# GROUNDWATER TREATMENT PLANT USING MEMBRANE DISTILLATION


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## ABSTRACT


The increasing population and limited water resources in Saudi Arabia have created a pressing need for efficient and cost-effective water treatment processes. This graduation project focuses on developing a Groundwater Treatment Plant using membrane distillation (MD) as an alternative approach. The project aims to modify the traditional treatment process by utilizing MD, which can operate at high temperatures and eliminate the need for costly pre-treatments such as cooling towers. The objective is to reduce the treatment process's overall cost while ensuring clean and safe water production. Through a comprehensive literature review and material balance analysis, this project explores the advantages of MD and compares it with traditional processes of reverse osmosis. The findings indicate that MD offers a promising solution for groundwater treatment, providing potential cost savings and improved efficiency. By implementing MD technology, Saudi Arabia can enhance its water management strategies, conserve valuable resources, and meet the increasing demand for clean water sustainably.


## PROBLEM STATEMENT

With the population increasing from 24 million in 2010 to approximately 33 million in 2022 (Figure 1), growing at an average rate of 3.5% per year, the strain on the limited water resources becomes even more pronounced. To tackle this issue, Saudi Arabia should implement effective water management strategies, optimize water usage, and explore innovative methods for water conservation to ensure a sustainable water supply. It is crucial to prioritize efficient water treatment processes and technologies to provide clean and safe water for various purposes, including domestic, industrial, and agricultural use. By prioritizing water conservation, investing in advanced water treatment techniques, and emphasizing research and development, Saudi Arabia can work towards mitigating the impact of water scarcity and ensuring a sustainable water supply for its increasing population.

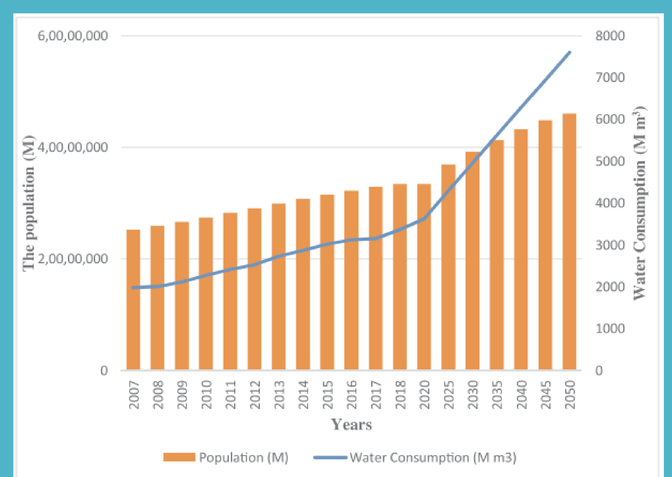


Figure 1:Population and water consumption in the Kingdom of Saudi Arabia from 2007 to 2050.

## COMPARISON OF TRADITIONAL DESALINATION VS. MEMBRANE DISTILLATION (MD).

Traditional desalination requires multiple pre-treatment steps like cooling, coagulation, flocculation, and sand filtration to protect Reverse Osmosis (RO) membranes from scaling and fouling. These steps add complexity and increase costs.

Membrane Distillation (MD), on the other hand, operates efficiently with hotter feed water (70-90°C), eliminating the need for pre-cooling. MD membranes are also more tolerant of suspended particles, reducing the need for extensive pre-treatment and lowering operating costs.

## PROCESS DESCRIPTION

The treatment process begins with air passing through the T-100 aeration tank to oxidize dissolved metals. The resulting solids are filtered out in the F-100 media filter. The filtered water, with a feed rate of 84,000 m³/day, is pumped by P-100 into the heat exchanger (E-100) to reach the desired temperature for the AGMD process. The heated water is then directed to the D-100, where membrane distillation separates the water vapor from contaminants, producing a purified stream at a rate of approximately 65,395 m³/day.

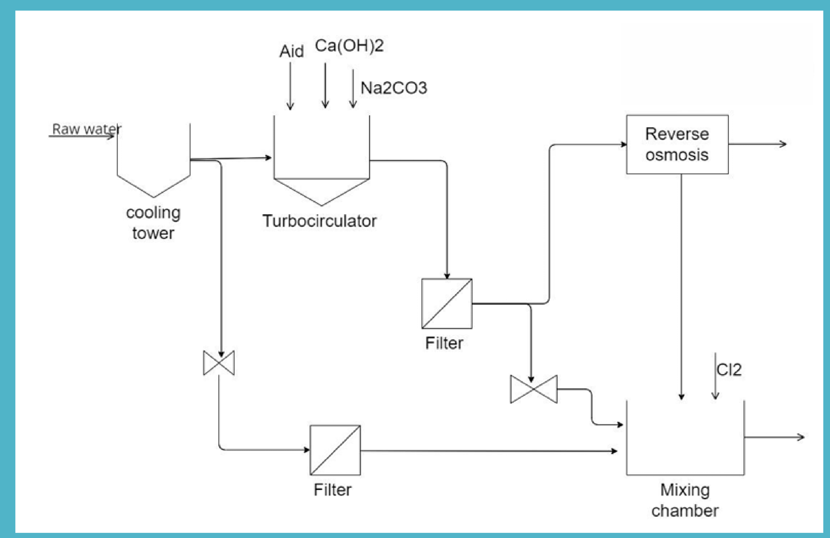


Figure 2:Typical equipment process

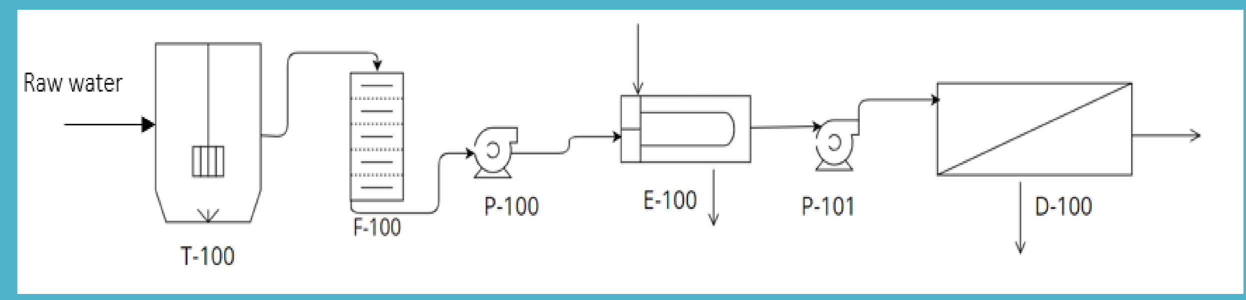


Figure 3:Water treatment process optimization recommendations

## EQUIPMENT DESIGN

AIR GAP MEMBRANE DISTILLATION DESIGN:

AGMD is a thermally driven separation process that utilizes a hydrophobic membrane to selectively permeate water vapor while retaining non-volatile solutes. This system was chosen for its efficiency in handling high-temperature feeds and reduced need for extensive pre-treatment compared to traditional methods. The AGMD system features a PTFE membrane with a thickness of 95 µm, a pore size of 0.3 µm, and a porosity of 83%. An optimized 2 mm air gap enhances heat transfer efficiency while minimizing thermal losses.

Table 1: The input parameters of the mathematical model used in analyzing AGMD process.

| Fluids | Feed | Coolant | Membrane | Dimension | Air gap width (mm) |
|---|---|---|---|---|---|
| Flow Rate (LPM) | 10 | 10 | Width (m) | 1 | 2 |
| Temperature (°C) | 90 | 25 | Length (m) | 2 | |
| Flow Regime | Co-current | | Pore Size (µm) | 0.3 | |
| | | | Tortuosity | 1.2 | |

The membrane area was determined based on a feed flow rate of 84,000 m³/day and a desired water recovery rate of 80%. With a vapor flux of 18 kg/m²·h, the required membrane area was calculated to be approximately 153,759.8 m². This design ensures that the AGMD system can efficiently process the feed water and achieve the targeted recovery, producing a purified stream at a rate of 65,395 m³/day.

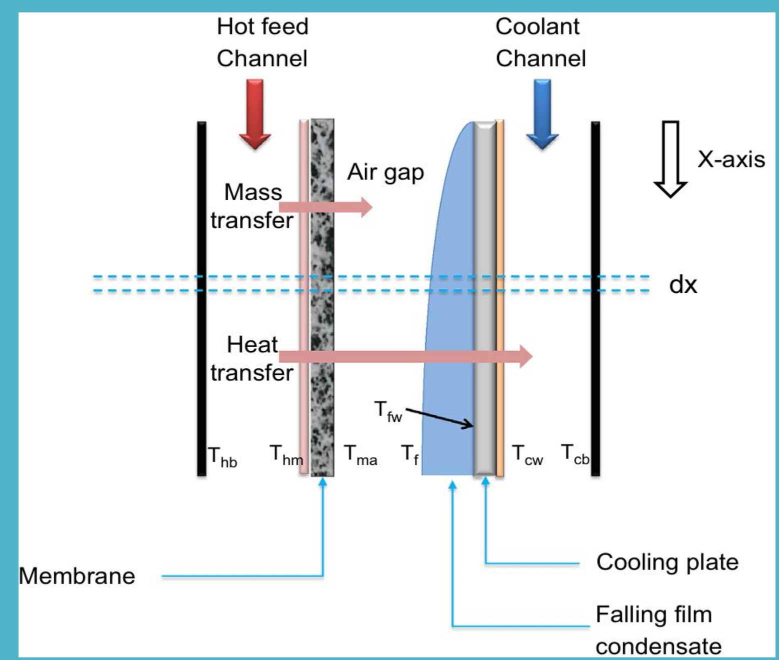


Figure 4: A schematic diagram of AGMD used in describing the model.

Table 2: Summary design of heat exchanger

| | |
|---|---|
| Outer diameter of tube (mm) | 50.8 |
| Inner diameter of tube (mm) | 44.70 |
| Tube thickness (mm) | 3.048 |
| Heat transfer area ($m^2$) | 921.75 |
| Number of tubes | 950 |
| Tube pass | 2 |
| Pitch type | Traingle |
| Pitch (mm) | 63.5 |
| Inlet temperature in tube ( C ) | 75 |
| Outlet temperature in tube ( C ) | 90 |
| Tube pressure drop (bar) | 0.08 |
| Heat transfer coefficient tube ($W/m^2$.C) | 9,341.4 |
| Shell diameter (mm) | 2,169.4 |
| Inlet temperature in shell ( C ) | 130.00 |
| Outlet temperature in shell ( C ) | 130.00 |
| Shell pass | 1 |
| Baffle spacing [mm] | 434.00 |
| Shell pressure drop (bar) | 0 |
| Heat transfer coefficient in shell ($W/m^2$.C) | 4,242.21 |
| Overall heat transfer coefficient ($W/m^2$.C) | 1,602 |

Table 3: Summary design of aeration tank

| Specification sheet of the Aeration tank | |
|---|---|
| Type of impeller | Rushton turbine. |
| Volume of Aeration | 700 m³ |
| Diameter of Aeration | 9.6 m |
| Length of Aeration | 9.6 m |
| Power for mixing | 27.6 kW |

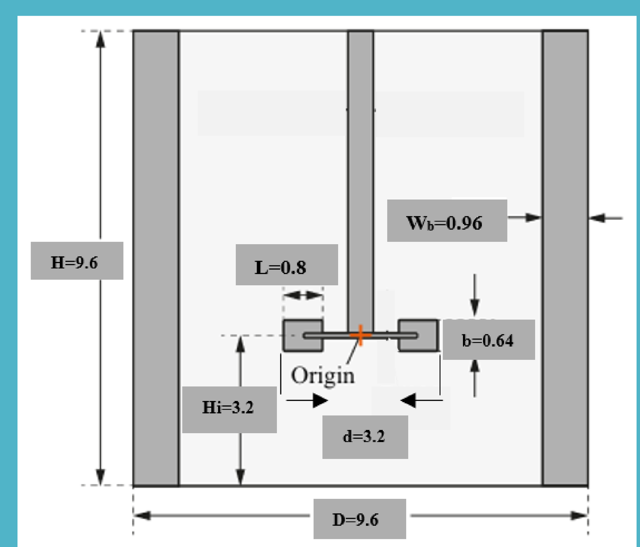


Figure 5: Dimensions of the aeration tank

## ECONOMIC STUDY

Table 4: Capital cost of the process plant

| Equipment type | Equipment code | Purchasing Cost ($) |
|---|---|---|
| Pump | P-100 | 48,700 |
| Pump | P-101 | 26,200 |
| Heat exchanger | E-100 | 851,000 |
| Aeration tank | T-100 | 859,445 |
| AGMD | D-100 | 8,456,789 |
| Media filter | F-100 | 380,000 |
| Total capital cost | | 10,622,134 |

Table 5: Utility cost of the process

| Unit type | Equipment | Utility type | Heat flow (kW)) | Heat flow (GJ/y) | Utility cost (millions $/GJ) | Annual Utility cost ( $/y) |
|---|---|---|---|---|---|---|
| Heat exchanger | E-100 | Lps | 75812.8 | 2,390,832.46 | 13.28 | 31,750,255.08 |
| Pump | P-100 | Electricity | 40.6 | 1,280.36 | 16.8 | 21,510.07 |
| Pump | P101 | Electricity | 10.5584747 4 | 332.97 | 16.8 | 5,593.93 |
| Aeration tank | T-100 | Electricity | 27.65 | 871.97 | 16.8 | 73,245.51 |
| Total | | | | | | 31,850,604.60 |

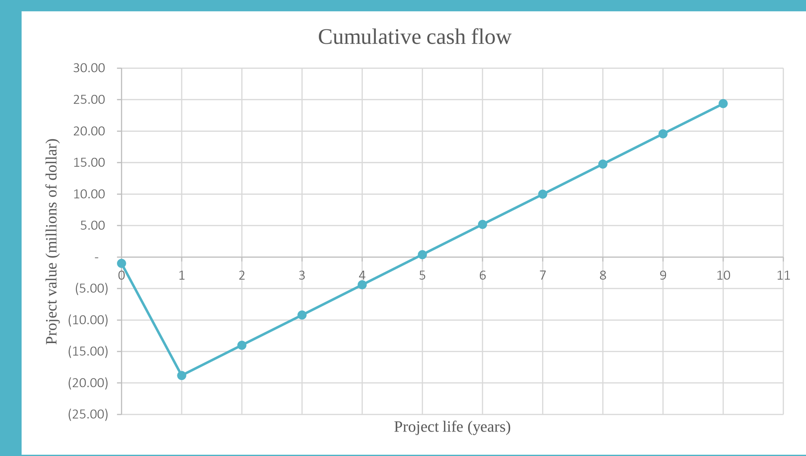


Figure 6: Cumulative cash flow diagram without working capital and land cost.

## CONCLUSION

This project demonstrates the effectiveness of using Membrane Distillation (MD) for groundwater treatment in Saudi Arabia. The findings show that MD is a viable alternative to conventional desalination methods, offering improved efficiency and reduced costs. Key results indicate effective removal of manganese ($Mn^{2+}$) and iron ($Fe^{2+}$) through oxidation and filtration, and substantial reductions in other ionic species such as sodium ($Na^+$), chloride ($Cl^-$), and sulfate ($SO_4^{2-}$). The AGMD process design achieved a required membrane area of 153,759.8 m², while the heat exchanger was optimized with a heat transfer area of 921.75 m². Economic analysis confirmed the system's viability, with profitability expected by the fifth year due to its lower operational costs. Overall, MD presents a sustainable and cost-effective solution for groundwater treatment, supporting future water management strategies in Saudi Arabia.

## ACKNOWLEDGMENTS


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