="

"State 70 - Effect No.5, Hot In"
T[70] = T[65]
P[70] = P[65]
s[70] = s[65]
h[70] = h[65]
z[70] = z[65]
x[70] = x[65]
e[70] = e[65]

"State 71 - Effect No.5, Evaporator, Hot Out"
T[71] = Temperature(Water, P=P[71], h=h[71])
P[71] = P[70]
s[71] = Entropy(Water, P=P[71], h=h[71])
h[71] = h[70] - (m_dot_D5 / m_dot_D4)*(h[75] - h[74]) - (m_dot_B5 / m_dot_D4)*(h[76] - h[74])
z[71] = z[70]
x[71] = Quality(Water, P=P[71], h=h[71])
e[71] = (h[71] - h_0) - T_0*(s[71] - s_0)

"State 72 - Effect No.5, Economizer, Hot Out"
T[72] = Temperature(Water, P=P[72], x=x[72])
P[72] = P[71]
s[72] = Entropy(Water, P=P[72], x=x[72])
h[72] = Enthalpy(Water, P=P[72], x=x[72])
h[72] = h[71] - (m_dot_f5 / m_dot_D4)*(h[74] - h[73])
z[72] = z[71]
x[72] = 0
e[72] = (h[72] - h_0) - T_0*(s[72] - s_0)

"State 73 - Effect No.5, Cold In"
T[73] = T[30]
P[73] = P[30]
s[73] = s[30]
h[73] = h[30]
z[73] = z[30]
e[73] = e[30]

"State 74 - Effect No.5, Economizer, Cold Out"
T[74] = T[72] - DELTAT_HX
P[74] = P[73]
s[74] = Entropy(Water, T=T[74], P=P[74])
h[74] = Enthalpy(Water, T=T[74], P=P[74])
z[74] = z[73]
e[74] = (h[74] - h_0) - T_0*(s[74] - s_0)

"State 75 - Effect No.5, Evaporator, Distillate Out"
T[75] = T[74]
P[75] = Pressure(Water, T=T[75], x=x[75])
s[75] = Entropy(Water, T=T[75], x=x[75])
h[75] = Enthalpy(Water, T=T[75], x=x[75])
z[75] = 0
x[75] = 1
e[75] = (h[75] - h_0) - T_0*(s[75] - s_0)

"State 76 - Effect No.5, Evaporator, Brine Out"
```

```
T[76] = T[75] + BPE_Seawater(z[76])
P[76] = P[75]
s[76] = Entropy(Water, T=T[76], x=x[76])
h[76] = Enthalpy(Water, T=T[76], x=x[76])
z[76] = z[74] * (m_dot_f5 / m_dot_B5)
z[76] = z_B
x[76] = 0
e[76] = (h[76] - h_0) - T_0*(s[76] - s_0)


"=================================================================================="
"                                        Effect No. 6                                        "
"=================================================================================="

"State 80 - Effect No.6, Hot In"
T[80] = T[75]
P[80] = P[75]
s[80] = s[75]
h[80] = h[75]
z[80] = z[75]
x[80] = x[75]
e[80] = e[75]

"State 81 - Effect No.6, Evaporator, Hot Out"
T[81] = Temperature(Water, P=P[81], h=h[81])
P[81] = P[80]
s[81] = Entropy(Water, P=P[81], h=h[81])
h[81] = h[80] - (m_dot_D6 / m_dot_D5)*(h[85] - h[84]) - (m_dot_B6 / m_dot_D5)*(h[86] - h[84])
z[81] = z[80]
x[81] = Quality(Water, P=P[81], h=h[81])
e[81] = (h[81] - h_0) - T_0*(s[81] - s_0)

"State 82 - Effect No.6, Economizer, Hot Out"
T[82] = Temperature(Water, P=P[82], x=x[82])
P[82] = P[81]
s[82] = Entropy(Water, P=P[82], x=x[82])
h[82] = Enthalpy(Water, P=P[82], x=x[82])
h[82] = h[81] - (m_dot_f6 / m_dot_D5)*(h[84] - h[83])
z[82] = z[81]
x[82] = 0
e[82] = (h[82] - h_0) - T_0*(s[82] - s_0)

"State 83 - Effect No.6, Cold In"
T[83] = T[30]
P[83] = P[30]
s[83] = s[30]
h[83] = h[30]
z[83] = z[30]
e[83] = e[30]

"State 84 - Effect No.6, Economizer, Cold Out"
T[84] = T[82] - DELTAT_HX
P[84] = P[83]
s[84] = Entropy(Water, T=T[84], P=P[84])
h[84] = Enthalpy(Water, T=T[84], P=P[84])
z[84] = z[83]
e[84] = (h[84] - h_0) - T_0*(s[84] - s_0)

"State 85 - Effect No.6, Evaporator, Distillate Out"
T[85] = T[84]
```

```
P[85] = Pressure(Water, T=T[85], x=x[85])
s[85] = Entropy(Water, T=T[85], x=x[85])
h[85] = Enthalpy(Water, T=T[85], x=x[85])
z[85] = 0
x[85] = 1
e[85] = (h[85] - h_0) - T_0*(s[85] - s_0)

"State 86 - Effect No.6, Evaporator, Brine Out"
T[86] = T[85] + BPE_Seawater(z[86])
P[86] = P[85]
s[86] = Entropy(Water, T=T[86], x=x[86])
h[86] = Enthalpy(Water, T=T[86], x=x[86])
z[86] = z[84] * (m_dot_f6 / m_dot_B6)
z[86] = z_B
x[86] = 0
e[86] = (h[86] - h_0) - T_0*(s[86] - s_0)


"=========================================================================================="
"                                        Effect No. 7                                       "
"=========================================================================================="

"State 90 - Effect No.7, Hot In"
T[90] = T[85]
P[90] = P[85]
s[90] = s[85]
h[90] = h[85]
z[90] = z[85]
x[90] = x[85]
e[90] = e[85]

"State 91 - Effect No.7, Evaporator, Hot Out"
T[91] = Temperature(Water, P=P[91], h=h[91])
P[91] = P[90]
s[91] = Entropy(Water, P=P[91], h=h[91])
h[91] = h[90] - (m_dot_D7 / m_dot_D6)*(h[95] - h[94]) - (m_dot_B7 / m_dot_D6)*(h[96] - h[94])
z[91] = z[90]
x[91] = Quality(Water, P=P[91], h=h[91])
e[91] = (h[91] - h_0) - T_0*(s[91] - s_0)

"State 92 - Effect No.7, Economizer, Hot Out"
T[92] = Temperature(Water, P=P[92], x=x[92])
P[92] = P[91]
s[92] = Entropy(Water, P=P[92], x=x[92])
h[92] = Enthalpy(Water, P=P[92], x=x[92])
h[92] = h[91] - (m_dot_f7 / m_dot_D6)*(h[94] - h[93])
z[92] = z[91]
x[92] = 0
e[92] = (h[92] - h_0) - T_0*(s[92] - s_0)

"State 93 - Effect No.7, Cold In"
T[93] = T[30]
P[93] = P[30]
s[93] = s[30]
h[93] = h[30]
z[93] = z[30]
e[93] = e[30]

"State 94 - Effect No.7, Economizer, Cold Out"
```

```
T[94] = T[92] - DELTAT_HX
P[94] = P[93]
s[94] = Entropy(Water, T=T[94], P=P[94])
h[94] = Enthalpy(Water, T=T[94], P=P[94])
z[94] = z[93]
e[94] = (h[94] - h_0) - T_0*(s[94] - s_0)

"State 95 - Effect No.7, Evaporator, Distillate Out"
T[95] = T[94]
P[95] = Pressure(Water, T=T[95], x=x[95])
s[95] = Entropy(Water, T=T[95], x=x[95])
h[95] = Enthalpy(Water, T=T[95], x=x[95])
z[95] = 0
x[95] = 1
e[95] = (h[95] - h_0) - T_0*(s[95] - s_0)

"State 96 - Effect No.7, Evaporator, Brine Out"
T[96] = T[95] + BPE_Seawater(z[96])
P[96] = P[95]
s[96] = Entropy(Water, T=T[96], x=x[96])
h[96] = Enthalpy(Water, T=T[96], x=x[96])
z[96] = z[94] * (m_dot_f7 / m_dot_B7)
z[96] = z_B
x[96] = 0
e[96] = (h[96] - h_0) - T_0*(s[96] - s_0)


"================================================================================"
"                                  Effect No. 8                                  "
"================================================================================"

"State 100 - Effect No.8, Hot In"
T[100] = T[95]
P[100] = P[95]
s[100] = s[95]
h[100] = h[95]
z[100] = z[95]
x[100] = x[95]
e[100] = e[95]

"State 101 - Effect No.8, Evaporator, Hot Out"
T[101] = Temperature(Water, P=P[101], h=h[101])
P[101] = P[100]
s[101] = Entropy(Water, P=P[101], h=h[101])
h[101] = h[100] - (m_dot_D8 / m_dot_D7)*(h[105] - h[104]) - (m_dot_B8 / m_dot_D7)*(h[106] - h[104])
z[101] = z[100]
x[101] = Quality(Water, P=P[101], h=h[101])
e[101] = (h[101] - h_0) - T_0*(s[101] - s_0)

"State 102 - Effect No.8, Economizer, Hot Out"
T[102] = Temperature(Water, P=P[102], x=x[102])
P[102] = P[101]
s[102] = Entropy(Water, P=P[102], x=x[102])
h[102] = Enthalpy(Water, P=P[102], x=x[102])
h[102] = h[101] - (m_dot_f8 / m_dot_D7)*(h[104] - h[103])
z[102] = z[101]
x[102] = 0
e[102] = (h[102] - h_0) - T_0*(s[102] - s_0)
```

```
"State 103 - Effect No.8, Cold In"
T[103] = T[30]
P[103] = P[30]
s[103] = s[30]
h[103] = h[30]
z[103] = z[30]
e[103] = e[30]

"State 104 - Effect No.8, Economizer, Cold Out"
T[104] = T[102] - DELTAT_HX
P[104] = P[103]
s[104] = Entropy(Water, T=T[104], P=P[104])
h[104] = Enthalpy(Water, T=T[104], P=P[104])
z[104] = z[103]
e[104] = (h[104] - h_0) - T_0*(s[104] - s_0)

"State 105 - Effect No.8, Evaporator, Distillate Out"
T[105] = T[104]
P[105] = Pressure(Water, T=T[105], x=x[105])
s[105] = Entropy(Water, T=T[105], x=x[105])
h[105] = Enthalpy(Water, T=T[105], x=x[105])
z[105] = 0
x[105] = 1
e[105] = (h[105] - h_0) - T_0*(s[105] - s_0)

"State 106 - Effect No.8, Evaporator, Brine Out"
T[106] = T[105] + BPE_Seawater(z[106])
P[106] = P[105]
s[106] = Entropy(Water, T=T[106], x=x[106])
h[106] = Enthalpy(Water, T=T[106], x=x[106])
z[106] = z[104] * (m_dot_f8 / m_dot_B8)
z[106] = z_B
x[106] = 0
e[106] = (h[106] - h_0) - T_0*(s[106] - s_0)


"=================================================================================="
"                                        Effect No. 9                                        "
"=================================================================================="

"State 110 - Effect No.9, Hot In"
T[110] = T[105]
P[110] = P[105]
s[110] = s[105]
h[110] = h[105]
z[110] = z[105]
x[110] = x[105]
e[110] = e[105]

"State 111 - Effect No.9, Evaporator, Hot Out"
T[111] = Temperature(Water, P=P[111], h=h[111])
P[111] = P[110]
s[111] = Entropy(Water, P=P[111], h=h[111])
h[111] = h[110] - (m_dot_D9 / m_dot_D8)*(h[115] - h[114]) - (m_dot_B9 / m_dot_D8)*(h[116] - h[114])
z[111] = z[110]
x[111] = Quality(Water, P=P[111], h=h[111])
e[111] = (h[111] - h_0) - T_0*(s[111] - s_0)
```

```
"State 112 - Effect No.9, Economizer, Hot Out"
T[112] = Temperature(Water, P=P[112], x=x[112])
P[112] = P[111]
s[112] = Entropy(Water, P=P[112], x=x[112])
h[112] = Enthalpy(Water, P=P[112], x=x[112])
h[112] = h[111] - (m_dot_f9 / m_dot_D8)*(h[114] - h[113])
z[112] = z[111]
x[112] = 0
e[112] = (h[112] - h_0) - T_0*(s[112] - s_0)

"State 113 - Effect No.9, Cold In"
T[113] = T[30]
P[113] = P[30]
s[113] = s[30]
h[113] = h[30]
z[113] = z[30]
e[113] = e[30]

"State 114 - Effect No.9, Economizer, Cold Out"
T[114] = T[112] - DELTAT_HX
P[114] = P[113]
s[114] = Entropy(Water, T=T[114], P=P[114])
h[114] = Enthalpy(Water, T=T[114], P=P[114])
z[114] = z[113]
e[114] = (h[114] - h_0) - T_0*(s[114] - s_0)

"State 115 - Effect No.9, Evaporator, Distillate Out"
T[115] = T[114]
P[115] = Pressure(Water, T=T[115], x=x[115])
s[115] = Entropy(Water, T=T[115], x=x[115])
h[115] = Enthalpy(Water, T=T[115], x=x[115])
z[115] = 0
x[115] = 1
e[115] = (h[115] - h_0) - T_0*(s[115] - s_0)

"State 116 - Effect No.9, Evaporator, Brine Out"
T[116] = T[115] + BPE_Seawater(z[116])
P[116] = P[115]
s[116] = Entropy(Water, T=T[116], x=x[116])
h[116] = Enthalpy(Water, T=T[116], x=x[116])
z[116] = z[114] * (m_dot_f9 / m_dot_B9)
z[116] = z_B
x[116] = 0
e[116] = (h[116] - h_0) - T_0*(s[116] - s_0)


"================================================================================"
"                                   Effect No. 10                                "
"================================================================================"

"State 120 - Effect No.10, Hot In"
T[120] = T[115]
P[120] = P[115]
s[120] = s[115]
h[120] = h[115]
z[120] = z[115]
x[120] = x[115]
```

```
e[120] = e[115]

"State 121 - Effect No.10, Evaporator, Hot Out"
T[121] = Temperature(Water, P=P[121], h=h[121])
P[121] = P[120]
s[121] = Entropy(Water, P=P[121], h=h[121])
h[121] = h[120] - (m_dot_D10 / m_dot_D9)*(h[125] - h[124]) - (m_dot_B10 / m_dot_D9)*(h[126] - h[124])
z[121] = z[120]
x[121] = Quality(Water, P=P[121], h=h[121])
e[121] = (h[121] - h_0) - T_0*(s[121] - s_0)

"State 122 - Effect No.10, Economizer, Hot Out"
T[122] = Temperature(Water, P=P[122], x=x[122])
P[122] = P[121]
s[122] = Entropy(Water, P=P[122], x=x[122])
h[122] = Enthalpy(Water, P=P[122], x=x[122])
h[122] = h[121] - (m_dot_f10 / m_dot_D9)*(h[124] - h[123])
z[122] = z[121]
x[122] = 0
e[122] = (h[122] - h_0) - T_0*(s[122] - s_0)

"State 123 - Effect No.10, Cold In"
T[123] = T[30]
P[123] = P[30]
s[123] = s[30]
h[123] = h[30]
z[123] = z[30]
e[123] = e[30]

"State 124 - Effect No.10, Economizer, Cold Out"
T[124] = T[122] - DELTAT_HX
P[124] = P[123]
s[124] = Entropy(Water, T=T[124], P=P[124])
h[124] = Enthalpy(Water, T=T[124], P=P[124])
z[124] = z[123]
e[124] = (h[124] - h_0) - T_0*(s[124] - s_0)

"State 125 - Effect No.10, Evaporator, Distillate Out"
T[125] = T[124]
P[125] = Pressure(Water, T=T[125], x=x[125])
s[125] = Entropy(Water, T=T[125], x=x[125])
h[125] = Enthalpy(Water, T=T[125], x=x[125])
z[125] = 0
x[125] = 1
e[125] = (h[125] - h_0) - T_0*(s[125] - s_0)

"State 126 - Effect No.10, Evaporator, Brine Out"
T[126] = T[125] + BPE_Seawater(z[126])
P[126] = P[125]
s[126] = Entropy(Water, T=T[126], x=x[126])
h[126] = Enthalpy(Water, T=T[126], x=x[126])
z[126] = z[124] * (m_dot_f10 / m_dot_B10)
z[126] = z_B
x[126] = 0
e[126] = (h[126] - h_0) - T_0*(s[126] - s_0)
```

```
"==========================================================================="
"                                   Effect No. 11                                   "
"==========================================================================="

"State 130 - Effect No.11, Hot In"
T[130] = T[125]
P[130] = P[125]
s[130] = s[125]
h[130] = h[125]
z[130] = z[125]
x[130] = x[125]
e[130] = e[125]

"State 131 - Effect No.11, Evaporator, Hot Out"
T[131] = Temperature(Water, P=P[131], h=h[131])
P[131] = P[130]
s[131] = Entropy(Water, P=P[131], h=h[131])
h[131] = h[130] - (m_dot_D11 / m_dot_D10)*(h[135] - h[134]) - (m_dot_B11 / m_dot_D10)*(h[136] - h[134])
z[131] = z[130]
x[131] = Quality(Water, P=P[131], h=h[131])
e[131] = (h[131] - h_0) - T_0*(s[131] - s_0)

"State 132 - Effect No.11, Economizer, Hot Out"
T[132] = Temperature(Water, P=P[132], x=x[132])
P[132] = P[131]
s[132] = Entropy(Water, P=P[132], x=x[132])
h[132] = Enthalpy(Water, P=P[132], x=x[132])
h[132] = h[131] - (m_dot_f11 / m_dot_D10)*(h[134] - h[133])
z[132] = z[131]
x[132] = 0
e[132] = (h[132] - h_0) - T_0*(s[132] - s_0)

"State 133 - Effect No.11, Cold In"
T[133] = T[30]
P[133] = P[30]
s[133] = s[30]
h[133] = h[30]
z[133] = z[30]
e[133] = e[30]

"State 134 - Effect No.11, Economizer, Cold Out"
T[134] = T[132] - DELTAT_HX
P[134] = P[133]
s[134] = Entropy(Water, T=T[134], P=P[134])
h[134] = Enthalpy(Water, T=T[134], P=P[134])
z[134] = z[133]
e[134] = (h[134] - h_0) - T_0*(s[134] - s_0)

"State 135 - Effect No.11, Evaporator, Distillate Out"
T[135] = T[134]
P[135] = Pressure(Water, T=T[135], x=x[135])
s[135] = Entropy(Water, T=T[135], x=x[135])
h[135] = Enthalpy(Water, T=T[135], x=x[135])
z[135] = 0
x[135] = 1
e[135] = (h[135] - h_0) - T_0*(s[135] - s_0)
```

```
"State 136 - Effect No.11, Evaporator, Brine Out"
T[136] = T[135] + BPE_Seawater(z[136])
P[136] = P[135]
s[136] = Entropy(Water, T=T[136], x=x[136])
h[136] = Enthalpy(Water, T=T[136], x=x[136])
z[136] = z[134] * (m_dot_f11 / m_dot_B11)
z[136] = z_B
x[136] = 0
e[136] = (h[136] - h_0) - T_0*(s[136] - s_0)


"=================================================================================="
"                                         Effect No. 12                                        "
"=================================================================================="

"State 140 - Effect No.12, Hot In"
T[140] = T[135]
P[140] = P[135]
s[140] = s[135]
h[140] = h[135]
z[140] = z[135]
x[140] = x[135]
e[140] = e[135]

"State 141 - Effect No.12, Evaporator, Hot Out"
T[141] = Temperature(Water, P=P[141], h=h[141])
P[141] = P[140]
s[141] = Entropy(Water, P=P[141], h=h[141])
h[141] = h[140] - (m_dot_D12 / m_dot_D11)*(h[145] - h[144]) - (m_dot_B12 / m_dot_D11)*(h[146] - h[144])
z[141] = z[140]
x[141] = Quality(Water, P=P[141], h=h[141])
e[141] = (h[141] - h_0) - T_0*(s[141] - s_0)

"State 142 - Effect No.12, Economizer, Hot Out"
T[142] = Temperature(Water, P=P[142], x=x[142])
P[142] = P[141]
s[142] = Entropy(Water, P=P[142], x=x[142])
h[142] = Enthalpy(Water, P=P[142], x=x[142])
h[142] = h[141] - (m_dot_f12 / m_dot_D11)*(h[144] - h[143])
z[142] = z[141]
x[142] = 0
e[142] = (h[142] - h_0) - T_0*(s[142] - s_0)

"State 143 - Effect No.12, Cold In"
T[143] = T[30]
P[143] = P[30]
s[143] = s[30]
h[143] = h[30]
z[143] = z[30]
e[143] = e[30]

"State 144 - Effect No.12, Economizer, Cold Out"
T[144] = T[142] - DELTAT_HX
P[144] = P[143]
s[144] = Entropy(Water, T=T[144], P=P[144])
h[144] = Enthalpy(Water, T=T[144], P=P[144])
z[144] = z[143]
```

```
e[144] = (h[144] - h_0) - T_0*(s[144] - s_0)

"State 145 - Effect No.12, Evaporator, Distillate Out"
T[145] = T[144]
P[145] = Pressure(Water, T=T[145], x=x[145])
s[145] = Entropy(Water, T=T[145], x=x[145])
h[145] = Enthalpy(Water, T=T[145], x=x[145])
z[145] = 0
x[145] = 1
e[145] = (h[145] - h_0) - T_0*(s[145] - s_0)

"State 146 - Effect No.12, Evaporator, Brine Out"
T[146] = T[145] + BPE_Seawater(z[146])
P[146] = P[145]
s[146] = Entropy(Water, T=T[146], x=x[146])
h[146] = Enthalpy(Water, T=T[146], x=x[146])
z[146] = z[144] * (m_dot_f12 / m_dot_B12)
z[146] = z_B
x[146] = 0
e[146] = (h[146] - h_0) - T_0*(s[146] - s_0)


"==============================================================================="
"                                   Effect No. 13                                   "
"==============================================================================="

"State 150 - Effect No.13, Hot In"
T[150] = T[145]
P[150] = P[145]
s[150] = s[145]
h[150] = h[145]
z[150] = z[145]
x[150] = x[145]
e[150] = e[145]

"State 151 - Effect No.13, Evaporator, Hot Out"
T[151] = Temperature(Water, P=P[151], h=h[151])
P[151] = P[150]
s[151] = Entropy(Water, P=P[151], h=h[151])
h[151] = h[150] - (m_dot_D13 / m_dot_D12)*(h[155] - h[154]) - (m_dot_B13 / m_dot_D12)*(h[156] - h[154])
z[151] = z[150]
x[151] = Quality(Water, P=P[151], h=h[151])
e[151] = (h[151] - h_0) - T_0*(s[151] - s_0)

"State 152 - Effect No.13, Economizer, Hot Out"
T[152] = Temperature(Water, P=P[152], x=x[152])
P[152] = P[151]
s[152] = Entropy(Water, P=P[152], x=x[152])
h[152] = Enthalpy(Water, P=P[152], x=x[152])
h[152] = h[151] - (m_dot_f13 / m_dot_D12)*(h[154] - h[153])
z[152] = z[151]
x[152] = 0
e[152] = (h[152] - h_0) - T_0*(s[152] - s_0)

"State 153 - Effect No.13, Cold In"
T[153] = T[30]
```

```
P[153] = P[30]
s[153] = s[30]
h[153] = h[30]
z[153] = z[30]
e[153] = e[30]

"State 154 - Effect No.13, Economizer, Cold Out"
T[154] = T[152] - DELTAT_HX
P[154] = P[153]
s[154] = Entropy(Water, T=T[154], P=P[154])
h[154] = Enthalpy(Water, T=T[154], P=P[154])
z[154] = z[153]
e[154] = (h[154] - h_0) - T_0*(s[154] - s_0)

"State 155 - Effect No.13, Evaporator, Distillate Out"
T[155] = T[154]
P[155] = Pressure(Water, T=T[155], x=x[155])
s[155] = Entropy(Water, T=T[155], x=x[155])
h[155] = Enthalpy(Water, T=T[155], x=x[155])
z[155] = 0
x[155] = 1
e[155] = (h[155] - h_0) - T_0*(s[155] - s_0)

"State 156 - Effect No.13, Evaporator, Brine Out"
T[156] = T[155] + BPE_Seawater(z[156])
P[156] = P[155]
s[156] = Entropy(Water, T=T[156], x=x[156])
h[156] = Enthalpy(Water, T=T[156], x=x[156])
z[156] = z[154] * (m_dot_f13 / m_dot_B13)
z[156] = z_B
x[156] = 0
e[156] = (h[156] - h_0) - T_0*(s[156] - s_0)


"================================================================================"
"                                   Effect No. 14                                   "
"================================================================================"

"State 160 - Effect No.3, Hot In"
T[160] = T[155]
P[160] = P[155]
s[160] = s[155]
h[160] = h[155]
z[160] = z[155]
x[160] = x[155]
e[160] = e[155]

"State 161 - Effect No.3, Evaporator, Hot Out"
T[161] = Temperature(Water, P=P[161], h=h[161])
P[161] = P[160]
s[161] = Entropy(Water, P=P[161], h=h[161])
h[161] = h[160] - (m_dot_D14 / m_dot_D13)*(h[165] - h[164]) - (m_dot_B14 / m_dot_D13)*(h[166] - h[164])
z[161] = z[160]
x[161] = Quality(Water, P=P[161], h=h[161])
e[161] = (h[161] - h_0) - T_0*(s[161] - s_0)
```

```
"State 162 - Effect No.3, Economizer, Hot Out"
T[162] = Temperature(Water, P=P[162], x=x[162])
P[162] = P[161]
s[162] = Entropy(Water, P=P[162], x=x[162])
h[162] = Enthalpy(Water, P=P[162], x=x[162])
h[162] = h[161] - (m_dot_f14 / m_dot_D13)*(h[164] - h[163])
z[162] = z[161]
x[162] = 0
e[162] = (h[162] - h_0) - T_0*(s[162] - s_0)

"State 163 - Effect No.14, Cold In"
T[163] = T[30]
P[163] = P[30]
s[163] = s[30]
h[163] = h[30]
z[163] = z[30]
e[163] = e[30]

"State 164 - Effect No.14, Economizer, Cold Out"
T[164] = T[162] - DELTAT_HX
P[164] = P[163]
s[164] = Entropy(Water, T=T[164], P=P[164])
h[164] = Enthalpy(Water, T=T[164], P=P[164])
z[164] = z[163]
e[164] = (h[164] - h_0) - T_0*(s[164] - s_0)

"State 165 - Effect No.14, Evaporator, Distillate Out"
T[165] = T[164]
P[165] = Pressure(Water, T=T[165], x=x[165])
s[165] = Entropy(Water, T=T[165], x=x[165])
h[165] = Enthalpy(Water, T=T[165], x=x[165])
z[165] = 0
x[165] = 1
e[165] = (h[165] - h_0) - T_0*(s[165] - s_0)

"State 166 - Effect No.14, Evaporator, Brine Out"
T[166] = T[165] + BPE_Seawater(z[166])
P[166] = P[165]
s[166] = Entropy(Water, T=T[166], x=x[166])
h[166] = Enthalpy(Water, T=T[166], x=x[166])
z[166] = z[164] * (m_dot_f14 / m_dot_B14)
z[166] = z_B
x[166] = 0
e[166] = (h[166] - h_0) - T_0*(s[166] - s_0)


"=================================================================================="
"                                        Effect No. 15                                        "
"=================================================================================="

"State 170 - Effect No.15, Hot In"
T[170] = T[165]
P[170] = P[165]
s[170] = s[165]
h[170] = h[165]
z[170] = z[165]
```

```
x[170] = x[165]
e[170] = e[165]

"State 171 - Effect No.15, Evaporator, Hot Out"
T[171] = Temperature(Water, P=P[171], h=h[171])
P[171] = P[170]
s[171] = Entropy(Water, P=P[171], h=h[171])
h[171] = h[170] - (m_dot_D15 / m_dot_D14)*(h[175] - h[174]) - (m_dot_B15 / m_dot_D14)*(h[176] - h[174])
z[171] = z[170]
x[171] = Quality(Water, P=P[171], h=h[171])
e[171] = (h[171] - h_0) - T_0*(s[171] - s_0)

"State 172 - Effect No.15, Economizer, Hot Out"
T[172] = Temperature(Water, P=P[172], x=x[172])
P[172] = P[171]
s[172] = Entropy(Water, P=P[172], x=x[172])
h[172] = Enthalpy(Water, P=P[172], x=x[172])
h[172] = h[171] - (m_dot_f15 / m_dot_D14)*(h[174] - h[173])
z[172] = z[171]
x[172] = 0
e[172] = (h[172] - h_0) - T_0*(s[172] - s_0)

"State 173 - Effect No.15, Cold In"
T[173] = T[30]
P[173] = P[30]
s[173] = s[30]
h[173] = h[30]
z[173] = z[30]
e[173] = e[30]

"State 174 - Effect No.15, Economizer, Cold Out"
T[174] = T[172] - DELTAT_HX
P[174] = P[173]
s[174] = Entropy(Water, T=T[174], P=P[174])
h[174] = Enthalpy(Water, T=T[174], P=P[174])
z[174] = z[173]
e[174] = (h[174] - h_0) - T_0*(s[174] - s_0)

"State 175 - Effect No.15, Evaporator, Distillate Out"
T[175] = T[174]
P[175] = Pressure(Water, T=T[175], x=x[175])
s[175] = Entropy(Water, T=T[175], x=x[175])
h[175] = Enthalpy(Water, T=T[175], x=x[175])
z[175] = 0
x[175] = 1
e[175] = (h[175] - h_0) - T_0*(s[175] - s_0)

"State 176 - Effect No.15, Evaporator, Brine Out"
T[176] = T[175] + BPE_Seawater(z[176])
P[176] = P[175]
s[176] = Entropy(Water, T=T[176], x=x[176])
h[176] = Enthalpy(Water, T=T[176], x=x[176])
z[176] = z[174] * (m_dot_f15 / m_dot_B15)
z[176] = z_B
x[176] = 0
```

```
e[176] = (h[176] - h_0) - T_0*(s[176] - s_0)


"=================================================================================="
"                                    Final Condenser                               "
"=================================================================================="

"State 180 - Final Condenser, Hot In"
T[180] = T[175]
P[180] = P[175]
s[180] = s[175]
h[180] = h[175]
z[180] = z[175]
x[180] = x[175]
e[180] = e[175]

"State 181 - Final Condenser, Hot Out"
T[181] = T[180]
P[181] = P[180]
s[181] = Entropy(Water, T=T[181], x=x[181])
h[181] = Enthalpy(Water, T=T[181], x=x[181])
z[181] = z[180]
x[181] = 0
e[181] = (h[181] - h_0) - T_0*(s[181] - s_0)

"State 182 - Final Condenser, Cold In"
T[182] = T[30]
P[182] = P[30]
s[182] = s[30]
h[182] = h[30]
z[182] = z[30]
e[182] = e[30]

"State 183 - Final Condenser, Cold Out"
T[183] = T[181] - 3 [C]
P[183] = P[182]
s[183] = Entropy(Water, T=T[183], P=P[183])
h[183] = Enthalpy(Water, T=T[183], P=P[183])
z[183] = z[182]
e[183] = (h[183] - h_0) - T_0*(s[183] - s_0)
m_dot_D15 * (h[180] - h[181]) = m_dot_cond * (h[183] - h[182])
```

SOLUTION

Unit Settings: SI C kPa kJ mass deg

Δh_{vap} = 2.315E+07 [kW]
$\Delta h_{vap,1}$ = 3.591E+06 [kW]
$\Delta h_{vap,10}$ = 990024 [kW]
$\Delta h_{vap,11}$ = 920261 [kW]
$\Delta h_{vap,12}$ = 867629 [kW]
$\Delta h_{vap,13}$ = 829737 [kW]
$\Delta h_{vap,14}$ = 804927 [kW]
$\Delta h_{vap,15}$ = 792159 [kW]
$\Delta h_{vap,2}$ = 2.943E+06 [kW]
$\Delta h_{vap,3}$ = 2.446E+06 [kW]
$\Delta h_{vap,4}$ = 2.062E+06 [kW]
$\Delta h_{vap,5}$ = 1.762E+06 [kW]
$\Delta h_{vap,6}$ = 1.527E+06 [kW]
$\Delta h_{vap,7}$ = 1.341E+06 [kW]
$\Delta h_{vap,8}$ = 1.195E+06 [kW]
$\Delta h_{vap,9}$ = 1.080E+06 [kW]
ΔT_{HX} = 5 [C]
η_{fp} = 0.85
η_{II} = 0.4736
η_{rpp} = 0.85
η_t = 0.9
E_{in} = 4.205E+06 [kW]
GOR_{hv} = 5.212
GOR_{steam} = 4.329
h_0 = 84.01 [kJ/kg]
$\dot{m}_B$ = 6957 [kg/s]
$\dot{m}_{B1}$ = 1108 [kg/s]
$\dot{m}_{B10}$ = 290.9 [kg/s]
$\dot{m}_{B11}$ = 269.1 [kg/s]
$\dot{m}_{B12}$ = 252.4 [kg/s]
$\dot{m}_{B13}$ = 240.2 [kg/s]
$\dot{m}_{B14}$ = 231.9 [kg/s]
$\dot{m}_{B15}$ = 227.1 [kg/s]
$\dot{m}_{B2}$ = 902.7 [kg/s]
$\dot{m}_{B3}$ = 746 [kg/s]
$\dot{m}_{B4}$ = 625.3 [kg/s]
$\dot{m}_{B5}$ = 531.4 [kg/s]
$\dot{m}_{B6}$ = 458 [kg/s]
$\dot{m}_{B7}$ = 400.4 [kg/s]
$\dot{m}_{B8}$ = 354.9 [kg/s]
$\dot{m}_{B9}$ = 319.1 [kg/s]
$\dot{m}_{cond}$ = 95912 [kg/s]

$\dot{m}_{D}$ = 9938 [kg/s]
$\dot{m}_{D1}$ = 1582 [kg/s]
$\dot{m}_{D10}$ = 415.6 [kg/s]
$\dot{m}_{D11}$ = 384.4 [kg/s]
$\dot{m}_{D12}$ = 360.6 [kg/s]
$\dot{m}_{D13}$ = 343.2 [kg/s]
$\dot{m}_{D14}$ = 331.3 [kg/s]
$\dot{m}_{D15}$ = 324.4 [kg/s]
$\dot{m}_{D2}$ = 1290 [kg/s]
$\dot{m}_{D3}$ = 1066 [kg/s]
$\dot{m}_{D4}$ = 893.2 [kg/s]
$\dot{m}_{D5}$ = 759.2 [kg/s]
$\dot{m}_{D6}$ = 654.3 [kg/s]
$\dot{m}_{D7}$ = 571.9 [kg/s]
$\dot{m}_{D8}$ = 507 [kg/s]
$\dot{m}_{D9}$ = 455.8 [kg/s]
$\dot{m}_{f}$ = 16895 [kg/s]
$\dot{m}_{f1}$ = 2690 [kg/s]
$\dot{m}_{f10}$ = 706.6 [kg/s]
$\dot{m}_{f11}$ = 653.5 [kg/s]
$\dot{m}_{f12}$ = 613 [kg/s]
$\dot{m}_{f13}$ = 583.4 [kg/s]
$\dot{m}_{f14}$ = 563.1 [kg/s]
$\dot{m}_{f15}$ = 551.5 [kg/s]
$\dot{m}_{f2}$ = 2192 [kg/s]
$\dot{m}_{f3}$ = 1812 [kg/s]
$\dot{m}_{f4}$ = 1519 [kg/s]
$\dot{m}_{f5}$ = 1291 [kg/s]
$\dot{m}_{f6}$ = 1112 [kg/s]
$\dot{m}_{f7}$ = 972.3 [kg/s]
$\dot{m}_{f8}$ = 861.9 [kg/s]
$\dot{m}_{f9}$ = 774.9 [kg/s]
$\dot{m}_{npp}$ = 2296 [kg/s]
$\dot{m}_{rcw}$ = 22870 [kg/s]
$Power_{out}$ = 1.138E+06 [kW]
PR_{fp} = 25
PR_{rpp} = 1.05
ψ_{D} = 2.213E+06 [kW]
$\psi_{D,B}$ = 1.432E+06 [kW]
$\psi_{D,B1}$ = 332860 [kW]
$\psi_{D,B10}$ = 35681 [kW]
$\psi_{D,B11}$ = 27723 [kW]
$\psi_{D,B12}$ = 21064 [kW]
$\psi_{D,B13}$ = 15346 [kW]
$\psi_{D,B14}$ = 10283 [kW]
$\psi_{D,B15}$ = 5638 [kW]
$\psi_{D,B2}$ = 253317 [kW]
$\psi_{D,B3}$ = 194538 [kW]
$\psi_{D,B4}$ = 150645 [kW]
$\psi_{D,B5}$ = 117515 [kW]
$\psi_{D,B6}$ = 92235 [kW]
$\psi_{D,B7}$ = 72722 [kW]
$\psi_{D,B8}$ = 57475 [kW]
$\psi_{D,B9}$ = 45397 [kW]
$\psi_{D,C}$ = 739016 [kW]
$\psi_{D,E}$ = 41758 [kW]
$\psi_{D,E1}$ = 8652 [kW]
$\psi_{D,E10}$ = 1294 [kW]
$\psi_{D,E11}$ = 1144 [kW]
$\psi_{D,E12}$ = 1036 [kW]
$\psi_{D,E13}$ = 962.3 [kW]
$\psi_{D,E14}$ = 917.9 [kW]
$\psi_{D,E15}$ = 900.7 [kW]
$\psi_{D,E2}$ = 6606 [kW]
$\psi_{D,E3}$ = 5111 [kW]
$\psi_{D,E4}$ = 4008 [kW]
$\psi_{D,E5}$ = 3188 [kW]
$\psi_{D,E6}$ = 2573 [kW]
$\psi_{D,E7}$ = 2110 [kW]
$\psi_{D,E8}$ = 1759 [kW]
$\psi_{D,E9}$ = 1494 [kW]
P_{0} = 101.3 [kPa]
$\dot{Q}_{npp}$ = 4.442E+06 [kW]
q_{in} = 2427 [kJ/kg]
q_{out} = 1935 [kJ/kg]
$q_{reactor}$ = 243.7 [kJ/kg]
ρ_{w} = 998.2 [kg/(m^{3})]
s_{0} = 0.2965 [kJ/(kg*C)]
T_{0} = 20 [C]
v_{w} = 0.001002 [(m^{3})/kg]
w_{c} = 2.984 [kJ/kg]
$\dot{W}_{1}$ = 26.62 [kW]
$\dot{W}_{10}$ = 37.05 [kW]
$\dot{W}_{11}$ = 35.33 [kW]
$\dot{W}_{12}$ = 33.94 [kW]
$\dot{W}_{13}$ = 32.9 [kW]
$\dot{W}_{14}$ = 32.22 [kW]
$\dot{W}_{15}$ = 31.9 [kW]
$\dot{W}_{2}$ = 40.32 [kW]
$\dot{W}_{3}$ = 46.46 [kW]
$\dot{W}_{4}$ = 48.28 [kW]
$\dot{W}_{5}$ = 47.74 [kW]
$\dot{W}_{6}$ = 45.99 [kW]
$\dot{W}_{7}$ = 43.72 [kW]
$\dot{W}_{8}$ = 41.34 [kW]
$\dot{W}_{9}$ = 39.08 [kW]
$\dot{W}_{p}$ = 582.9 [kW]
$w_{reactor}$ = 1.142 [kJ/kg]
w_{t} = 495.7 [kJ/kg]
z_{0} = 35 [g/kg]
z_{B} = 85 [g/kg]

No unit problems were detected.

```
"-----------------------------------------------------------------------------------------------------------------------------------------------"
"                                                    SLTD Model                                                                                 "
"-----------------------------------------------------------------------------------------------------------------------------------------------"


"Salinity Boiling Point Function"
FUNCTION BPE_Seawater(z)
"Boiling Point Elevation for Seawater as a function of salinity"
"Input: z = salinity [g/kg of water]"
"Output: BPE = boiling point elevation [°C]"

   i = 1.9 [-]                    "van 't Hoff factor for seawater"
   K_b = 0.512 [C*kg/mol]   "ebullioscopic constant for water"
   M = 58.44 [g/mol]           "molar mass of NaCl"

   BPE_Seawater = (i * K_b / M) * z   "boiling point elevation [C]"
END

"--------------------------------------------------------------------------------------------------"
"Note: This version as of 11/29 still needs some work for a complete analysis"
"--------------------------------------------------------------------------------------------------"

"Spray Evaporatored Water"
E = 0.1

"Ambient Conditions"
T_0 = 20 [C]
P_0 = 101.325 [kPa]
h_0 = Enthalpy(Water, T=T_0, P=P_0)
s_0 = Entropy(Water, T=T_0, P=P_0)
z_0 = 35 [g/kg]

"Plant Mass Flow Rate"
m_dot_npp = 2296 [kg/s] "Nuclear Power Plant Flowrate"
m_dot_rcw = 4592 [kg/s] "Reactor cooling water flowrate"

"Conservation of mass"
m_dot_f1 = m_dot_D1 + m_dot_B1   "Evaporator No.1"
m_dot_f2 = m_dot_D2 + m_dot_B2   "Evaporator No.2"
m_dot_f3 = m_dot_D3 + m_dot_B3   "Evaporator No.3"
m_dot_f4 = m_dot_D4 + m_dot_B4   "Evaporator No.4"
m_dot_f5 = m_dot_D5 + m_dot_B5   "Evaporator No.5"
m_dot_f6 = m_dot_D6 + m_dot_B6   "Evaporator No.6"
m_dot_f7 = m_dot_D7 + m_dot_B7   "Evaporator No.7"

"Total Mass Flow"
Q_hx_npp = m_dot_npp * (h[25] - h[20])
Q_hx_npp = m_dot_f * (h[33] - h[30])
m_dot_D = m_dot_D1 + m_dot_D2 + m_dot_D3 + m_dot_D4 + m_dot_D5 + m_dot_D6 + m_dot_D7 + m_dot_D8 "Total distillate flowrate"
m_dot_B = m_dot_B8 "Total waste brine flowrate"

"Allowable Brine Salinity"
z_B = 85 [g/kg]

"Temperature Parameters"
DELTAT_HX = 5 [C]  "Heat transfer temperature difference"
DELTAT_Spray = 2 [C] "Spray Evaporator Temperature Loss"

"Isentropic Efficiencies"
eta_rpp = 0.8 "Reactor Primary Pump"
eta_fw = 0.85       "Feed Water Pump"
eta_t = 0.90             "Steam Turbine"
```

```
"Pressure Ratios"
PR_rpp =  1.05
PR_fp = 25

"Gained Output Ratio"
h_fg_sw = 2258 [kJ/kg]
Q_dot_in = m_dot_f * Cp(Water,T=T[30],P=P[30]) * (T[40] - T[30])
GOR_hv = (m_dot_D) * h_fg_sw / Q_dot_in
GOR_mass = m_dot_D / m_dot_npp

"Distillate Production"
Power_NPP = 1138 [MW]
Distillate_prod = m_dot_D / (Power_NPP * 1000) "kg/kJ"

"================================================================================="
"                                    Nuclear Power Plant                                    "
"================================================================================="


"State 10 - Reactor Side, After Steam Generator"
T[10] = 275 [C]
P[10] = 15000 [kPa]
s[10] = Entropy(Water, T=T[10], P=P[10])
h[10] = Enthalpy(Water, T=T[10], P=P[10])
e[10] = (h[10] - h_0) - T_0*(s[10] - s_0)

"State 11 - Reactor Primary Pump, Ideal"
T[11] = Temperature(Water, s=s[11], P=P[11])
P[11] = P[10] * PR_rpp
s[11] = s[10]
h[11] = Enthalpy(Water, T=T[11], P=P[11])
e[11] = (h[11] - h_0) - T_0*(s[11] - s_0)

"State 12 - Reactor Primary Pump, Real"
T[12] = Temperature(Water, h=h[12], P=P[12])
P[12] = P[11]
s[12] = Entropy(Water, T=T[12], P=P[12])
h[12] = h[10] + (h[11] - h[10])/eta_rpp
e[12] = (h[12] - h_0) - T_0*(s[12] - s_0)

"State 13 - After Reactor, Entering Steam Generator"
T[13] = 320 [C]
P[13] = P[12]
s[13] = Entropy(Water, T=T[13], P=P[13])
h[13] = Enthalpy(Water, T=T[13], P=P[13])
e[13] = (h[13] - h_0) - T_0*(s[13] - s_0)

"State 20 - Interloop-side, After NPP Condenser"
T[20] = Temperature(Water, P=P[20], x=x[20])
P[20] = P_0
s[20] = Entropy(Water, x=x[20], P=P[20])
h[20] = Enthalpy(Water, x=x[20], P=P[20])
e[20] = (h[20] - h_0) - T_0*(s[20] - s_0)
x[20] = 0

"State 21 - Feed Pump, Ideal"
T[21] = Temperature(Water, s=s[21], P=P[21])
P[21] = P[20] * PR_fp
s[21] = s[20]
h[21] = Enthalpy(Water, T=T[21], P=P[21])
e[21] = (h[21] - h_0) - T_0*(s[21] - s_0)
```

```
"State 22 - Feed Pump, Real"
T[22] = Temperature(Water, h=h[22], P=P[22])
P[22] = P[21]
s[22] = Entropy(Water, T=T[22], P=P[22])
h[22] = h[20] + (h[21] - h[20])/eta_fw
e[22] = (h[22] - h_0) - T_0*(s[22] - s_0)

"State 23 - Interloop-side, After Steam Generator"
Q_steam_gen = 2470 [kJ/kg]
T[23] = Temperature(Water,h=h[23],P=P[23])
P[23] = P[22]
s[23] = Entropy(Water, T=T[23], P=P[23])
h[23] = h[22] + Q_steam_gen
e[23] = (h[23] - h_0) - T_0*(s[23] - s_0)

"State 24 - Turbine, Ideal"
T[24] = Temperature(Water, s=s[24], P=P[24])
P[24] = P[23] / PR_fp
s[24] = s[23]
h[24] = Enthalpy(Water, T=T[24], s=s[24])
e[24] = (h[24] - h_0) - T_0*(s[24] - s_0)
x[24] = Quality(Water, s=s[24], P=P[24])

"State 25 - Turbine, Real"
T[25] = Temperature(Water, h=h[25], P=P[25])
P[25] = P[24]
s[25] = Entropy(Water, T=T[25], h=h[25])
h[25] = h[23] - eta_t*(h[23] - h[24])
e[25] = (h[25] - h_0) - T_0*(s[25] - s_0)
x[25] = Quality(Water,  h=h[25], P=P[25])


"State Point 30: Seawater at Pump Intake"
T[30] = T_0
P[30] = P_0
h[30] = h_0
s[30] = s_0
sal[30] = z_0

"State Point 32: Seawater at Condenser Intake"
T[32] = T[30]
P[32] = P[30]
h[32] = h[30]
s[32] = s[30]
sal[32] = sal[30]

"State Point 33: Seawater at Condenser Outlet"
T[33] = T[25] - DELTAT_HX
P[33] = P[32]
h[33] = Enthalpy(Water,T=T[33],P=P[33])
s[33] = Entropy(Water,T=T[33],P=P[33])
sal[33] = sal[32]

"================================================================================"
"                                  Evaporator No. 1                              "
"================================================================================"


"State Point 40: Evaporator No. 1 Hot In"
T[40] = T[33]
P[40] = P[33]
h[40] = h[33]
```

```
s[40] = s[33]
sal[40] = sal[33]

"State 41 - Feed Pump, Ideal"
T[41] = Temperature(Water, s=s[41], P=P[41])
P[41] = P[40] * PR_rpp
s[41] = s[40]
h[41] = Enthalpy(Water, T=T[41], P=P[41])
e[41] = (h[41] - h[40]) - T_0*(s[41] - s[40])
sal[41] = sal[40]

"State 42 - Feed Pump, Real"
T[42] = Temperature(Water, h=h[42], P=P[42])
P[42] = P[41]
s[42] = Entropy(Water, T=T[42], P=P[42])
h[42] = h[40] + (h[41] - h[40])/eta_fw
e[42] = (h[42] - h[40]) - T_0*(s[42] - s[40])
sal[42] = sal[41]

"State Point 43: Evaporator No. 1 Direct Contact Evaporator"
T[43] = T[42] - DELTAT_Spray
P[43] = Pressure(Water,T=T[43],x=x[43])
h[43] = Enthalpy(Water,T=T[43],x=x[43])
s[43] = Entropy(Water,T=T[43],x=x[43])
x[43] = E
sal[43] = 100 * sal[42] / (100 * (1 - x[43]))
e[43] = (h[43] - h[42]) - T_0*(s[43] - s[42])
m_dot_B1 = (1 - x[43]) * m_dot_f

"State Point 44: Evaporator No. 1 Distillate"
T[44] = T[43]
P[44] = Pressure(Water,T=T[44],x=x[44])
h[44] = Enthalpy(Water,T=T[44],x=x[44])
s[44] = Entropy(Water,T=T[44],x=x[44])
x[44] = 1
sal[44] = 0
e[44] = (h[44] - h[43]) - T_0*(s[44] - s[43])
m_dot_D1 = x[43] * m_dot_f

"State Point 45: Evaporator No. 1 Condenser Distillate"
T[45] = T[44]
P[45] = Pressure(Water,T=T[45],x=x[45])
h[45] = Enthalpy(Water,T=T[45],x=x[45])
s[45] = Entropy(Water,T=T[45],x=x[45])
x[45] = 0
sal[45] = 0
e[45] = (h[45] - h[44]) - T_0*(s[45] - s[44])

"=================================================================================="
"                                   Evaporator No. 2                               "
"=================================================================================="

"State Point 50: Evaporator No. 2 Intake"
T[50] = T[43]
P[50] = Pressure(Water, T=T[50],x=x[50])
h[50] = Enthalpy(Water, T=T[50],x=x[50])
s[50] = Entropy(Water,T=T[50],x=x[50])
x[50] = 0
sal[50] = sal[43]

"State 51 - Feed Pump, Ideal"
```

```
T[51] = Temperature(Water, s=s[51], P=P[51])
P[51] = P[50] * PR_rpp
s[51] = s[50]
h[51] = Enthalpy(Water, T=T[51], P=P[51])
e[51] = (h[51] - h[50]) - T_0*(s[51] - s[50])
sal[51] = sal[50]

"State 52 - Feed Pump, Real"
T[52] = Temperature(Water, h=h[52], P=P[52])
P[52] = P[51]
s[52] = Entropy(Water, T=T[52], P=P[52])
h[52] = h[50] + (h[51] - h[50])/eta_fw
e[52] = (h[52] - h[50]) - T_0*(s[52] - s[50])
sal[52] = sal[51]

"State Point 53: Evaporator No. 2 Direct Contact Evaporator"
T[53] = T[52] - DELTAT_Spray
P[53] = Pressure(Water,T=T[53],x=x[53])
h[53] = Enthalpy(Water,T=T[53],x=x[53])
s[53] = Entropy(Water,T=T[53],x=x[53])
x[53] = E
sal[53] = 100 * z_0 / (100 * (1 - x[53])^2)
e[53] = (h[53] - h[52]) - T_0*(s[53] - s[52])
m_dot_B2 = (1 - x[53]) * m_dot_B1

"State Point 54: Evaporator No. 2 Distillate"
T[54] = T[53]
P[54] = Pressure(Water,T=T[54],x=x[54])
h[54] = Enthalpy(Water,T=T[54],x=x[54])
s[54] = Entropy(Water,T=T[54],x=x[54])
x[54] = 1
sal[54] = 0
e[54] = (h[54] - h[53]) - T_0*(s[54] - s[53])
m_dot_D2 = x[53] * m_dot_B1

"State Point 55: Evaporator No. 2 Condenser Distillate"
T[55] = T[54]
P[55] = Pressure(Water,T=T[55],x=x[55])
h[55] = Enthalpy(Water,T=T[55],x=x[55])
s[55] = Entropy(Water,T=T[55],x=x[55])
e[55] = (h[55] - h[54]) - T_0*(s[55] - s[54])
x[55] = 0

"=================================================================================="
"                                   Evaporator No. 3                                 "
"=================================================================================="

"State Point 60: Evaporator No. 3 Intake"
T[60] = T[53]
P[60] = Pressure(Water, T=T[60],x=x[60])
h[60] = Enthalpy(Water, T=T[60],x=x[60])
s[60] = Entropy(Water,T=T[60],x=x[60])
x[60] = 0
sal[60] = sal[53]

"State 61 - Feed Pump, Ideal"
T[61] = Temperature(Water, s=s[61], P=P[61])
P[61] = P[60] * PR_rpp
s[61] = s[60]
h[61] = Enthalpy(Water, T=T[61], P=P[61])
```

```
e[61] = (h[61] - h[60]) - T_0*(s[61] - s[60])
sal[61] = sal[60]

"State 62 - Feed Pump, Real"
T[62] = Temperature(Water, h=h[62], P=P[62])
P[62] = P[61]
s[62] = Entropy(Water, T=T[62], P=P[62])
h[62] = h[60] + (h[61] - h[60])/eta_fw
e[62] = (h[62] - h[60]) - T_0*(s[62] - s[60])
sal[62] = sal[61]

"State Point 63: Evaporator No. 3 Direct Contact Evaporator"
T[63] = T[62] - DELTAT_Spray
P[63] = Pressure(Water,T=T[63],x=x[63])
h[63] = Enthalpy(Water,T=T[63],x=x[63])
s[63] = Entropy(Water,T=T[63],x=x[63])
x[63] = E
sal[63] = 100 * z_0 / (100 * (1 - x[53])^3)
e[63] = (h[63] - h[62]) - T_0*(s[63] - s[62])
m_dot_B3 = (1 - x[63]) * m_dot_B2

"State Point 64: Evaporator No. 3 Distillate"
T[64] = T[63]
P[64] = Pressure(Water,T=T[64],x=x[64])
h[64] = Enthalpy(Water,T=T[64],x=x[64])
s[64] = Entropy(Water,T=T[64],x=x[64])
x[64] = 1
sal[64] = 0
e[64] = (h[64] - h[63]) - T_0*(s[64] - s[63])
m_dot_D3 = x[63] * m_dot_B2

"State Point 65: Evaporator No. 3 Condenser Distillate"
T[65] = T[64]
P[65] = Pressure(Water,T=T[65],x=x[65])
h[65] = Enthalpy(Water,T=T[65],x=x[65])
s[65] = Entropy(Water,T=T[65],x=x[65])
e[65] = (h[65] - h[64]) - T_0*(s[65] - s[64])
x[65] = 0

"==================================================================================="
"                                        Evaporator No. 4                                        "
"==================================================================================="

"State Point 70: Evaporator No. 4 Intake"
T[70] = T[63]
P[70] = Pressure(Water, T=T[70],x=x[70])
h[70] = Enthalpy(Water, T=T[70],x=x[70])
s[70] = Entropy(Water,T=T[70],x=x[70])
x[70] = 0
sal[70] = sal[63]

"State 71 - Feed Pump, Ideal"
T[71] = Temperature(Water, s=s[71], P=P[71])
P[71] = P[70] * PR_rpp
s[71] = s[70]
h[71] = Enthalpy(Water, T=T[71], P=P[71])
e[71] = (h[71] - h[70]) - T_0*(s[71] - s[70])
sal[71] = sal[70]

"State 72 - Feed Pump, Real"
```

```
T[72] = Temperature(Water, h=h[72], P=P[72])
P[72] = P[71]
s[72] = Entropy(Water, T=T[72], P=P[72])
h[72] = h[70] + (h[71] - h[70])/eta_fw
e[72] = (h[72] - h[70]) - T_0*(s[72] - s[70])
sal[72] = sal[71]

"State Point 73: Evaporator No. 4 Direct Contact Evaporator"
T[73] = T[72] - DELTAT_Spray
P[73] = Pressure(Water,T=T[73],x=x[73])
h[73] = Enthalpy(Water,T=T[73],x=x[73])
s[73] = Entropy(Water,T=T[73],x=x[73])
x[73] = E
sal[73] = 100 * z_0 / (100 * (1 - x[53])^4)
e[73] = (h[73] - h[72]) - T_0*(s[73] - s[72])
m_dot_B4 = (1 - x[73]) * m_dot_B3

"State Point 74: Evaporator No. 4 Distillate"
T[74] = T[73]
P[74] = Pressure(Water,T=T[74],x=x[74])
h[74] = Enthalpy(Water,T=T[74],x=x[74])
s[74] = Entropy(Water,T=T[74],x=x[74])
x[74] = 1
sal[74] = 0
e[74] = (h[74] - h[73]) - T_0*(s[74] - s[73])
m_dot_D4 = x[73] * m_dot_B3

"State Point 75: Evaporator No. 4 Condenser Distillate"
T[75] = T[74]
P[75] = Pressure(Water,T=T[75],x=x[75])
h[75] = Enthalpy(Water,T=T[75],x=x[75])
s[75] = Entropy(Water,T=T[75],x=x[75])
e[75] = (h[75] - h[74]) - T_0*(s[75] - s[74])
x[75] = 0


"==============================================================================="
"                                        Evaporator No. 5                                        "
"==============================================================================="

"State Point 80: Evaporator No. 5 Intake"
T[80] = T[73]
P[80] = Pressure(Water, T=T[80],x=x[80])
h[80] = Enthalpy(Water, T=T[80],x=x[80])
s[80] = Entropy(Water,T=T[80],x=x[80])
x[80] = 0
sal[80] = sal[73]

"State 81 - Feed Pump, Ideal"
T[81] = Temperature(Water, s=s[81], P=P[81])
P[81] = P[80] * PR_rpp
s[81] = s[80]
h[81] = Enthalpy(Water, T=T[81], P=P[81])
e[81] = (h[81] - h[80]) - T_0*(s[81] - s[80])
sal[81] = sal[80]

"State 82 - Feed Pump, Real"
T[82] = Temperature(Water, h=h[82], P=P[82])
P[82] = P[81]
```

```
s[82] = Entropy(Water, T=T[82], P=P[82])
h[82] = h[80] + (h[81] - h[80])/eta_fw
e[82] = (h[82] - h[80]) - T_0*(s[82] - s[80])
sal[82] = sal[81]

"State Point 83: Evaporator No. 5 Direct Contact Evaporator"
T[83] = T[82] - DELTAT_Spray
P[83] = Pressure(Water,T=T[83],x=x[83])
h[83] = Enthalpy(Water,T=T[83],x=x[83])
s[83] = Entropy(Water,T=T[83],x=x[83])
x[83] = E
sal[83] = 100 * z_0 / (100 * (1 - x[53])^5)
e[83] = (h[83] - h[82]) - T_0*(s[83] - s[82])
m_dot_B5 = (1 - x[83]) * m_dot_B4

"State Point 84: Evaporator No. 5 Distillate"
T[84] = T[83]
P[84] = Pressure(Water,T=T[84],x=x[84])
h[84] = Enthalpy(Water,T=T[84],x=x[84])
s[84] = Entropy(Water,T=T[84],x=x[84])
x[84] = 1
sal[84] = 0
e[84] = (h[84] - h[83]) - T_0*(s[84] - s[83])
m_dot_D5 = x[83] * m_dot_B4

"State Point 85: Evaporator No. 5 Condenser Distillate"
T[85] = T[84]
P[85] = Pressure(Water,T=T[85],x=x[85])
h[85] = Enthalpy(Water,T=T[85],x=x[85])
s[85] = Entropy(Water,T=T[85],x=x[85])
e[85] = (h[85] - h[84]) - T_0*(s[85] - s[84])
x[85] = 0

"=================================================================================="
"                                    Evaporator No. 6                                  "
"=================================================================================="

"State Point 90: Evaporator No. 6 Intake"
T[90] = T[83]
P[90] = Pressure(Water, T=T[90],x=x[90])
h[90] = Enthalpy(Water, T=T[90],x=x[90])
s[90] = Entropy(Water,T=T[90],x=x[90])
x[90] = 0
sal[90] = sal[83]

"State 91 - Feed Pump, Ideal"
T[91] = Temperature(Water, s=s[91], P=P[91])
P[91] = P[90] * PR_rpp
s[91] = s[90]
h[91] = Enthalpy(Water, T=T[91], P=P[91])
e[91] = (h[91] - h[90]) - T_0*(s[91] - s[90])
sal[91] = sal[90]

"State 92 - Feed Pump, Real"
T[92] = Temperature(Water, h=h[92], P=P[92])
P[92] = P[91]
s[92] = Entropy(Water, T=T[92], P=P[92])
h[92] = h[90] + (h[91] - h[90])/eta_fw
e[92] = (h[92] - h[90]) - T_0*(s[92] - s[90])
```

```
sal[92] = sal[91]

"State Point 93: Evaporator No. 6 Direct Contact Evaporator"
T[93] = T[92] - DELTAT_Spray
P[93] = Pressure(Water,T=T[93],x=x[93])
h[93] = Enthalpy(Water,T=T[93],x=x[93])
s[93] = Entropy(Water,T=T[93],x=x[93])
x[93] = E
sal[93] = 100 * z_0 / (100 * (1 - x[53])^6)
e[93] = (h[93] - h[92]) - T_0*(s[93] - s[92])
m_dot_B6 = (1 - x[93]) * m_dot_B5

"State Point 94: Evaporator No. 6 Distillate"
T[94] = T[93]
P[94] = Pressure(Water,T=T[94],x=x[94])
h[94] = Enthalpy(Water,T=T[94],x=x[94])
s[94] = Entropy(Water,T=T[94],x=x[94])
x[94] = 1
sal[94] = 0
e[94] = (h[94] - h[93]) - T_0*(s[94] - s[93])
m_dot_D6 = x[93] * m_dot_B5

"State Point 95: Evaporator No. 6 Condenser Distillate"
T[95] = T[94]
P[95] = Pressure(Water,T=T[95],x=x[95])
h[95] = Enthalpy(Water,T=T[95],x=x[95])
s[95] = Entropy(Water,T=T[95],x=x[95])
e[95] = (h[95] - h[94]) - T_0*(s[95] - s[94])
x[95] = 0


"=================================================================================="
"                                    Evaporator No. 7                              "
"=================================================================================="

"State Point 100: Evaporator No. 7 Intake"
T[100] = T[93]
P[100] = Pressure(Water, T=T[100],x=x[100])
h[100] = Enthalpy(Water, T=T[100],x=x[100])
s[100] = Entropy(Water,T=T[100],x=x[100])
x[100] = 0
sal[100] = sal[93]

"State 101 - Feed Pump, Ideal"
T[101] = Temperature(Water, s=s[101], P=P[101])
P[101] = P[100] * PR_rpp
s[101] = s[100]
h[101] = Enthalpy(Water, T=T[101], P=P[101])
e[101] = (h[101] - h[100]) - T_0*(s[101] - s[100])
sal[101] = sal[100]

"State 102 - Feed Pump, Real"
T[102] = Temperature(Water, h=h[102], P=P[102])
P[102] = P[101]
s[102] = Entropy(Water, T=T[102], P=P[102])
h[102] = h[100] + (h[101] - h[100])/eta_fw
e[102] = (h[102] - h[100]) - T_0*(s[102] - s[100])
sal[102] = sal[101]
```

```
"State Point 103: Evaporator No. 7 Direct Contact Evaporator"
T[103] = T[102] - DELTAT_Spray
P[103] = Pressure(Water,T=T[103],x=x[103])
h[103] = Enthalpy(Water,T=T[103],x=x[103])
s[103] = Entropy(Water,T=T[103],x=x[103])
x[103] = E
sal[103] = 100 * z_0 / (100 * (1 - x[53])^7)
e[103] = (h[103] - h[102]) - T_0*(s[103] - s[102])
m_dot_B7 = (1 - x[103]) * m_dot_B6

"State Point 104: Evaporator No. 7 Distillate"
T[104] = T[103]
P[104] = Pressure(Water,T=T[104],x=x[104])
h[104] = Enthalpy(Water,T=T[104],x=x[104])
s[104] = Entropy(Water,T=T[104],x=x[104])
x[104] = 1
sal[104] = 0
e[104] = (h[104] - h[103]) - T_0*(s[104] - s[103])
m_dot_D7 = x[103] * m_dot_B6

"State Point 105: Evaporator No. 7 Condenser Distillate"
T[105] = T[104]
P[105] = Pressure(Water,T=T[105],x=x[105])
h[105] = Enthalpy(Water,T=T[105],x=x[105])
s[105] = Entropy(Water,T=T[105],x=x[105])
e[105] = (h[105] - h[104]) - T_0*(s[105] - s[104])
x[105] = 0

"===================================================================================="
"                                        Evaporator No. 8                                        "
"===================================================================================="

"State Point 110: Evaporator No. 8 Intake"
T[110] = T[103]
P[110] = Pressure(Water, T=T[110],x=x[110])
h[110] = Enthalpy(Water, T=T[110],x=x[110])
s[110] = Entropy(Water,T=T[110],x=x[110])
x[110] = 0
sal[110] = sal[103]

"State 111 - Feed Pump, Ideal"
T[111] = Temperature(Water, s=s[111], P=P[111])
P[111] = P[110] * PR_rpp
s[111] = s[110]
h[111] = Enthalpy(Water, T=T[111], P=P[111])
e[111] = (h[111] - h[110]) - T_0*(s[111] - s[110])
sal[111] = sal[110]

"State 112 - Feed Pump, Real"
T[112] = Temperature(Water, h=h[112], P=P[112])
P[112] = P[111]
s[112] = Entropy(Water, T=T[112], P=P[112])
h[112] = h[110] + (h[111] - h[110])/eta_fw
e[112] = (h[112] - h[110]) - T_0*(s[112] - s[110])
sal[112] = sal[111]

"State Point 113: Evaporator No. 8 Direct Contact Evaporator"
T[113] = T[112] - DELTAT_Spray
```

```
P[113] = Pressure(Water,T=T[113],x=x[113])
h[113] = Enthalpy(Water,T=T[113],x=x[113])
s[113] = Entropy(Water,T=T[113],x=x[113])
x[113] = E
sal[113] = 100 * z_0 / (100 * (1 - x[53])^8)
e[113] = (h[113] - h[112]) - T_0*(s[113] - s[112])
m_dot_B8 = (1 - x[113]) * m_dot_B7

"State Point 114: Evaporator No. 8 Distillate"
T[114] = T[113]
P[114] = Pressure(Water,T=T[114],x=x[114])
h[114] = Enthalpy(Water,T=T[114],x=x[114])
s[114] = Entropy(Water,T=T[114],x=x[114])
x[114] = 1
sal[114] = 0
e[114] = (h[114] - h[113]) - T_0*(s[114] - s[113])
m_dot_D8 = x[113] * m_dot_B7

"State Point 115: Evaporator No. 8 Condenser Distillate"
T[115] = T[114]
P[115] = Pressure(Water,T=T[115],x=x[115])
h[115] = Enthalpy(Water,T=T[115],x=x[115])
s[115] = Entropy(Water,T=T[115],x=x[115])
e[115] = (h[115] - h[114]) - T_0*(s[115] - s[114])
x[115] = 0

"=============================================================================="
"                                        Full Condenser                                        "
"=============================================================================="



"=============================================================================="
"                                        Brine Wastewater                                        "
"=============================================================================="
```

SOLUTION

Unit Settings: SI C kPa kJ mass deg

ΔT_{HX} = 5 [C]
ΔT_{Spray} = 2 [C]
$Distillate_{prod}$ = 0.007197
E = 0.1
η_{fw} = 0.85
η_{rpp} = 0.8
η_t = 0.9
GOR_{hv} = 4.1
GOR_{mass} = 3.567
h_0 = 84.01
$h_{fg,sw}$ = 2258 [kJ/kg]
$\dot{m}_B$ = 6190 [kg/s] {6190 [gal/s]}
$\dot{m}_{B1}$ = 12942
$\dot{m}_{B2}$ = 11648
$\dot{m}_{B3}$ = 10483
$\dot{m}_{B4}$ = 9435
$\dot{m}_{B5}$ = 8491
$\dot{m}_{B6}$ = 7642
$\dot{m}_{B7}$ = 6878
$\dot{m}_{B8}$ = 6190
$\dot{m}_D$ = 8190 [kg/s] {8190 [gal/s]}
$\dot{m}_{D1}$ = 1438
$\dot{m}_{D2}$ = 1294
$\dot{m}_{D3}$ = 1165
$\dot{m}_{D4}$ = 1048
$\dot{m}_{D5}$ = 943.5
$\dot{m}_{D6}$ = 849.1
$\dot{m}_{D7}$ = 764.2
$\dot{m}_{D8}$ = 687.8
$\dot{m}_f$ = 14380 [kg/s] {14380 [gal/s]}
$\dot{m}_{f1}$ = 14380
$\dot{m}_{f2}$ = 12942
$\dot{m}_{f3}$ = 11648
$\dot{m}_{f4}$ = 10483
$\dot{m}_{f5}$ = 9435
$\dot{m}_{f6}$ = 8491
$\dot{m}_{f7}$ = 7642
$\dot{m}_{npp}$ = 2296 [kg/s]
$\dot{m}_{rcw}$ = 4592 [kg/s]
$Power_{NPP}$ = 1138 [MW]
PR_{fp} = 25
PR_{rpp} = 1.05
P_0 = 101.3 [kPa]
$\dot{Q}_{in}$ = 4.511E+06
$Q_{hx,npp}$ = 4.515E+06
$Q_{steam,gen}$ = 2470 [kJ/kg]
s_0 = 0.2965
T_0 = 20 [C]
z_0 = 35 [g/kg]
z_B = 85 [g/kg]

107 potential unit problems were detected.

```
"------------------------------------------ Intake Pump Specifications --------------------------------------------"

"MED Intake Pump"
z = 0 [m]
OD_med = 3.4 [m]
length_med = 300 [m]
v_flow_med = vol_flow_med / A_med
T_0 = 20 [C]
A_med = pi * OD_med^2 / 4
vol_flow_med = m_dot_med / rho_med
P_0 = 101325 [Pa]
m_dot_med = 16896 [kg/s]
rho_med = 1026 [kg/m^3]
mu_med = 0.00109 [Pa*s]
Re_med = rho_med * v_flow_med * OD_med / mu_med
roughness = 0.001 [m]
rel_rough = roughness / OD_med
"Friction factor taken from moody diagram"
fric_med = 0.019
g = 9.81 [m/s^2]
k_med = 0.45
n_bend = 0
h_L_med = rho_med*(fric_med * length_med / OD_med * v_flow_med^2 / (2) + (k_med * n_bend) * v_flow_med^2/(2))
h_pump = rho_med*g*z + h_L_med
h_pump_H2O = Convert(Pa,mH2O) * h_pump
power_pump = vol_flow_med * h_L_med / 0.8

"------------------------------------------ Brine Outflow Specifications ------------------------------------------"

"MED Brine Outflow Pump"
z_b = 0 [m]
length_brine = 500 [m]
rho_brine = 1026 [kg/m^3]
mu_brine = 0.00109 [Pa*s]
T_brine = 75 [C]
P_brine = 84530 [Pa]
vol_flow_brine = m_dot_brine / rho_brine
m_dot_brine = 6957 [kg/s]

"Pre Diffuser Specs"
OD_brine = 1 [m]
v_1_flow_b = vol_flow_brine / A_1_b
A_1_b = OD_brine^2 / 4 * pi

"Post Diffuser Specs"
OD_diff = 3.5 [m]
A_2_b = OD_diff^2 / 4 * pi
v_2_flow_b = vol_flow_brine /A_2_b

"Pump Requirements"
Re_brine = rho_brine * v_1_flow_b * OD_brine / mu_brine
fric_brine = 0.019
rough_b = 0.001 [m]
k_b = 0.45
0.5 * rho_brine * v_1_flow_b^2 + P_brine = 0.5 * rho_brine * v_2_flow_b^2 + P_diff
DELTAP_brine = rho_brine / 2 *(v_1_flow_b^2 - v_2_flow_b^2) + P_brine - P_diff + rho_brine*(fric_brine*length_brine /
OD_brine * v_1_flow_b^2 /2 + k_b * v_1_flow_b^2 /2)
Head_brine = Convert(Pa,mH2O) *DELTAP_brine
power_brine = vol_flow_brine * DELTAP_brine / 0.8
```