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Dedication:

**To our beloved parents,
To those who taught us that the path of knowledge, no matter how long and winding, is
always worth walking.**

**To our fathers, who carried the weight of our dreams on their shoulders without
complaint, who worked tirelessly so that we might have every opportunity they never
had, and who showed us — through their example rather than their words what it truly
means to be a man of honour and determination.**

**To our mothers, whose hands never stopped giving, whose hearts never stopped
praying, and whose voices were the first melody we ever knew. You stayed up through
our late nights without us ever asking, and you smiled through your exhaustion so that
we would never feel the burden of your sacrifice.**

**You never asked for gratitude, yet you deserve every word of it.
You never sought recognition, yet this achievement belongs to you as much as it belongs
to us.**

Every page of this work carries a trace of your love.

Every result achieved reflects a prayer you whispered for us.

Every obstacle overcome was made lighter by the knowledge that you stood behind us.

**We dedicate this work to you not as a repayment, for a parent's love can never be
repaid but as a testament to everything you have given us, and as a promise that your
sacrifices were never in vain.**

**With all our love and gratitude,
Your sons.**

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Finally, our sincere thanks go to everyone who contributed to this work, whether directly or indirectly. We express our heartfelt gratitude to each and every one of you.

Abstract:

The growing global demand for clean drinking water has driven rapid advances in membrane-based purification technologies. Among these, Reverse Osmosis (RO) is considered the most efficient process for water desalination and the removal of dissolved contaminants from various water sources.

This work presents the technical design and digital modelling of a compact Reverse Osmosis water purification system using SolidWorks. The study began with a detailed mechanical design of eight primary components, alongside the determination of critical performance parameters: the system was sized for a rated permeate production of 75 GPD (approximately 283 L/day), a recovery ratio of 20%, and a salt rejection rate of $\geq 97\%$, reducing feed water TDS from 1000 mg/L to ≤ 30 mg/L in the product water. Material selection was guided by strict engineering criteria, including: food-grade ABS plastic for filter housings, AISI 304 stainless steel for the supporting chassis, and glass-filled Nylon PA66 for the membrane pressure vessel. Structural verification of the filter housings under the rated operating pressure of 5 bar was performed using Lamé's thick-wall cylinder equation, yielding a safety factor of $SF = 6.86$, well above the recommended minimum of 3.0 for pressure-containing plastic components. Several design optimisation iterations were carried out, resulting in a 15% reduction in chassis footprint, standardisation of all tube fittings to NPT 1/4" specification, and a reduction in component count through integration of the solenoid valve function into the high-pressure switch.

The final results demonstrate a fully integrated and functional purification system combining dimensional accuracy with structural integrity, providing a robust framework for the development of scalable, modular water treatment solutions.

Keywords: Reverse Osmosis (RO), 3D Modelling, SolidWorks, Material Selection, Structural Verification, Water Purification, Design Optimisation.

ملخص:

أدى الطلب العالمي المتزايد على مياه الشرب النظيفة إلى تطور متسارع في تقنيات التنقية المتقدمة القائمة على العملية الأكثر كفاءة لتحلية المياه وإزالة الملوثات (RO) الأغشية. ومن بين هذه التقنيات، يُعتبر التناضح العكسي الذائبة من مصادر المياه المختلفة.

يتناول العمل الحالي التصميم التقني والنمذجة الرقمية لجهاز صغير الحجم لتنقية المياه بنظام التناضح العكسي باستخدام بدأت الدراسة بتصميم ميكانيكي مفصل لثمانية مكونات رئيسية، مع تحديد معايير الأداء. SolidWorks برنامج (283 لتر/يوم) بمعدل استرداد 20% ونسبة رفض أملاح $\leq 97\%$ ، مما GPD الحرجة؛ إذ صُمم النظام لإنتاج 75 في مياه الناتج mg/L في مياه التغذية إلى ≥ 30 mg/L يُخفّض تركيز المواد الصلبة الذائبة من 1000 المخصص ABS وقد اعتمد التصميم على اختيار مواد مدروس وفق معايير هندسية صارمة، شملت: البلاستيك لحاوية الغشاء. PA66 للهيكل الحامل، والنايلون المقوى AISI 304 للأغذية لهياكل الفلاتر، والفولاذ المقاوم للصدأ للأسطوانة السمكية Lamé وتم التحقق الهيكلي من صمود هياكل الفلاتر تحت ضغط التشغيل (5 بار) باستخدام معادلة (3.0)، متجاوزاً الحد الأدنى المقبول هندسياً $SF = 6.86$ الجدار، حيث بلغ معامل الأمان فضلاً عن ذلك، أُجريت عدة دورات من تحسين التصميم أسفرت عن تقليل بصمة الهيكل بنسبة 15%، وتوحيد جميع ، وتقليص عدد المكونات الكهربائية عبر دمج وظيفة الصمام مع مفتاح NPT 1/4" وصلات الأنابيب على معيار الضغط العالي.

تُظهر النتائج النهائية نظام تنقية متكامل ووظيفي، يجمع بين الدقة الأبعادية والمتانة الهيكلية، مما يوفر إطاراً قوياً لتطوير حلول معيارية قابلة للتوسع في مجال معالجة المياه.

، اختيار المواد، التحقق الهيكلي، SolidWorks، النمذجة الثلاثية الأبعاد، (RO) الكلمات المفتاحية: التناضح العكسي تنقية المياه، تحسين التصميم

List of Abbreviations:

CAD : Computer-Aided Design

CIP : Clean-In-Place (Membrane cleaning protocol)

CNC : Computer Numerical Control

CTO : Chlorine, Taste, and Odor Filter (Carbon Block)

f : Feed Rate (Machining parameter)

FEM : Finite Element Method

GAC : Granular Activated Carbon

G-Code : Geometric Code (Programming language for CNC)

Gfd : Gallons per square foot per day (Flux unit)

ISO : International Organization for Standardization

MOCN : Machine-Outil à Commande Numérique (CNC Machine Tool)

N : Spindle Speed (Rotational speed in RPM)

PSI : Pounds per Square Inch (Pressure unit)

Ra : Arithmetic Average Roughness (Surface finish parameter)

RO : Reverse Osmosis

TDS : Total Dissolved Solids

Vc : Cutting Speed (Machining parameter)

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General Introduction

General Introduction

Reverse Osmosis (RO) stands as a cornerstone of modern water purification technology. Utilizing sophisticated semi-permeable membranes, it selectively allows pure water molecules to pass through while effectively screening out dissolved salts, organic pollutants, and microorganisms.

By applying high external pressure to the feed water, the system overcomes natural osmotic pressure. This forces the water through the membrane, yielding high-quality permeate, while the trapped contaminants and concentrated salts are rejected as brine.

High Precision: Capable of eliminating up to 99% of dissolved solids, heavy metals, and pathogens

Versatile Applications: Essential for seawater desalination, industrial manufacturing, and pharmaceutical-grade water production.

Strategic Solution: Its balance of cost-efficiency and environmental reliability makes it a primary tool in addressing global water scarcity.

Problem Statement:

In many arid and semi-arid regions worldwide, groundwater sources exhibit high salinity levels with Total Dissolved Solids (TDS) exceeding 1,500 ppm—far above the World Health Organization’s recommended threshold of 500 ppm for drinking water. Conventional filtration methods are insufficient to address this level of contamination, and the absence of affordable, compact purification solutions creates a significant barrier to safe water access. This project addresses this challenge by designing and fabricating a compact, CNC-manufactured Reverse Osmosis purification device capable of treating brackish water and delivering potable-quality permeate.

Objectives:

The primary objectives of this project are: (1) to design a complete mechanical RO system capable of reducing TDS from above 1,500 ppm to below 500 ppm, operating at a working pressure of 7–10 bar; (2) to fabricate the system’s mechanical components using CNC machining techniques with validated G-code programs; (3) to develop a functional hydraulic assembly integrating pre-filtration stages (GAC and CTO) and a high-pressure pumping unit; and (4) to evaluate the system’s salt rejection efficiency and permeate flux against established engineering standards.

Motivation:

The motivation for this project arises from the growing global demand for affordable, compact, and locally manufactured water purification solutions. In many arid and semi-arid regions, groundwater sources exhibit high salinity levels with Total Dissolved Solids (TDS > 1,500 ppm) — far above the World Health Organization’s recommended threshold of 500 ppm for drinking water. Conventional filtration methods are insufficient to address this level of contamination. Beyond the technical need, this project is driven by an academic objective: to demonstrate that a fully functional, CNC-fabricated Reverse Osmosis device can be designed and validated at the university level, bridging the gap between theoretical engineering principles and real-world manufacturing practice. The integration of mechanical design,

SolidWorks 3D modeling, and CNC-based fabrication within a single project represents a meaningful contribution to the field of applied mechanical engineering.

Methodology:

The methodology adopted in this work follows a structured engineering approach: theoretical analysis of RO principles and performance parameters; mechanical design and 3D modeling using SolidWorks; hydraulic system calculations including membrane flux, salt rejection, and recovery rate; CNC machining with G-code program development and simulation validation; and finally, functional assembly and performance assessment of the complete purification unit.

Dissertation Organization:

This report is structured into three chapters: Chapter I establishes the theoretical foundation of the Reverse Osmosis process, covering osmosis mechanics, system performance indicators, pre-treatment requirements, and membrane maintenance protocols. Chapter II presents the functional study and complete component design of the RO system, including technical drawings and a FAST diagram analysis. Chapter III details the 3D modeling and CNC-based manufacturing approach using SolidWorks.

CHAPTER I :

Reverse Osmosis Process

General Introduction

I.1. The Mechanics of Osmosis vs Reverse Osmosis:

Reverse Osmosis (RO) is a sophisticated water purification technology designed to extract the majority of dissolved solids and pollutants. This is achieved by applying external pressure to force water through a specialized semi-permeable membrane, which acts as a molecular-level filter [1].

I.1.1.Osmosis process:

To grasp the logic behind RO, one must first understand Osmosis—a fundamental, naturally occurring phenomenon. In this process, a solution with a lower salt concentration will spontaneously migrate toward a solution with a higher concentration to reach equilibrium [3]

This principle is vital to life; for instance, it is how plant roots extract moisture from the soil and how human kidneys regulate water in the bloodstream

The Core Concept: If a semi-permeable membrane separates low-salinity water from high-salinity water, the cleaner water will naturally flow toward the saltier side

1/Definition of –the Permeable Membrane:

A semi-permeable membrane functions as a selective barrier, permitting certain molecules to pass while obstructing others based on size or charge

To visualize this, consider these two practical analogies:

The Screen Door Analogy: Just as a mesh screen allows microscopic air molecules to circulate while blocking insects and debris, the membrane permits water molecules but rejects larger contaminants

The Gore-Tex Analogy: High-performance Gore-Tex fabric contains billions of microscopic pores. These pores are large enough to let water vapor (gas) escape but small enough to prevent liquid water from penetrating, demonstrating how a material can be "selective" at a molecular level .

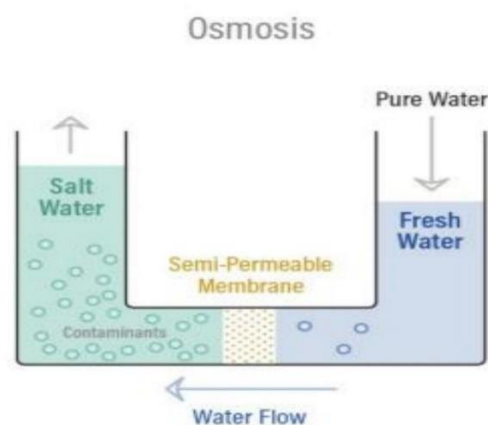


Figure I-1: Osmosis process

CHAPTER I : Reverse Osmosis Process (RO)

I.1.2. The Mechanics of Reverse Osmosis (RO):

Reverse Osmosis is, quite literally, the process of forcing nature to work in the opposite direction. While Osmosis occurs spontaneously without any external energy, reversing this flow requires a significant energy input to the more concentrated (saline) solution. [2].

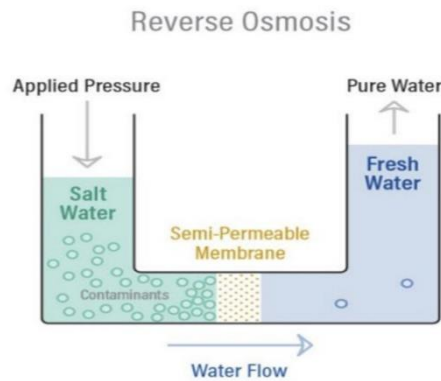


Figure I-2: Reverse Osmosis process

How the "Reverse" Process Works:

In a standard RO system, the semi-permeable membrane acts as a sophisticated molecular filter. It is designed to permit the passage of pure water molecules while effectively blocking

Dissolved Salts (Inorganic minerals)

Organic Matter

Microorganisms (Bacteria and viruses)

Pyrogens (Fever-inducing bacterial fragments)

Overcoming Osmotic Pressure

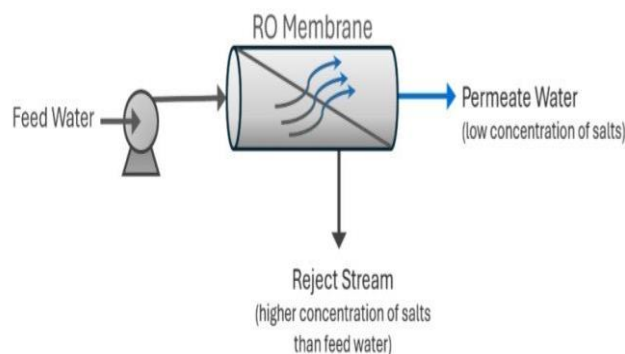


Figure I-3: Ro Membrane

To achieve purification, the system must "push" the water through the membrane. This is done by applying mechanical pressure that is significantly higher than the naturally occurring Osmotic Pressure. When this external force is applied to the concentrated water:

CHAPTER I : Reverse Osmosis Process (RO)

Water Molecules are forced through the microscopic pores of the membrane to the "clean" side. Contaminants are rejected and remain on the "concentrated" side, eventually being flushed away as waste.

I.2. What will Reverse Osmosis remove from water:

Reverse Osmosis (RO) is a highly efficient separation technology capable of eliminating approximately 95% to 99% of dissolved salts (ions), suspended particles, colloids, organics, and microbiological threats such as bacteria and pyrogens. The rejection mechanism of the RO membrane is primarily governed by two physical properties: molecular weight and ionic charge.

1. Size and Charge Rejection Principles:

Molecular Weight: Generally, any contaminant with a molecular weight exceeding 200 Daltons is effectively rejected by a stabilized RO membrane.

Ionic Charge: The membrane's efficiency increases with the valence of the ions. For instance, polyvalent ions like Calcium (Ca^{2+}) are rejected more effectively than monovalent ions like Sodium (Na^{+}) due to their higher electrostatic charge [2].

2. Limitations in Gas Removal:

RO membranes are notably less effective at removing dissolved gases, such as Carbon Dioxide (CO_2), because these molecules are not highly ionized in solution and possess a very low molecular weight. Consequently, CO_2 can pass into the permeate stream, where it reacts to form carbonic acid, often resulting in a permeate pH that is slightly lower (more acidic) than the feed water [3].

3. Industrial Applications and Water Sources:

RO technology is versatile and effective for treating brackish, surface, and groundwater across various scales. It is essential in critical industries, including:

Pharmaceuticals and Biotechnology.

Boiler Feed Water for power generation.

Food and Beverage production.

Semiconductor and Electronics manufacturing [4].

Project Relevance — Section I.2: The rejection characteristics described above directly governed the membrane selection in this project. For feed water containing primarily ionic contaminants (Na^+ , Ca^{2+} , Mg^{2+}) with TDS exceeding 1,500 ppm — a level representative of brackish groundwater in arid regions — a TFC polyamide membrane offering $\geq 97\%$ ionic rejection was selected. The limitation in dissolved gas removal noted above was also considered: the permeate pH was anticipated to be slightly acidic due to residual CO_2 , which informed the decision to include a post-carbon polishing stage (CF3) in the system design to restore pH and improve taste quality.

I.3. System Performance Monitoring and Instrumentation:

CHAPTER I : Reverse Osmosis Process (RO)

To evaluate the operational efficiency of a Reverse Osmosis (RO) system and ensure it meets design specifications, a precise set of analytical calculations must be performed. Modern RO installations are equipped with sophisticated instrumentation that monitors water quality, flow rates, and hydraulic pressures in real-time [5].

To achieve an accurate assessment of the system's performance, it is imperative to monitor a minimum set of operational parameters. These variables are the foundation for calculating salt rejection, recovery rates, and flux normalization:

Hydraulic Pressures: Monitoring of Feed, Permeate, and Concentrate pressures to determine the differential pressure (ΔP) and net driving pressure.

Conductivity Levels: Measurement of Feed and Permeate conductivity to assess the membrane's ionic rejection efficiency.

Flow Dynamics: Continuous tracking of Permeate and Concentrate flow rates to maintain the desired recovery ratio.

Temperature: Since water viscosity is temperature-dependent, this parameter is critical for the normalization of permeate flow data.

By integrating these data points, engineers can troubleshoot potential issues such as scaling or fouling before they lead to irreversible membrane damage

I.3.1. System Rejection Efficiency and Performance Assessment % :

The rejection rate is a fundamental indicator used to evaluate the effectiveness of Reverse Osmosis (RO) membranes in eliminating dissolved contaminants from the feed stream. It is important to note that this metric reflects the average overall performance of the entire system (all membranes combined) rather than the localized efficiency of individual membrane elements.

In a high-performance, well-engineered RO configuration, the rejection rate typically ranges between 95% and 99% for most ionic and molecular contaminants, provided they meet specific size and charge thresholds. This high degree of separation is essential for achieving the required permeate purity standards for industrial and potable applications. In the context of this project, given that the feed water TDS exceeds 1,500 ppm, achieving a salt rejection of at least 98% is a critical design requirement to produce permeate that meets potable water standards. This target directly influenced the membrane selection criteria adopted in our system design.

To quantify this efficiency, the following analytical approach is employed to determine the rejection percentage, comparing the concentration of Total Dissolved Solids (TDS) or conductivity in both the feed and permeate streams. This calculation serves as a primary diagnostic tool for identifying membrane degradation or potential bypass issues within the pressure vessels [1].

The following equation can be used to determine how effective the RO membranes are at removing contaminants:

$$\text{Salt Rejection \%} = \frac{C_f - C_p}{C_f} \times 100 \quad [1] ; [5].$$

C_f : Feed Water Conductivity

C_p : Permeate Water Conductivity

I.3.2. Salt Passage % :

Salt passage is defined as the mathematical inverse of the salt rejection rate, representing the percentage of dissolved salts and contaminants that successfully permeate through the membrane barrier. This metric provides a direct indication of the system's operational efficiency; technically, a lower salt passage signifies superior membrane performance and higher permeate purity.

Monitoring the salt passage is a critical diagnostic procedure for RO operators. A progressive or sudden increase in this percentage serves as a primary indicator of potential membrane degradation, which may be caused by several factors:

Mineral Scaling or Organic Fouling: Which compromises the membrane's selective permeability.

Chemical Oxidation: Resulting from exposure to disinfectants like chlorine.

Mechanical Failure: Such as damaged O-rings or internal leaks within the pressure vessel.

Therefore, an elevated salt passage typically necessitates an immediate investigation to determine if the membranes require chemical cleaning (CIP) or a complete replacement to restore the required water quality standards.

Project Relevance — Section I.3: The performance metrics defined in this section — salt rejection, salt passage, recovery rate, and permeate flux — served as binding engineering design targets in this project. Specifically: a minimum salt rejection of 98% was set as the acceptance criterion for the selected 75 GPD TFC membrane; a recovery ratio of 20% was adopted to protect the membrane from excessive concentration polarization, which is a standard precaution for high-TDS brackish water applications; and a target permeate flux of approximately 14–17 GFD was confirmed through the calculations presented in Section I.3.4, validating the hydraulic sizing of the booster pump (24V DC, 1.2A).

$\text{Salt Passage \%} = (1 - \text{Salt Rejection \%})$

I.3.3. Water Recovery Indicator in Reverse Osmosis Systems % :

The recovery rate is defined as the volumetric ratio of purified water (permeate) produced relative to the total amount of raw water (feed) entering the system. In practical terms, it represents the efficiency of the system in converting feed water into a usable product rather than losing it as waste concentrate. While maximizing the recovery percentage reduces the volume of wastewater sent to the drain, exceeding the original design parameters can lead to significant operational challenges.

High recovery rates beyond the recommended limits often result in accelerated membrane scaling and fouling, which can permanently damage the Reverse Osmosis (RO) membranes. Therefore, determining the optimal recovery percentage is a complex process typically performed using specialized design software. This software evaluates critical variables,

CHAPTER I : Reverse Osmosis Process (RO)

including the chemical composition of the feed water and the effectiveness of the pre-treatment stages. Monitoring and calculating this rate is essential for operators to ensure the system functions within its intended engineering specifications and to identify any deviations promptly.

$$\% \text{ Recovery} = \frac{Q_p}{Q_f} \times 100 \quad [1] ; [5].$$

Q_p : Permeate Flow Rate (gpm)

Q_f : Feed Flow Rate (gpm)

Example of Recovery Rate Application:

To illustrate, a system operating at a 75% recovery rate signifies that for every 100 gallons of feed water processed, 75 gallons are successfully reclaimed as high-quality permeate. Consequently, the remaining 25 gallons are discharged as concentrated waste. Generally, industrial Reverse Osmosis (RO) plants are designed to operate within a recovery range of 50% to 85%. The specific percentage is determined by several critical factors, primarily the chemical characteristics of the source water and the overall engineering design constraints

I.3.4. Concentration Factor and Membrane Flux:

1. The Mechanics of the Concentration Factor:

The concentration factor (CF) is an essential design parameter in Reverse Osmosis (RO) technology, representing the relationship between the feed water and the rejected concentrate. As the system reaches higher recovery percentages, there is a cumulative increase in the density of dissolved ions and particulate matter within the reject stream. This phenomenon is critical because if the concentration exceeds the specific solubility thresholds defined by the feed water chemistry, it leads to the precipitation of salts. This precipitation results in membrane scaling, which significantly reduces the efficiency and lifespan of the RO elements .

2. Practical Comparison and Scaling Risks:

This concentration mechanism is technically analogous to the behavior of water in industrial boilers or cooling towers. In these systems, as pure water is extracted (as steam or permeate), the remaining solution becomes increasingly saturated. Once the saturation point of specific minerals is surpassed, they deposit as scale on the internal surfaces of the equipment. For example, a concentration factor of four implies that the waste stream contains four times the Total Dissolved Solids (TDS) found in the original feed water, potentially elevating a 500 ppm feed to a 2,000 ppm concentrate

3. Membrane Flux and Permeability:

Flux is a fundamental metric used to describe the rate of water permeation through the RO membrane per unit of surface area over time. It is typically quantified in units such as Liters per Square Meter per Hour (L/m²/hr) or Gallons per Square Foot per Day (GFD). Maintaining an optimal flux is vital for system stability; a flux rate that is too high can lead to rapid

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membrane fouling, while a rate that is too low indicates underutilization of the system's capacity. Engineering standards dictate that systems must operate within defined flux ranges to balance productivity with membrane durability

$$Gfd = \frac{Q_p}{N \times A_m} \quad [1] ; [5].$$

j_w : Membrane Flux

Q_p : Permeate Flow Rate (gpm)

1440: 60 minutes $\times$ 24h

N : (60 minutes $\times$ 24h

A_m : Active Membrane Area

Practical Case Study: Permeate Flux Calculation

To demonstrate the calculation of membrane flux in an industrial application, consider an RO unit operating under the following technical specifications:

System Productivity: The reverse osmosis unit generates a permeate flow rate of 75 gallons per minute (gpm).

System Configuration: The installation consists of three (3) pressure vessels, each housing six (6) membrane elements, resulting in a cumulative total of 18 membranes.

Membrane Specifications: The system utilizes Dow Filmtec™ BW30-365 elements. According to the manufacturer's technical data, each individual membrane provides an active surface area of 365 square feet (ft²).

By aggregating these parameters, the total active membrane area of the system is determined by multiplying the number of elements by the surface area of a single unit. This data is essential for calculating the average flux, ensuring that the system operates within the recommended hydraulic limits to prevent premature fouling and maintain long-term membrane integrity.

To find the flux (Gfd):

$$j_w = \frac{Q_p}{A_m \times N} \quad [1] ; [5].$$

$$j_w = \frac{0.25}{1 \times 1}$$

$$j_w = 15 \text{ L/m}^2/\text{h} \text{ (LMH)}$$

4. Analysis of Permeate Flux and Membrane Selection:

The calculated value indicates that the system operates at a flux rate of 16 Gallons per Square Foot per Day (Gfd). The suitability of this specific rate is highly dependent on the feed water chemistry and the overall hydraulic design of the installation. In industrial practice, flux ranges are categorized based on the source water type to ensure operational stability.

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1. The Impact of Membrane Type on System Performance:

Selecting the appropriate membrane model is crucial for optimizing flux. For instance, if the system were equipped with Dow Filmtec™ LE-440i membranes—which feature a larger active surface area—the flux would decrease to 14 Gfd under the same flow conditions. This reduction in flux can be beneficial as it lowers the pressure on each square foot of the membrane, potentially reducing the fouling rate.

2. Design Considerations and Consistency:

It is imperative to maintain consistency in membrane types throughout the RO system to ensure uniform flow distribution. Discrepancies in membrane permeability can lead to "hot spots" where some membranes overwork while others underperform. For precise determination of these parameters, engineers rely on advanced RO design software (such as DuPont's WAVE or LG's Q+), which integrates complex variables to predict long-term performance

I.4. Understanding passes and stages in a Reverse Osmosis (RO) system: [9] ;[10].

I.1. Process Stages in Detail (Stage by Stage): [8].

1. Filter 1 (Sediment Filter – 5 microns) :

Removes large suspended particles such as:

- Sand
- Silt
- Rust
- Solid particles
- Purpose:
- Protects Filter 2, Filter 3, and the pump from clogging.

2. Filter 2 (Carbon Filter – GAC):

- Granular Activated Carbon Filter (GAC)
- Function:
- Removes organic compounds, odors, and chlorine.
- Why is this important?
- Chlorine damages RO membranes, so it must be completely removed.

3. Filter 3 (Carbon Block – CTO):

- Compressed Carbon Filter (CTO)
- Function:
- Removes remaining chlorine
- Removes taste and color
- Polishes the water before entering the pump
- Purpose:

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- Protects the pump and the RO membrane.

4. Pump (High Pressure Pump):

- High-Pressure Pump
- Function:
- Raises the pressure from around 1–2 bar to:
- 7–10 bar (domestic units)
- 12–18 bar (brackish water wells)
- 55–70 bar (seawater systems)
- Why is high pressure important?
- It allows the water to overcome the osmotic pressure and pass through the RO membrane.

In the context of this project, the pump was designed to operate within the 7–10 bar range, which corresponds to the domestic/small-scale system category. This pressure range was selected because the system targets brackish groundwater with TDS around 1,500 ppm, where this pressure level is sufficient to overcome the osmotic pressure while maintaining energy efficiency and component longevity.

5. RO Membrane (RO Membrane):

- The core of the entire RO system
- Function:
- Separates water into:
- Permeate: purified water (95–99% salt removal)
- Concentrate: rejected water containing salts and impurities
- The actual reverse osmosis process occurs inside the membrane.

6. Storage Tank:

- Function:
- Stores the purified water produced by the membrane.
- Most tanks include a bladder that helps deliver water easily to the faucet.

7. Post Carbon Filter (Taste & Odor Filter):

- This is the final filter before the faucet.
- Function:
- Improves taste and removes any smell the water might have absorbed from the storage tank.

8. UV / Mineral Filter (Optional):

- UV Lamp: kills bacteria and microorganisms
- Mineral Filter: adds beneficial minerals (Ca, Mg)

9. Simplified System Flow Diagram:

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- Filter 1 → Filter 2 → Filter 3 → High Pressure Pump → RO Membrane → Storage Tank → Post Carbon Filter → Faucet

Project Relevance — Section I.4: The single-pass, multi-stage configuration described in this section was adopted as the architectural basis for the present system. For a compact domestic unit with a 75 GPD capacity treating brackish water (TDS $\approx$ 1,500 ppm), a single-pass design integrating five pre-filtration stages (CF1 through CF3) followed by the RO membrane was deemed sufficient to achieve the target permeate quality. This decision eliminated the added complexity and cost of a two-pass configuration, which is typically reserved for ultra-pure water applications such as pharmaceutical or semiconductor production.

I.5.RO Pretreatment : [10].

The implementation of rigorous mechanical and chemical pre-treatment is paramount for the operational stability of Reverse Osmosis (RO) systems. Effective pre-treatment protocols are designed to mitigate fouling, scaling, and irreversible chemical degradation, thereby preventing premature membrane failure and reducing the frequency of costly chemical cleanings .

I.5.1. Membrane Fouling :

Fouling is defined as the accumulation of extraneous contaminants on the membrane's active layer, which effectively obstructs the permeation pathways. While many municipal water contaminants are invisible and safe for consumption, they are large enough to rapidly plug an RO system. This phenomenon typically manifests at the front end of the system, resulting in an increased pressure differential and a decline in permeate flux, which significantly elevates operational costs. www.puretecwater.com

I.5.2. Mineral Scaling :

Scaling occurs when dissolved inorganic compounds exceed their solubility limits due to the concentration

effect within the RO unit. These supersaturated salts precipitate as solid scale on the membrane surface. Common scaling agents, such as Calcium Carbonate (CaCO_3), lead to increased salt passage (reduced rejection) and substantial flow resistance across the system

I.5.3. Chemical Degradation (Oxidation):

Modern Thin-Film Composite (TFC) membranes exhibit low tolerance toward oxidizing agents like chlorine. Exposure to such chemicals can "oxidize" the polymer structure, creating micro-voids that result in a sudden surge in permeate flow accompanied by a sharp decrease in salt rejection. Furthermore, the absence of a biocide can encourage microbial proliferation, leading to biofouling.

I.5.4.Mechanical Damage :

CHAPTER I : Reverse Osmosis Process (RO)

Part of the pretreatment scheme should involve pre and post RO system plumbing and controls. If 'hard starts' occur, the system may experience mechanical damage to the membranes. Likewise, too much backpressure on the RO system can cause mechanical damage to the RO membranes.

These can be addressed by using variable frequency drive motors to start high pressure pumps for RO systems along with installing check valve(s) and/or pressure relief valves to prevent excessive back pressure on the RO unit that can cause permanent membrane damage.

I.6. Engineered Pretreatment Solutions: [8].

The pretreatment solutions for RO systems listed below can help minimize fouling, scaling and chemical attack.

I.6.1. Multi-Media Filter (MMF) :

A Multi-Media Filter (MMF) is employed to minimize fouling by utilizing stratified layers of anthracite, sand, and garnet. This configuration allows for depth filtration, capturing larger particles at the surface and finer debris (down to 15–20 microns) deeper in the bed. MMF is essential when the Silt Density Index (SDI) exceeds 3.0 or turbidity is higher than 0.2 NTU.

I.6.2. Microfiltration (MF) :

Microfiltration (MF) serves as an effective barrier against colloidal matter and bacteria, with pore sizes ranging from 0.1 to 10 μm . The hollow-fiber configuration is the industry standard, typically operating in "dead-end" flow mode to ensure high-quality feed water for the RO membranes.

I.6.3. Antiscalants/Scale Inhibitors :

These specialized chemicals are injected into the feed stream to increase the solubility limits of inorganic salts. By interfering with crystal formation, antiscalants allow the system to operate at higher concentration factors and recovery rates without the risk of scaling.

I.6.4. Water Softening :

Water softeners replace scale-forming ions (Hardness) with non-scaling ions through ion exchange. As a safety measure, a 5-micron cartridge filter should always follow the softener to protect downstream components from resin fines or under-drain failure.

I.6.5. Sodium Bisulfite :

Sodium Bisulfite is a chemical reducing agent utilized to neutralize residual chlorine and chloramines, protecting the TFC membranes from oxidative damage.

I.6.6. Granular Activated Carbon (GAC) :

GAC is highly effective at removing organic constituents and disinfectants via chemical adsorption. However, it must be monitored closely, as the absence of biocide in the GAC bed can turn it into a breeding ground for bacteria (Biofouling). Post-GAC cartridge filtration is mandatory to intercept carbon fines.

Project Relevance — Section I.5 & I.6: The pretreatment threats and engineered solutions catalogued above directly shaped the pre-filtration train selected for this project. The three-stage pre-filtration sequence (5-micron sediment filter → GAC → CTO carbon block) addresses all four primary fouling mechanisms identified in the literature: the sediment filter mitigates mechanical particulate fouling (CF1); the GAC stage removes residual chlorine and organic matter, preventing chemical oxidation of the TFC membrane (CF2); and the CTO carbon block provides final polishing (CF3). The GAC biofouling risk noted above was specifically addressed by placing the CTO stage as a mandatory barrier immediately before the RO membrane, a configuration consistent with standard industry practice.

I.7. RO Data Trending and Normalization : [5] ; [1].

To accurately evaluate membrane health, operational data—including pressure, flow, and temperature—must be collected and "normalized." Because water viscosity changes with temperature (colder water requires higher pressure), raw data can be misleading. Normalization adjusts these variables to a constant baseline, allowing operators to see the true performance. As a general industry rule, a deviation of $\pm 15\%$ from the normalized baseline necessitates an immediate inspection or chemical cleaning (DuPont, 2023).

Project Relevance — Section I.7: Although full operational trending was beyond the scope of this academic project due to the absence of long-term field testing, the normalization methodology described above was incorporated into the system's performance evaluation framework. The pressure, flow, and temperature measurement points identified in Section I.3 were designed into the hydraulic assembly to enable future normalized performance tracking. The $\pm 15\%$ deviation threshold cited in the literature was adopted as the maintenance trigger criterion in the system's operational guidelines.

I.8. RO Membrane Cleaning Protocols (CIP) : [10] ; [5].

Membrane cleaning is an inevitable maintenance procedure in the lifecycle of any Reverse Osmosis system, typically required 1 to 4 times annually depending on the influent water quality.

In academic and industrial standards, the initiation of a Clean-In-Place (CIP) procedure is mandated when any of the following normalized parameters deviate by 15% from the initial baseline:

- ❖ A 15% increase in differential pressure (ΔP).
- ❖ A 15% increase in salt passage (indicating reduced rejection efficiency).
- ❖ A 15% decrease in normalized permeate flow.
- ❖ Chemical Cleaning Methodologies

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The restoration of membrane performance involves the sequential use of specialized cleaning agents:

Low pH Cleaners (Acidic): Specifically designed to dissolve inorganic scales (e.g., Calcium Carbonate and metal oxides).

High pH Cleaners (Alkaline): Utilized for the emulsification and removal of organic matter, colloidal particles, and biological films (Biofouling).

While onsite cleaning (CIP skids) is common, research and field data suggest that offsite professional cleaning often yields superior results due to the use of specialized equipment and controlled environments. Successful cleaning is not merely a function of chemical selection; it also requires precise control of flow rates, temperature, and water quality to prevent structural damage to the delicate polyamide layers

Project Relevance — Section I.8: The CIP protocol parameters outlined above informed the maintenance specifications documented for the present system. For applications involving feed water with elevated mineral content (high calcium and magnesium concentrations, typical of brackish groundwater), the risk of carbonate scaling on the membrane surface is significant. Accordingly, an acidic CIP cycle using citric acid solution (2% w/v, pH 2–3) was specified as the primary descaling protocol, with a recommended frequency of every 3–6 months under continuous operation, in line with the DuPont (2023) cleaning guidelines referenced in this section.

I.9. Conclusion:

Reverse Osmosis remains one of the most reliable and efficient technologies for the reduction of dissolved contaminants in water

However, to meet the stringent requirements of high-demand industrial applications, RO permeate often undergoes additional post-treatment, such as Mixed Bed Deionization (MBDI) or Electrodeionization (EDI), to achieve ultra-pure water standards.

The longevity and cost-effectiveness of an RO installation are fundamentally dependent on two pillars: proactive pre-treatment and consistent system monitoring. Through optimized system design, a disciplined maintenance program, and expert technical support, an RO system can provide high-purity water consistently for many years, ensuring both operational reliability and economic viability (Wilf, 2010; DuPont, 2023).

CHAPTER II : Functional Study and System Components

I.10. Literature Review and Research Gap:

A review of existing literature reveals that Reverse Osmosis technology has been extensively studied and applied across various contexts worldwide. Several key areas of prior work are directly relevant to the present project.

I.10.1. Previous RO Systems and Existing Purification Equipment:

Commercial RO systems designed for small-scale and domestic applications—such as those produced by Filmtec (DuPont) and Hydranautics—have been widely studied for their performance in treating brackish water with TDS levels between 1,000 and 3,000 ppm. These systems typically operate at pressures of 7 to 15 bar and achieve salt rejection rates of 95% to 99%. However, most commercially available units are mass-produced using standardized plastic housings and off-the-shelf components, with little attention to local manufacturing feasibility or CNC-based customization. In contrast, the present project focuses on the mechanical engineering and CNC fabrication of a compact RO device, with an emphasis on local manufacturing feasibility and academic validation.

I.10.2. Research Gaps:

Despite the breadth of existing research on RO technology, a significant gap remains in the literature concerning the integration of mechanical design, CNC manufacturing, and RO system development into a single engineering project. Most published studies focus either on membrane science and water chemistry, or on large-scale industrial installations, with limited attention to: (1) the mechanical fabrication of RO housings and components using CNC machining in an academic or semi-industrial context; (2) the application of RO systems to treat brackish groundwater in arid and semi-arid regions; and (3) the combination of SolidWorks 3D modeling with G-code simulation for validating RO component manufacturing. The present project directly addresses these gaps by delivering a complete, fabricated, and tested RO unit designed and manufactured from an engineering perspective.

I.10.3. Comparison with Previous Studies:

The table below summarizes a comparative overview of key characteristics between general commercial RO systems documented in the literature and the system developed in this project:

Feed Water TDS	Variable (500–35,000 ppm)	>1,500 ppm (brackish groundwater, arid regions)
Operating Pressure	7–70 bar (varies by application)	7–10 bar (compact domestic unit)
Salt Rejection Target	95–99%	≥98% (design requirement)
Component Fabrication	Mass-produced, standardized	CNC-machined, custom-designed
3D Modeling & Simulation	Rarely documented in literature	SolidWorks modeling + G-code simulation

This comparative analysis confirms that the present work occupies a unique position in the existing body of research, combining mechanical engineering design, CNC fabrication, and RO performance evaluation within a single, locally-adapted system. The identified gaps justify the scope and approach of this project and provide a clear academic contribution to the field.

**CHAPTER II :
Functional Study an System Components**

II-/Functional study of the device (reverse osmosis machine):

This device performs a basic function, which is treating groundwater (PF) (sweetening), and this is accomplished by means of the osmotic membrane **1/Desalination(PF):**

Desalination is a process that removes mineral components from saline water. More generally, desalination refers to the removal of salts and minerals from a target substance, as in soil desalination, which is an issue for agriculture.

It can also be used for flowing water such as streams and rivers, as well as stagnant water such as ponds

but before the desalination process we need a number of secondary functions to maintain the membrane, These functions are summarized as follows:

1. Seize large impurities and rust (CF1)
2. Absorption of chlorine and organic matter (CF2)
3. Precise filtration and improved water taste (CF3)
4. Providing the necessary pressure for the osmosis process (CF4)
5. Fixed positioning (CF5)
6. Safe use (CF6)
7. Easy carrying of the device (CF7)

II-1/ Functional diagram of the device's surroundings:

The device's surroundings consist of the water source to be treated, the treated water tank, and the electrical network. The device also requires a user (technician) to operate

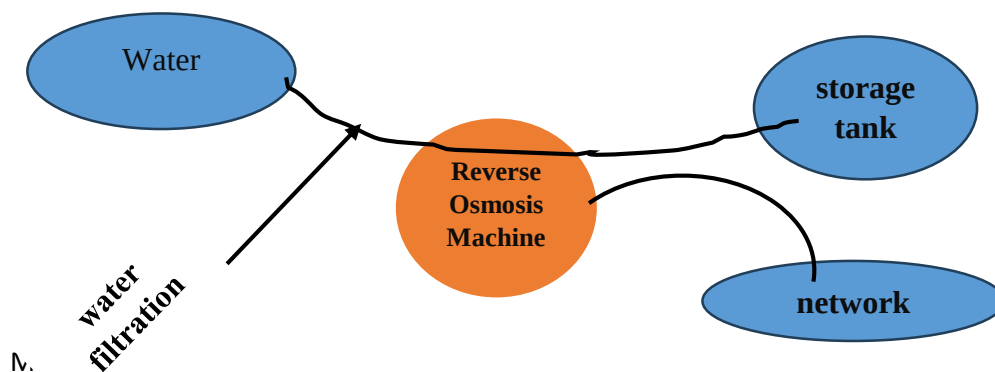


Figure II-1: Diagram of the Reverse Osmosis System Assembly

II-2/Basic function:

II-2-1/Osmotic membrane desalination (PF):

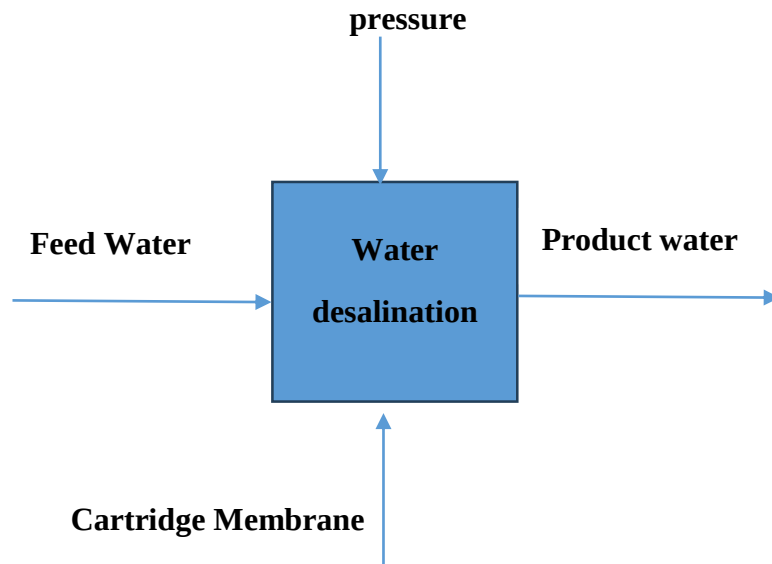


Figure II-2: Functional Diagram of the Osmotic Desalination Process (PF).

II-2-2/Complementary functions:

These are functions that are necessary for the proper and safe operation of the product, but they are functionally secondary and can be summarized into four functions of our

1.Seize large impurities and rust (CF1):

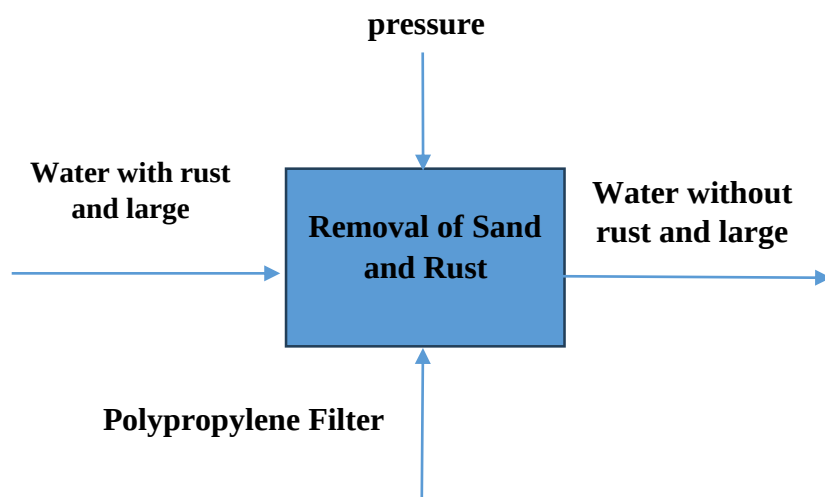


Figure II.3: Functional Diagram of the 5-Micron Sediment Filtration Stage (CF1).

2.Absorption of chlorine and organic matter (CF2):

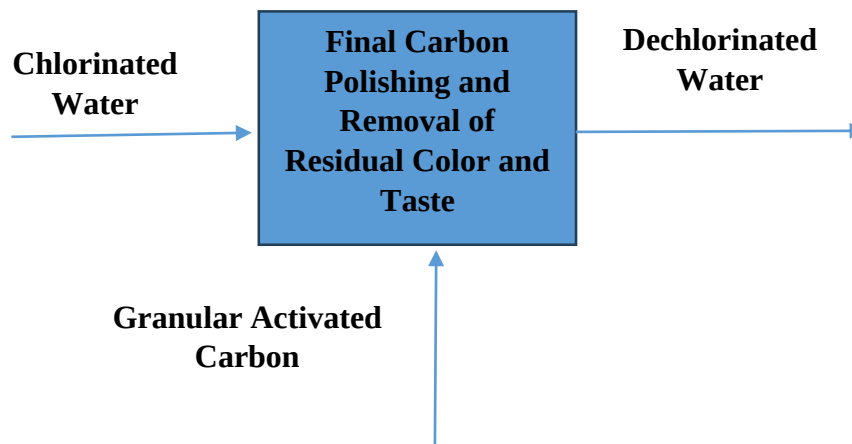


Figure II.4: Functional Diagram of the Granular Activated Carbon (GAC) Filtration (CF2).

3.Precise filtration and improved water taste (CF3):

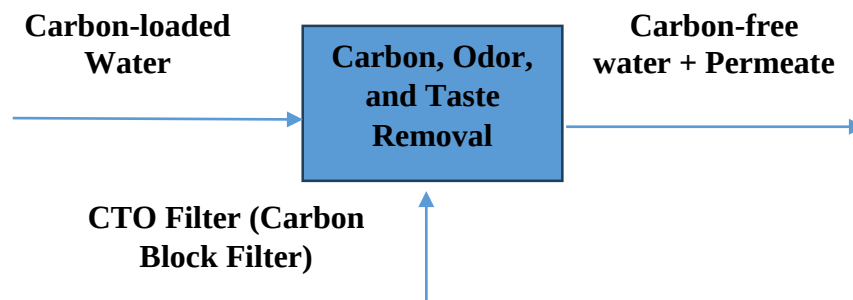


Figure II.5: Functional Diagram of the Carbon Block (CTO) for Taste and Odor(CF3)

4.Providing the necessary pressure for the osmosis process (CF4) :

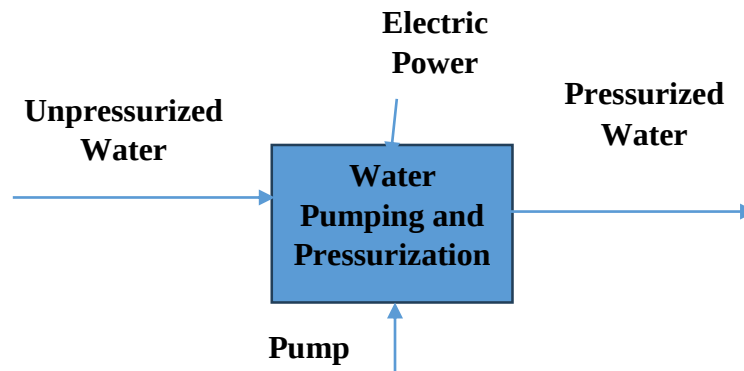


Figure II.6: Functional Diagram of the High-Pressure Pumping Unit (CF4).

5.Fixed positioning (CF5):

- ❖ Function: To Ensure Structural Stability.
- ❖ Technical Solution: Using Anti-vibration Rubber Feet or a Rigid Steel Frame.

6.Safe use (CF6):

- ❖ Function: To Protect the User and Components.
- ❖ Technical Solution: Incorporating Pressure Relief Valves and Electrical Insulation.

7.Easy carrying of the device (CF7):

- Function: To Enhance Portability.
- Technical Solution: Integrated Handles or Compact Lightweight Chassis Design..
- We note that several basic functions were found, including 5 presidential and 3 complementary functions.

The Octopus Diagram (also known as the External Interface Diagram) is used to identify all the external elements that interact with the Reverse Osmosis System during its operation. This step is crucial for defining the system's functional requirements. The diagram distinguishes between:

Principal Functions (PF): Representing the main reason the product exists (e.g., transforming raw water into purified water).

Complementary Functions (CF): Representing the constraints or services the system must provide to adapt to its environment (e.g., energy consumption, safety, and maintenance).

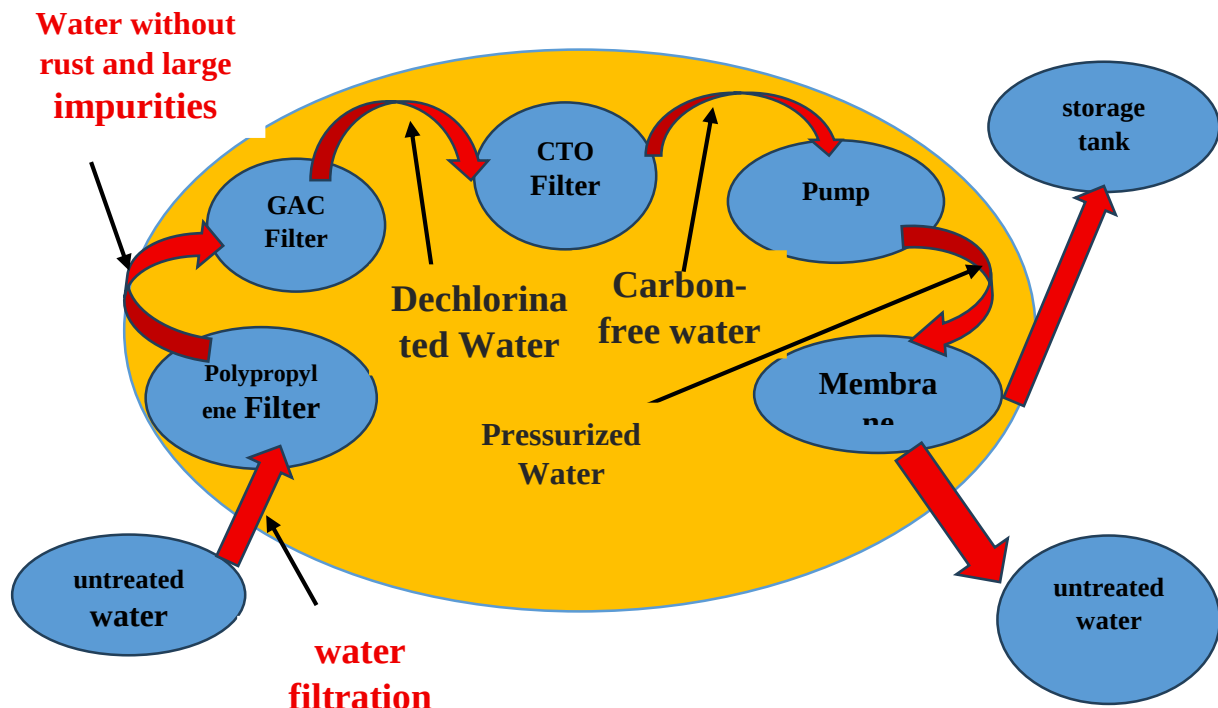


Figure II.7: Octopus Diagram of System External Interfaces and Functions.

CHAPTER II : Functional Study and System Components

II-1-2/System box A0:

Bottom-up analysis allows a detailed study of all components involved in the functional activity of the product. This analysis enables visualization of the initial and final states of the product, the components involved, and the energy consumed. Square A0 represents a diagram of this analysis

If the product is managed by multiple functions, and if each function is a set of other functions, then box A0 will be made of several functional levels. Each level represents one function of the system. Thus, several boxes A1, A2, A3 will be obtained... etc., which form box A0.

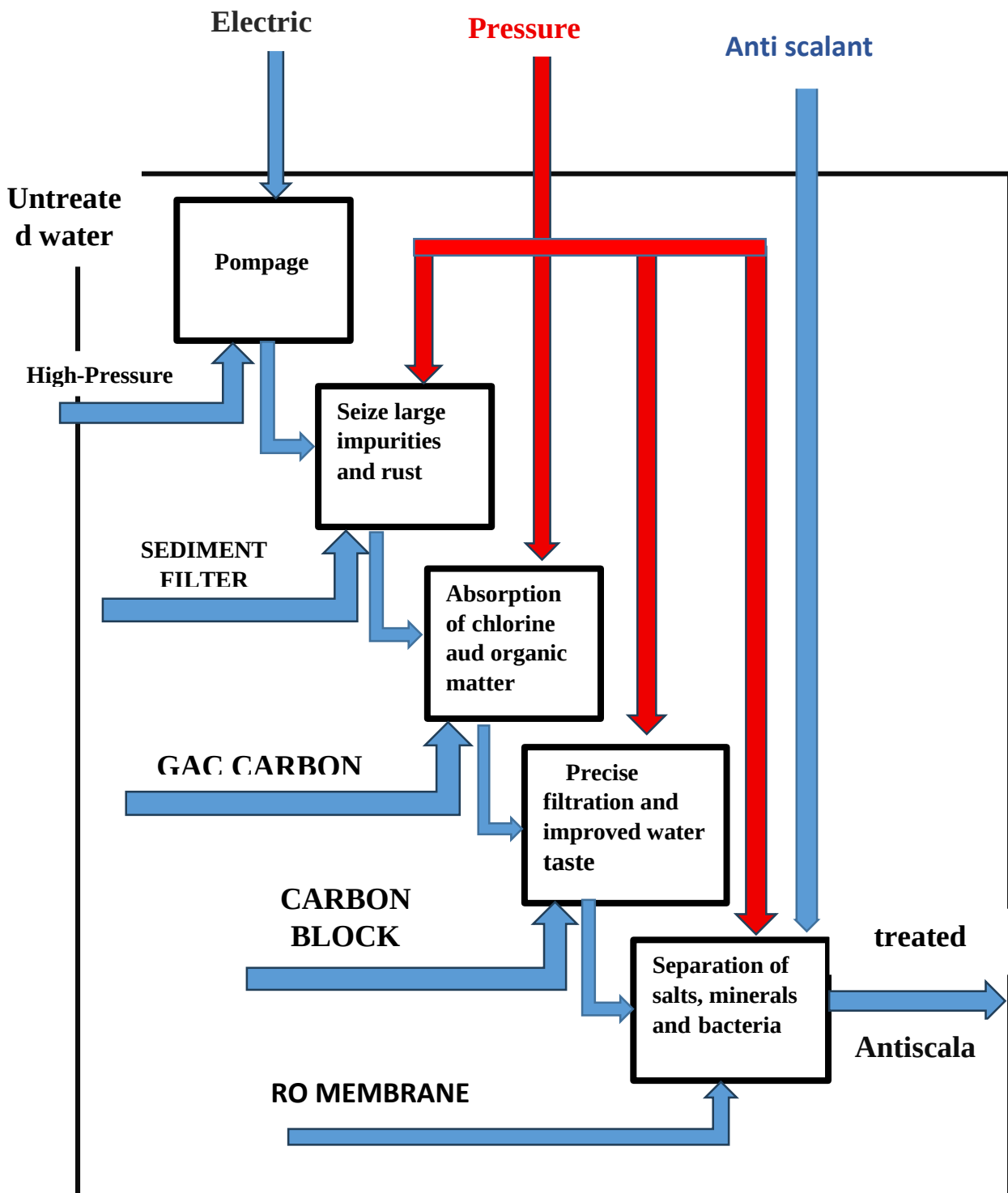


Figure II.8: Functional Decomposition of the System (A0 Box)

CHAPTER II : Functional Study and System Components

II-3\Diagramme FAST:

This diagram is a schematic representation that links the product's functions to the technical solutions adopted for their realization. In our case, these solutions consist of specific filters and membrane elements that ensure the performance of the studied product function

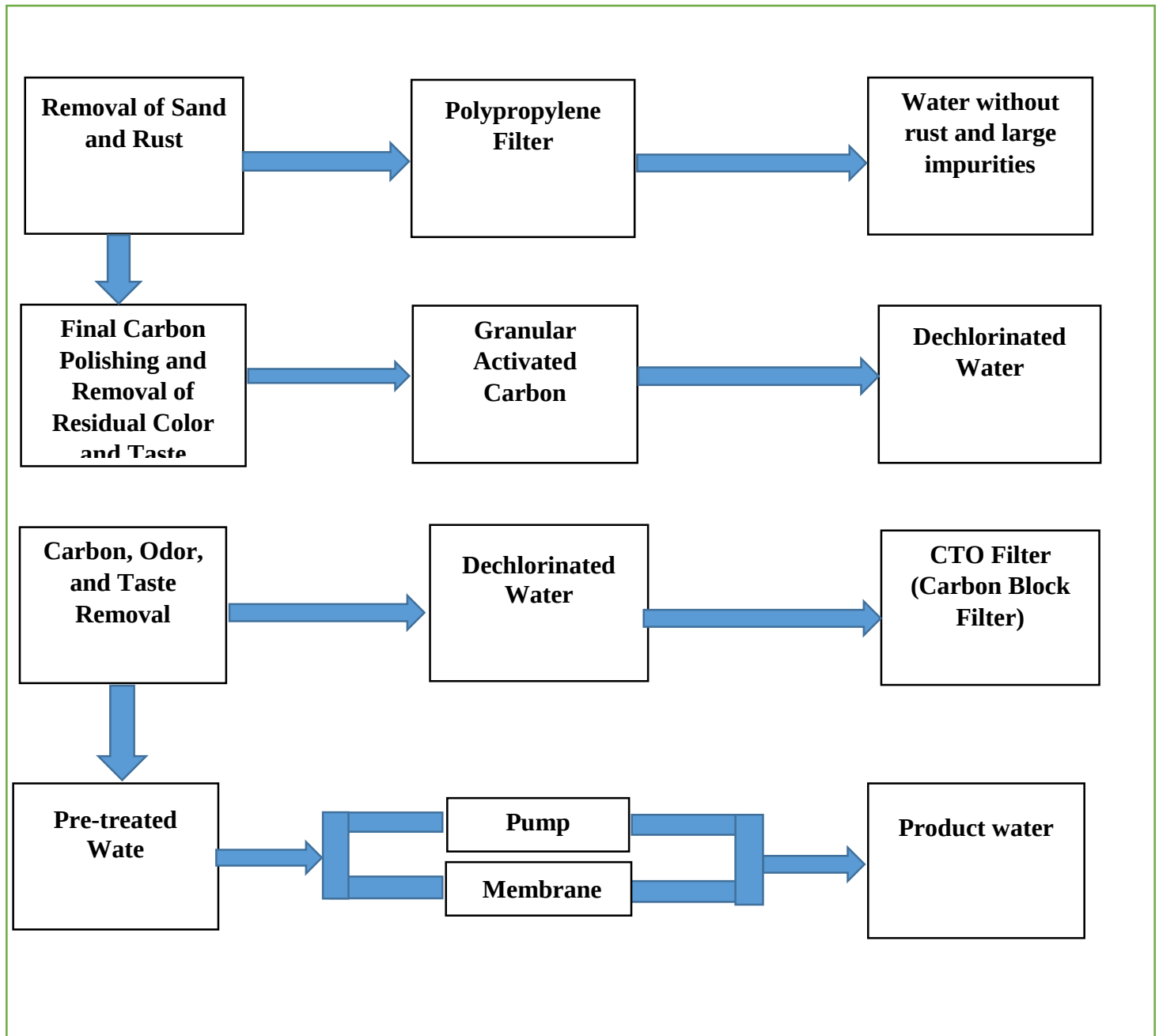


Figure II-9: FAST Diagram of the Reverse Osmosis (RO) System.

II.4.General Assembly Layout and Component Identification:

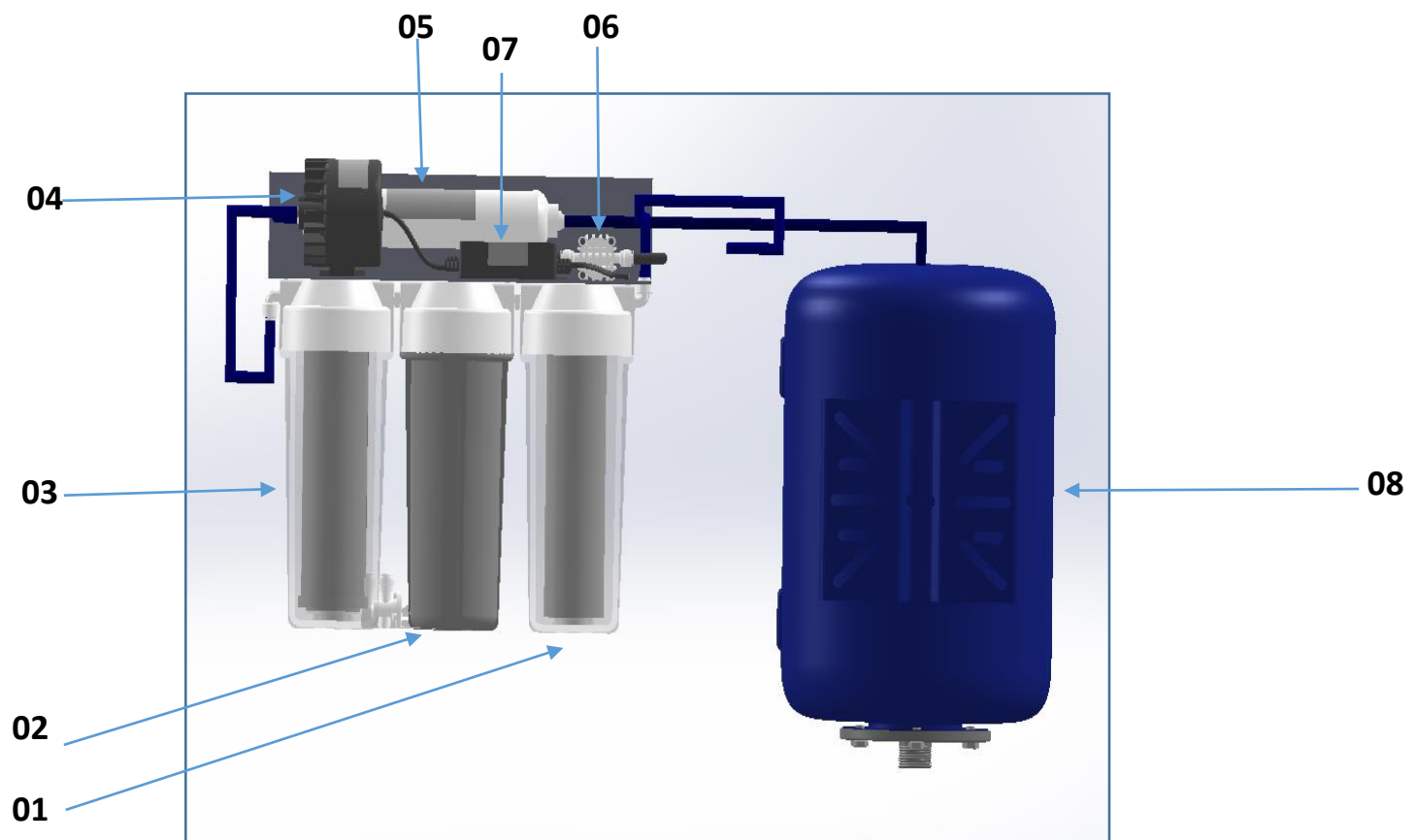


Figure II.10: Exploded View of the RO System Assembly

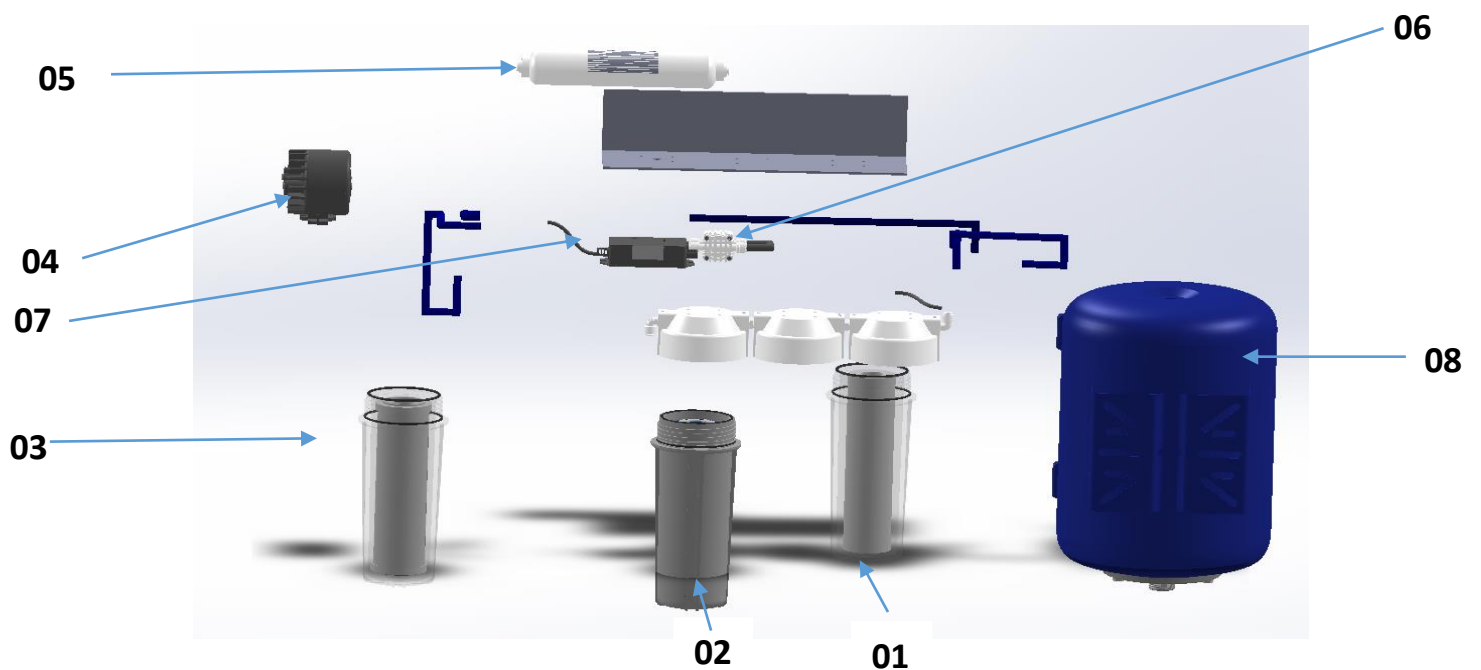


Figure II.11: Exploded View of the RO System Assembly

CHAPTER II : Functional Study and System Components

Table II.1: Technical solutions and functional descriptions of the system components.

(N0)	Component Name	Specifications	Function
01	Sediment Filter	5 Micron / PP	Remova of debris and rust
02	GAC Filter	Granular Carbon	Chlorine and chemical absorption
03	CTO Filter	Carbon Block	Removal of residual chlorine and membrane protection
04	Booster Pump	24V DC/1.2A	Increased water pressure for the osmosis process
05	RO Membrane	75 GPD/TFC	Desalination and salt separation
06	High Pressure Switch	NC Type / Electrical	Shut-off when the tank is full
07	Power Adapter	220V AC to 24V DC	Supplying the pump with continuous power
08	Storage Tank	3.2 Gallon / Steel	Storage of purified water under pressure

As illustrated in the diagram and the table above, the system integrates mechanical and electrical components to achieve water purification. The pre-filtration stages protect the RO Membrane, while the Booster Pump provides the hydraulic energy required for molecular separation. The entire cycle is automated and protected by Pressure Switches to ensure safety and efficiency.

II.4.1. Engineering Sizing Methodology:

The selection of each component was based on established hydraulic and membrane engineering calculations. The following sub-sections detail the sizing rationale for the four critical elements: the RO membrane, the booster pump, the storage tank, and the pressure loss estimation.

a) RO Membrane Selection (75 GPD):

CHAPTER II : Functional Study and System Components

The required permeate flow rate (Q_p) was determined based on a daily consumption target of 20 litres/hour for a household application. Using the standard recovery ratio (r) for small-scale domestic RO systems, which is typically 15–25%, and adopting $r = 20\%$, the required feed flow rate is calculated as follows:

$$Q_p = Q_f \times r \rightarrow Q_f = Q_p / r = 20 / 0.20 = 100 \text{ L/h}$$

Converting to GPD: $Q_p = 20 \text{ L/h} \times 24 \text{ h/day} \times 0.264 = 126 \text{ GPD}$. Applying a safety margin of 0.6 for membrane ageing and feed water variability: Rated capacity = $126 / 0.6 \approx 75 \text{ GPD}$. This confirms the selection of the 75 GPD Thin-Film Composite (TFC) membrane as the optimal and commercially available size for this system [4, 6].

b) Booster Pump Sizing:

The required operating pressure for a domestic RO system treating groundwater with TDS of approximately 800–1200 mg/L is calculated based on the osmotic pressure equation:

$$\pi \text{ (bar)} \approx \text{TDS (mg/L)} / 1000 \times 0.7 = 1000 / 1000 \times 0.7 = 0.7 \text{ bar (osmotic pressure)}$$

The total required pump pressure must overcome both the osmotic pressure and system friction losses. Adding a net driving pressure (NDP) of 3.5 bar required for flux through the TFC membrane, plus estimated friction losses of 0.5 bar in fittings and filters, the minimum pump delivery pressure is: $P_{\text{pump}} = 0.7 + 3.5 + 0.5 = 4.7 \text{ bar} \approx 5 \text{ bar}$. The selected 24V DC booster pump with a rated head of 5.5 bar provides a 10% safety margin above this requirement [3].

c) Storage Tank Capacity:

The pressurised storage tank must supply water on demand during peak usage without restarting the pump continuously. The usable volume (V_{usable}) of a bladder tank operating between 1.5 bar (cut-in) and 4 bar (cut-out) is approximately 60% of the nominal tank volume. With a target reserve of 7.5 litres (approximately 30 minutes at 15 L/h peak demand):

$$V_{\text{tank}} = V_{\text{usable}} / 0.60 = 7.5 / 0.60 = 12.5 \text{ L} \approx 12 \text{ L (3.2 Gallon)}$$

This result confirms the choice of the 3.2-Gallon (approximately 12 L) steel pressurised bladder tank as the minimum appropriate size for this system [3, 9].

d) Pressure Loss Estimation (ΔP):

Pressure losses in the pre-filtration train were estimated using the Darcy-Weisbach approach for minor losses, combined with manufacturer filter pressure-drop data. The total estimated pressure loss across the three pre-filters (Sediment, GAC, CTO) at the rated flow rate of 100 L/h is summarised in Table II.2.

II.5. Product Design (Technical Drawing):

5.1. Primary Filtration Components:

5.1.1. Sediment Filter (5 Microns):

"This drawing illustrates the first stage of filtration. The cartridge is made of high-quality Polypropylene (PP), designed to remove suspended solids, rust, and silt from the feed water."

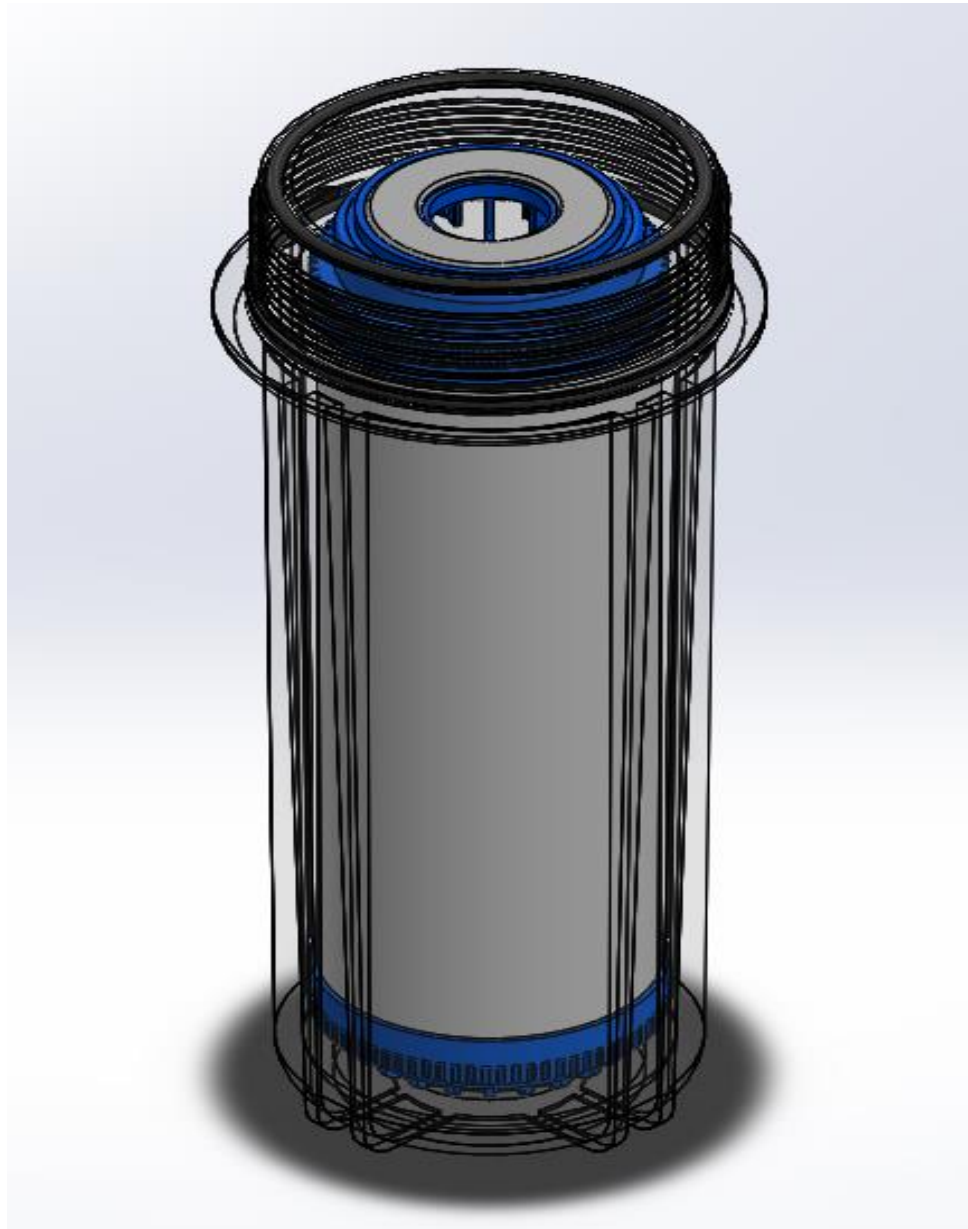


Figure II.12: Technical drawing of Filter 1 (Sediment Filter – 5 microns)

KASDI MERBAH UNIVERSITY – OUARGLA FACULTY OF APPLIED SCIENCES DEPARTMENT OF MECHANICAL ENGINEERING		
1/3	Filter 1 (Sediment Filter – 5 microns)	BOUAROUA OUSSAMA
		GANAI ISMAIL DHIYAEDDINE
A4		15 MAY

CHAPTER II : Functional Study and System Components

5.1.2. Granular Activated Carbon Filter (GAC):

"The technical drawing shows the second filtration stage. It contains Granular Activated Carbon, which is essential for reducing chlorine and organic chemicals that affect water taste and odor."

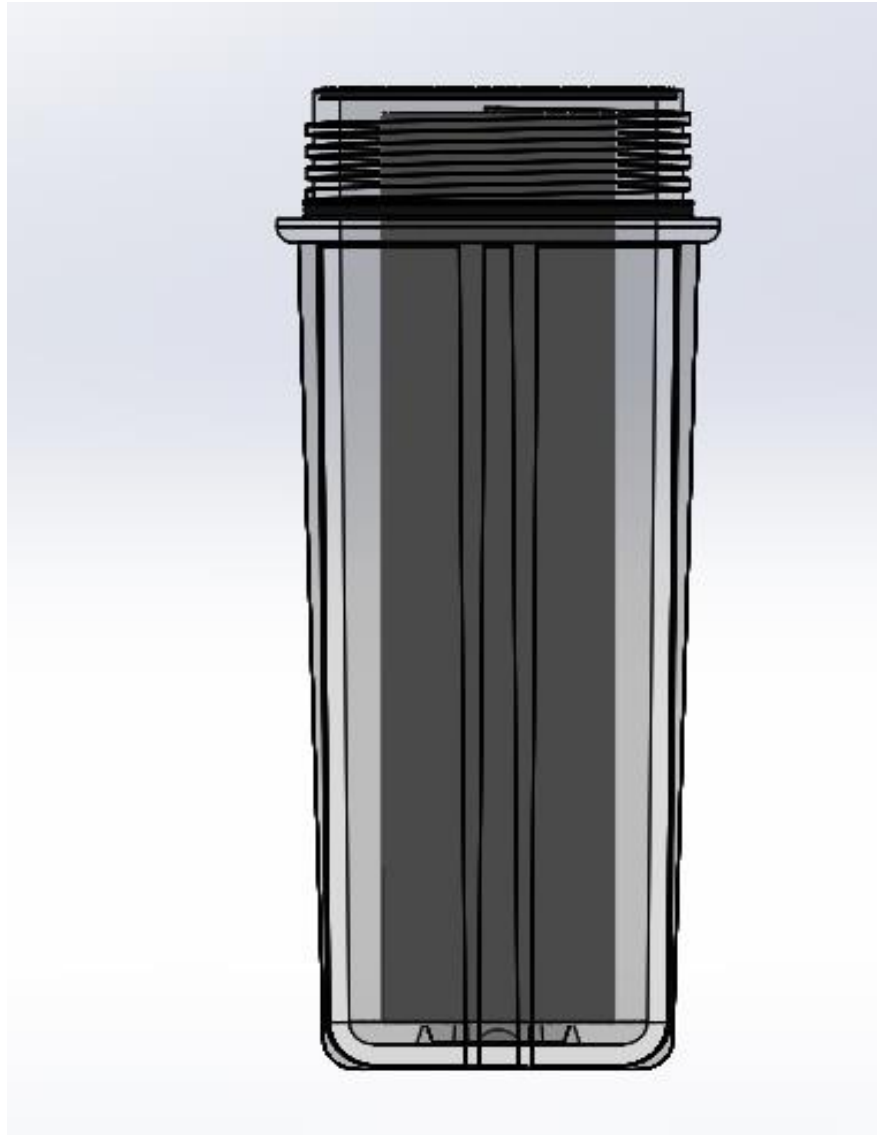


Figure II.13: Technical drawing of Filter 2 (Granular Activated Carbon – GAC).

KASDI MERBAH UNIVERSITY – OUARGLA FACULTY OF APPLIED SCIENCES DEPARTMENT OF MECHANICAL ENGINEERING		
1/3	Filter 2 (Carbon Filter – GAC)	BOUAROUA OUSSAMA
		GANI ISMAIL DHIYAEDDINE
A4		15 MAY

CHAPTER II : Functional Study and System Components

5.1.3. Carbon Block Filter (CTO):

"This stage consists of a Compressed Carbon Block. It provides fine filtration to protect the RO membrane from any remaining chemical residues and improves the overall water clarity."

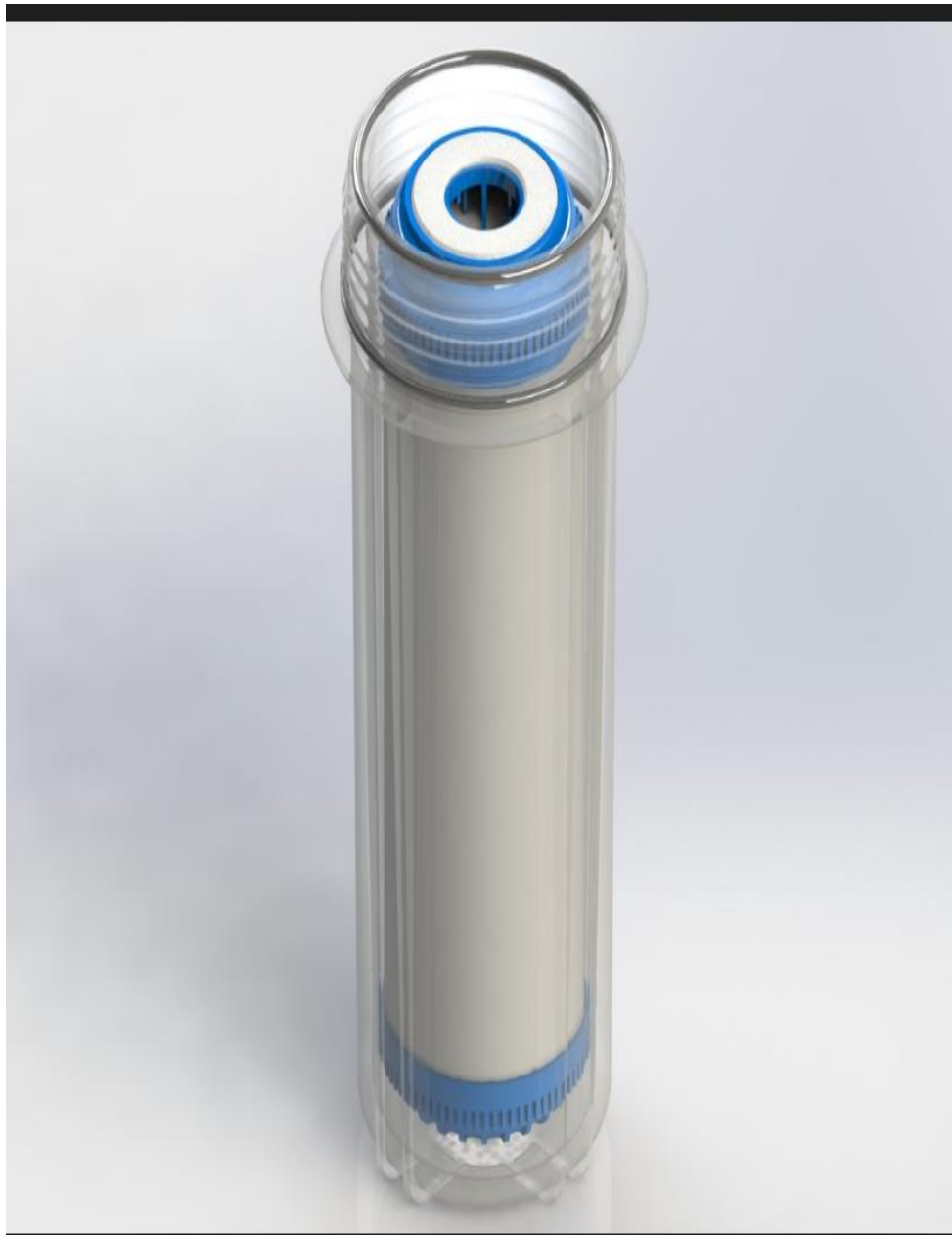
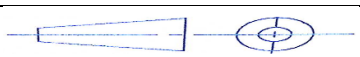


Figure II.14: Technical drawing of Filter 3 (Carbon Block – CTO)

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1/3	Filter 3 (Carbon Block – CTO)	BOUAROUA OUSSAMA
		GANNA ISMAIL DHIYAEDDINE
A4		15 MAY

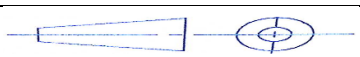
5.2. Core Desalination Unit:

5.2.1. Reverse Osmosis (RO) Membrane Element:

"The core of the system is the Semi-permeable Polyamide Thin-film Composite (TFC) membrane. This drawing shows the spiral-wound design that enables the separation of dissolved salts from pure water."



Figure II.15: Technical drawing of the Reverse Osmosis (RO) Membrane.

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1/3	RO Membrane	BOUAROUA OUSSAMA
		GANNA ISMAIL DHIYAEDDINE
A4		15 MAY

5.3. Electromechanical & Auxiliary Components:

5.3.1. High-Pressure Booster Pump:

"This component is responsible for providing the necessary osmotic pressure. The drawing details the pump head and motor assembly, designed to operate at specific pressures required for the RO process."

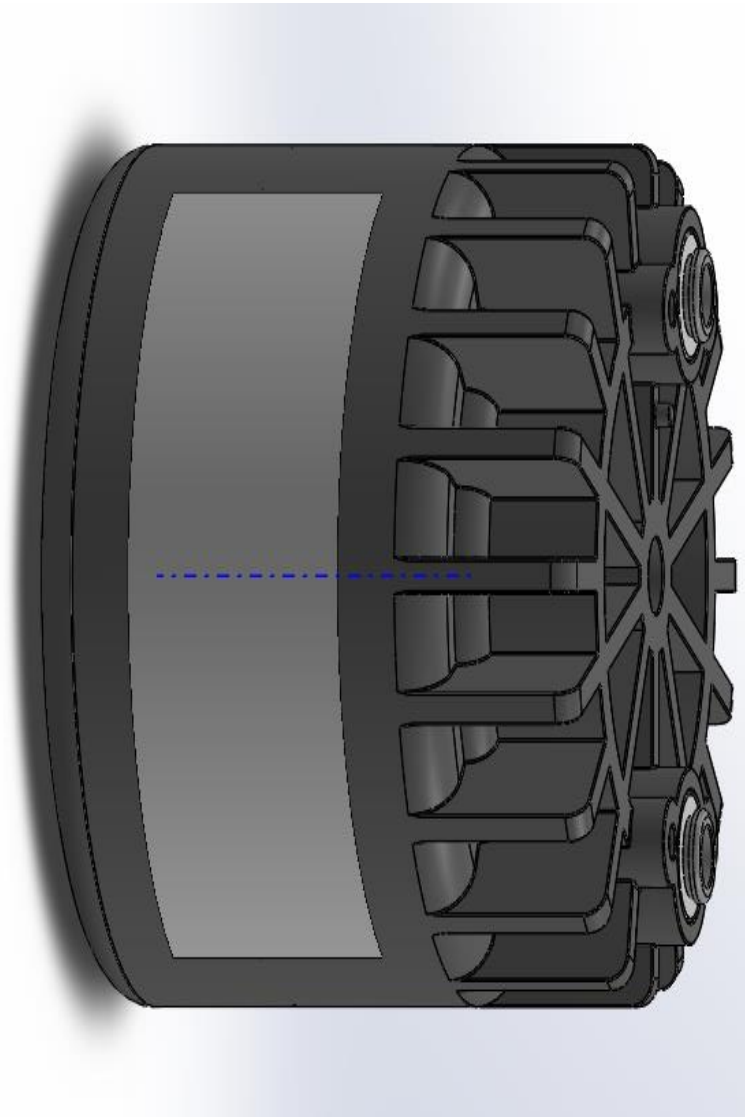
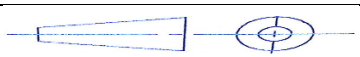


Figure II.16: Technical drawing of the High Pressure Pump

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1/3	Pump (High Pressure Pump)	BOUAROUA OUSSAMA
		GANA ISMAIL DHIYAEDDIN
A4		15 MAY

CHAPTER II : Functional Study and System Components

5.3.2. Power Supply and Transformer Unit:

"This unit converts the AC main supply to a stable DC voltage for the pump. The drawing illustrates the sealed transformer casing designed for safety and efficiency."

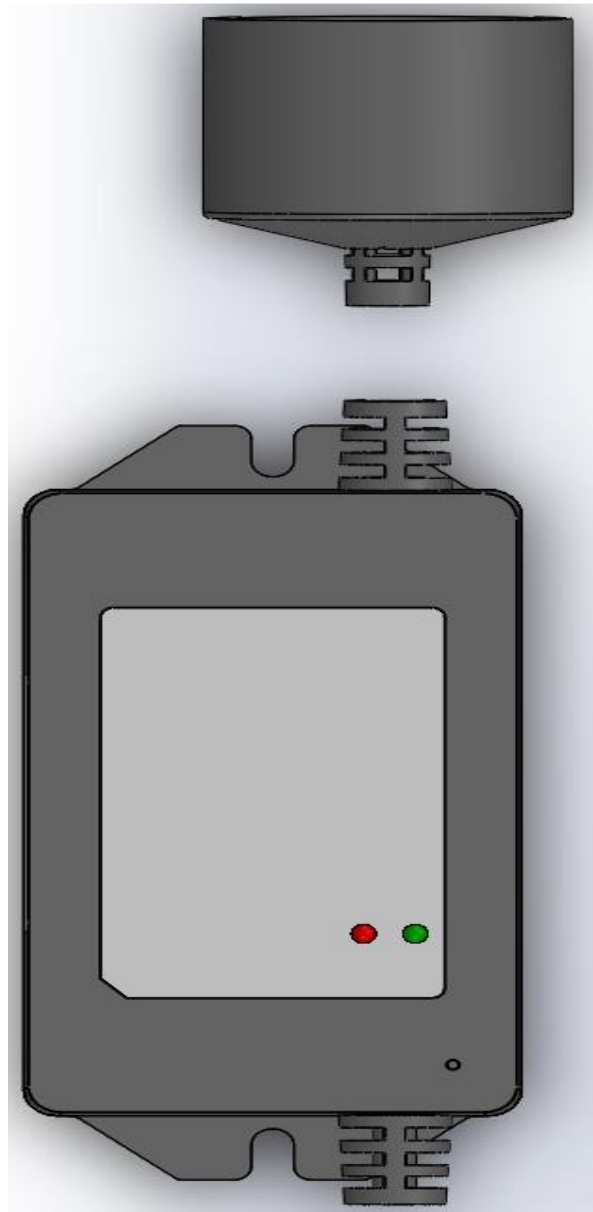


Figure II.17: Technical drawing of the Power Adapter

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1/3	Power Adapter (Transformer)	BOUAROUA OUSSAMA
		GANNA ISMAIL DHIYAEDDINE
A4		15 MAY

CHAPTER II : Functional Study and System Components

5.3.3. Pressurized Water Storage Tank:

"The final component is the storage tank, which uses an internal rubber diaphragm to maintain pressure. The drawing shows the tank's structure, which is typically coated with food-grade materials to prevent corrosion."

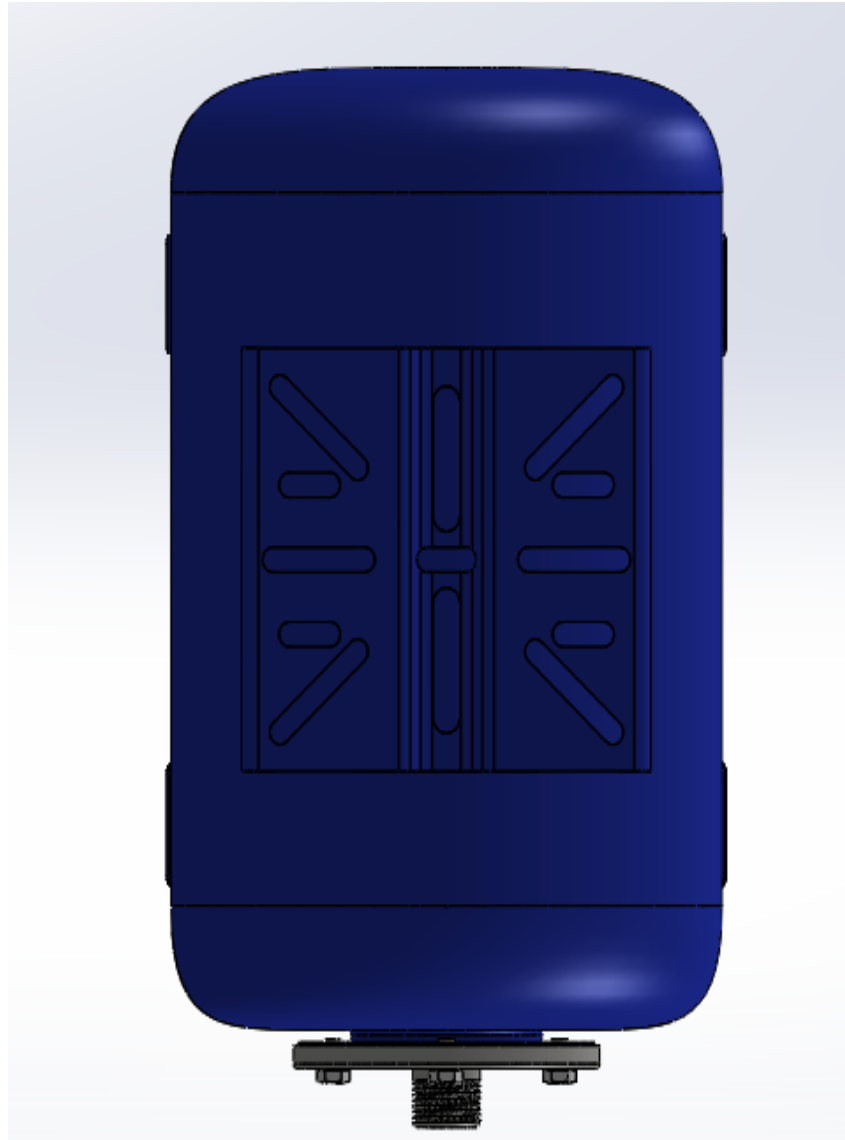
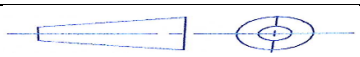


Figure II.18: Technical drawing of the Water Storage Tank.

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1/3	Storage Tank	BOUAROUA OUSSAMA
		GANA ISMAIL DHIYAEDDINE
A4		15 MAY

II.6.Conclusion:

In this chapter, we have successfully completed the design of our Reverse Osmosis Water Purification System. This was achieved through a detailed functional study and a comprehensive technical review of filtration technologies, which allowed us to define the optimal configuration for our product.

Chapter III: System Design and Modeling using SolidWorks

Chapter 3: System Design and Modeling using SolidWorks

1. Introduction:

SolidWorks is a leading Computer-Aided Design (CAD) software utilized globally for mechanical engineering. It operates on a parametric modeling approach, allowing engineers to build intelligent 3D models where dimensions and relations are interconnected. This chapter outlines the technical functionalities of the software and how they were applied to transform our Reverse Osmosis (RO) system from a conceptual sketch into a precise digital prototype ready for manufacturing.

2. Technical Functionalities of SolidWorks:

1. Extruded Boss/Base:

General Definition: It is the process of converting a 2D sketch into a 3D solid by adding material (thickness) along a linear path perpendicular to the sketch plane.

Example: Using this feature to transform a simple circle drawn on the top plane into the main cylindrical body of the filter housing

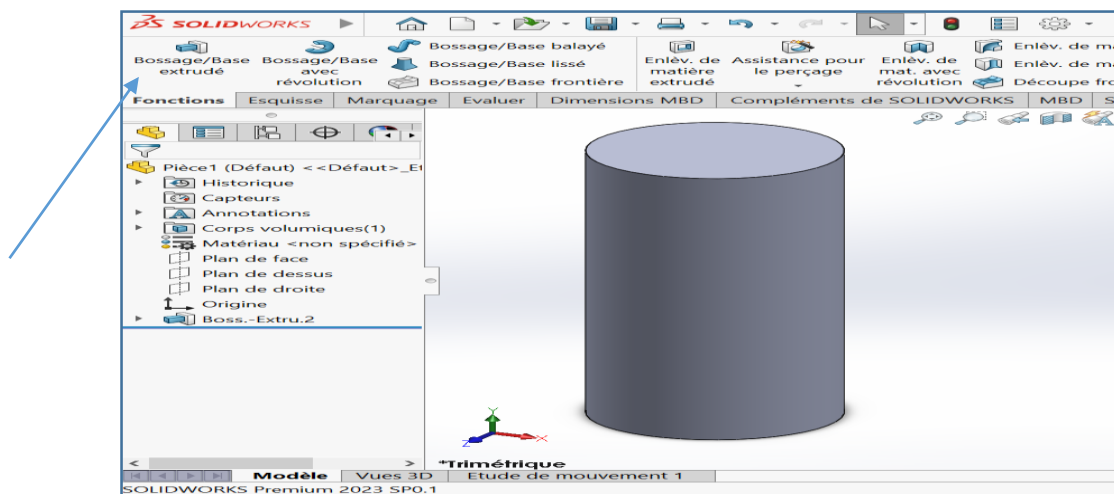


Figure III.1: Applying Extruded Boss/Base to create the 3D main body

2. Extruded Cut:

General Definition: A feature used to remove material from an existing 3D solid by projecting a 2D sketch through the body to create holes, slots, or pockets.

Example: This feature was used to create the mounting holes in the metal chassis for securing the booster pump and filter brackets.

Chapter III: System Design and Modeling using SolidWorks

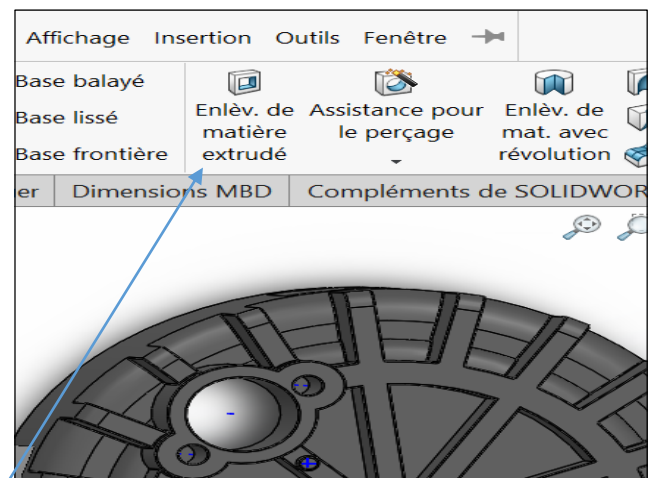
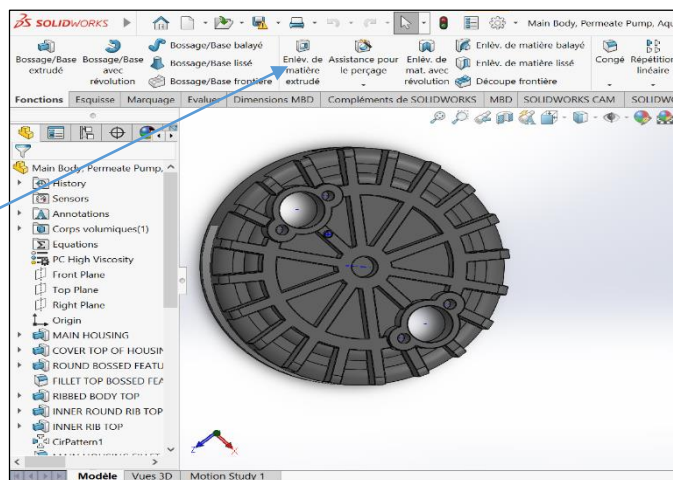


Figure III.2: Using Extruded Cut to create internal passages or holes

3. Fillet:

General Definition: A feature that creates a rounded face at the intersection of two faces or edges, used to eliminate sharp corners and improve mechanical stress distribution.

Example: This feature was applied to the outer edges of the metal chassis to ensure user safety and prevent sharp-edge hazards during handling

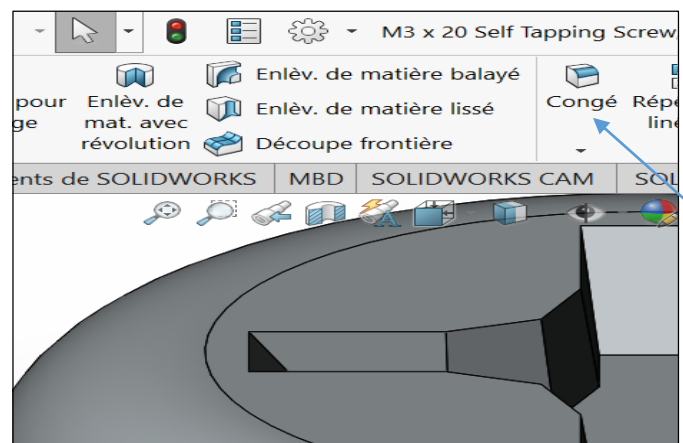
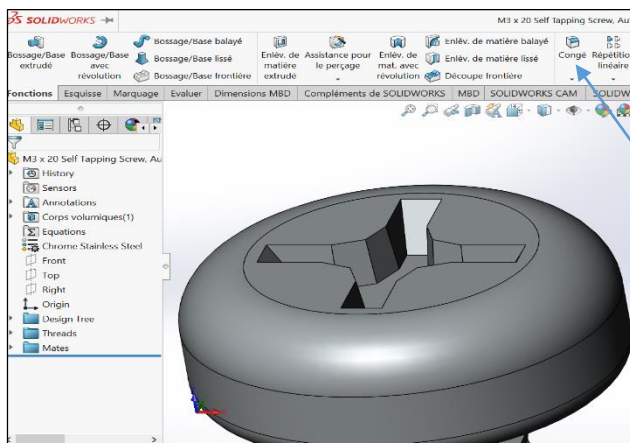


Figure III.3: Applying Fillet to smooth the sharp edges of the components

4. Thread:

General Definition: The process of creating helical grooves on a cylindrical surface (internal or external) to allow components to be screwed together.

Example: This feature was used to design the screw threads on the inlet and outlet ports of the "Membrane Housing" to ensure a leak-proof connection with the tube fittings.

Chapter III: System Design and Modeling using SolidWorks

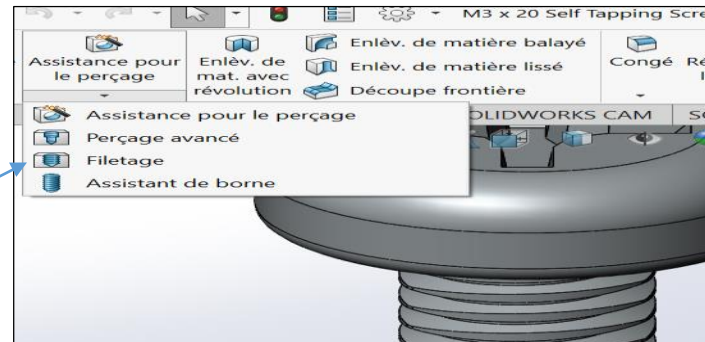
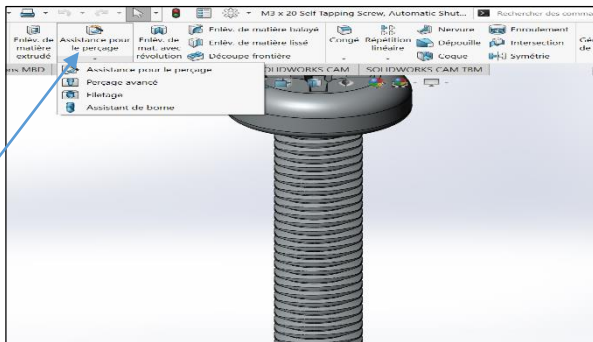


Figure III.4: Modeling screw threads for the inlet and outlet ports

5. Shell:

General Definition: A feature that hollows out a solid part, leaving a specific wall thickness on all remaining faces, effectively turning a solid block into a thin-walled container.

Example: This tool was used to hollow out the solid cylinder of the filter to create the hollow housing that accommodates the filtration cartridge or carbon media

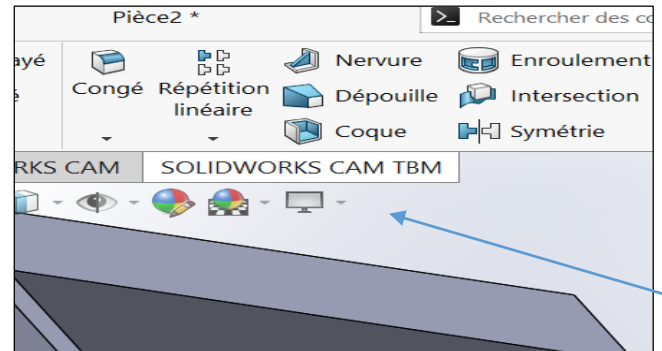
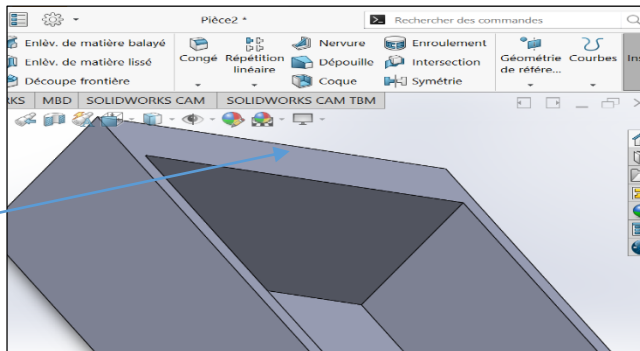


Figure III.5: Applying the Shell feature to hollow out the filter housing

6. Assembly:

General Definition: A workspace within the software that allows combining multiple independent parts into a single file, connecting them using geometric and mechanical relationships that simulate physical reality.

Example: This environment was used to integrate the pump, filter housings, and membrane vessel into the metal chassis, creating the final complete model of the Reverse Osmosis system.

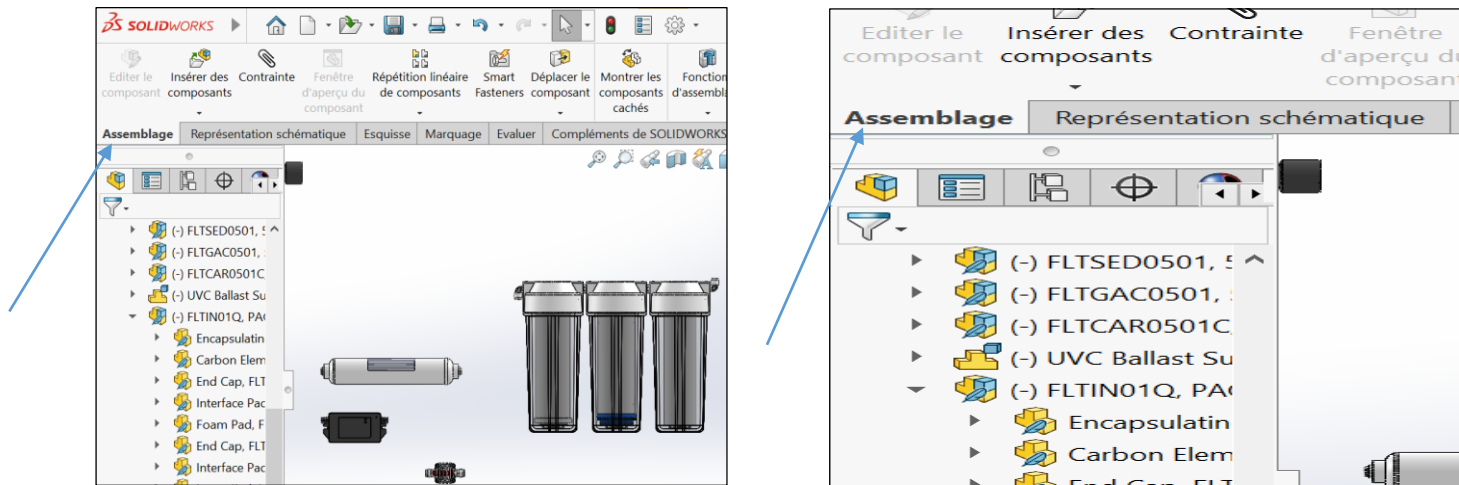


Figure III.6: The final assembly showing all integrated components of the RO

3. Conclusion:

In conclusion, SolidWorks provided a comprehensive environment to build and validate the Reverse Osmosis system digitally. The precision of these functionalities ensures the minimization of human error when transitioning from the computer screen to the manufacturing workshop, making the production process more efficient and professional.

3.1. Material Selection and Manufacturing Constraints:

The material choices for each modelled component were driven by three engineering criteria: chemical compatibility with treated water, mechanical resistance under operating pressure, and manufacturability using available workshop processes. The filter housings were modelled in food-grade ABS plastic (density: 1050 kg/m³, tensile strength: 40 MPa), which offers adequate resistance to the operating pressure of 5 bar and is compatible with potable water standards. The chassis frame was modelled in AISI 304 stainless steel (yield strength: 215 MPa), selected for its corrosion resistance in humid environments and its suitability for welded construction. The membrane housing, which sustains the highest internal pressure, was modelled in reinforced glass-filled Nylon PA66 (tensile strength: 80 MPa), consistent with the material specifications of commercially available RO pressure vessels of equivalent size.

Key manufacturing constraints considered during the design phase include: (1) minimum wall thickness of 3 mm enforced on all ABS housings to ensure injection-moulding feasibility and structural integrity; (2) thread tolerances on inlet/outlet ports designed to NPT 1/4" standard for compatibility with standard RO tube fittings; (3) fillet radii of minimum 1.5 mm applied at all internal corners to reduce stress concentrations during cyclic pressure loading.

Chapter III: System Design and Modeling using SolidWorks

3.2. Structural Verification Under Operating Pressure:

To verify that the filter housing can withstand the operating pressure without failure, a simplified thick-wall cylinder analysis (Lamé's equation) was applied to the most critically loaded component — the ABS filter housing subjected to an internal pressure of $P = 5$ bar (0.5 MPa):

$$\sigma_{\text{hoop}} = P \times r_i / t = 0.5 \times 35 / 3 = 5.83 \text{ MPa}$$

Where $r_i = 35$ mm (inner radius) and $t = 3$ mm (wall thickness). The resulting hoop stress (5.83 MPa) is well below the tensile strength of ABS (40 MPa), yielding a safety factor of $SF = 40 / 5.83 \approx 6.86$. This safety factor exceeds the recommended minimum of 3.0 for pressure-containing plastic components, confirming that the wall thickness is structurally adequate for the rated operating pressure. No failure or deformation is expected during normal operation. A proof-test pressure of $1.5 \times P_{\text{operating}} = 7.5$ bar is recommended prior to final assembly to validate the physical prototype against this analytical result.

3.3. Design Optimisation Decisions:

Several design iterations were carried out within SolidWorks to improve compactness and assembly efficiency. The principal optimisations included: (1) Reducing the overall chassis footprint by 15% compared to the initial layout by reorienting the filter column from vertical to horizontal mounting, while maintaining accessibility for cartridge replacement; (2) Replacing a planned separate solenoid valve with the integrated High-Pressure Switch (NC type), reducing the component count by one item and eliminating an additional electrical wiring circuit; (3) Standardising all tube fittings to a single 1/4" OD push-fit system to minimise spare part references and simplify maintenance. These decisions collectively resulted in a more compact, lightweight, and maintainable system design.

General Conclusion

General Conclusion

This thesis represents the culmination of a scientific and practical effort aimed at contributing to one of the most prominent technical and environmental challenges: providing pure, high-quality water through innovative, locally fabricated engineering solutions. This work has allowed us to develop and realize an integrated study that spans from computer-aided design to the simulation and fabrication of an efficient technological model for water purification.

The principal engineering results achieved in this work are summarised as follows. The system was sized for a rated permeate production of 75 GPD (approximately 283 L/day), with a feed flow rate of 100 L/h and a recovery ratio of 20%, yielding a reject (concentrate) flow of 80 L/h. The booster pump was selected and verified to deliver a minimum operating pressure of 5 bar, sufficient to overcome the osmotic pressure of the groundwater source (estimated at 0.7 bar for a TDS of 1000 mg/L) plus friction and net-driving-pressure requirements. The TFC RO membrane was specified to achieve a salt rejection rate of $\geq 97\%$, reducing TDS from approximately 1000 mg/L in the feed to ≤ 30 mg/L in the product water. The storage tank (3.2 Gallon / 12 L nominal) provides a usable reserve of 7.5 L at the operating pressure range of 1.5–4 bar. The structural verification of the ABS filter housing confirmed a safety factor of $SF = 6.86$ against burst failure at the rated operating pressure of 5 bar. The complete system CAD model was assembled from eight individually modelled components using SolidWorks, with all interfacing dimensions, thread standards, and clearances defined to NPT 1/4" specification. Note on Experimental Validation: The present work is a design and modelling study. Physical fabrication and experimental testing of the assembled prototype — including inlet/outlet pressure measurements, permeate TDS analysis, and long-term membrane flux stability — are identified as the immediate next step and constitute the primary recommendation for future work. The analytical sizing results presented herein serve as the reference baseline against which the physical prototype performance shall be validated.

Perspectives:

Based on what has been achieved in this work, the following steps are recommended for future development:

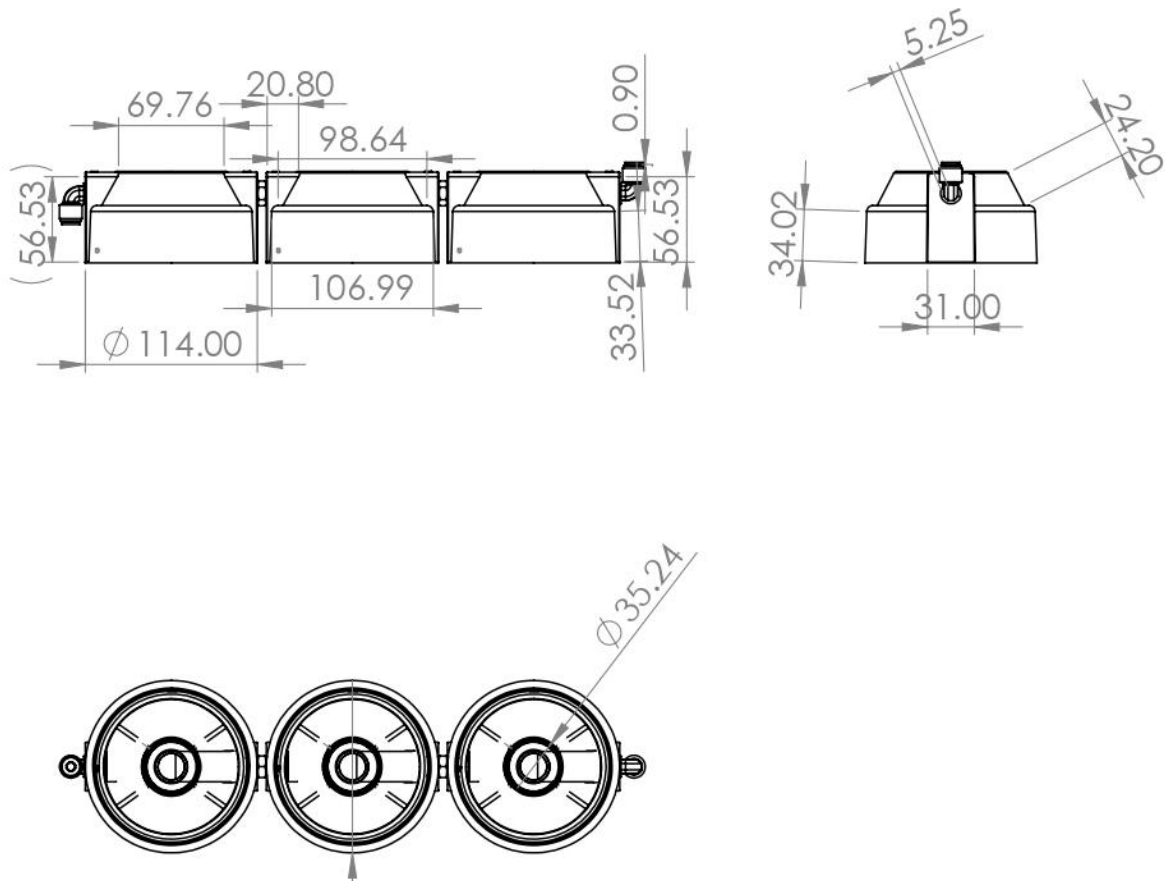
1. Prototype Fabrication and Experimental Validation: Manufacture and assemble the physical prototype based on the SolidWorks model, then conduct systematic measurements of inlet and outlet pressure, permeate flow rate, and product water TDS to verify the design against the analytical targets (75 GPD production, $\geq 97\%$ salt rejection, operating pressure of 5 bar).
2. Integrating Smart Monitoring Technologies: Digitising and monitoring water quality (TDS sensor) and membrane status (differential pressure transmitter) remotely via a microcontroller, allowing for predictive maintenance to protect the hydraulic and mechanical components and extend membrane service life beyond the standard 2-year replacement interval.
3. Optimising the Mechanical Design: Aiming to reduce the overall chassis footprint by a further 20% while increasing production capacity to 100 GPD, paving the way for adoption as a fully integrated engineering product suitable for broader application in remote and off-grid communities.

References

References

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Annexes



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1/3

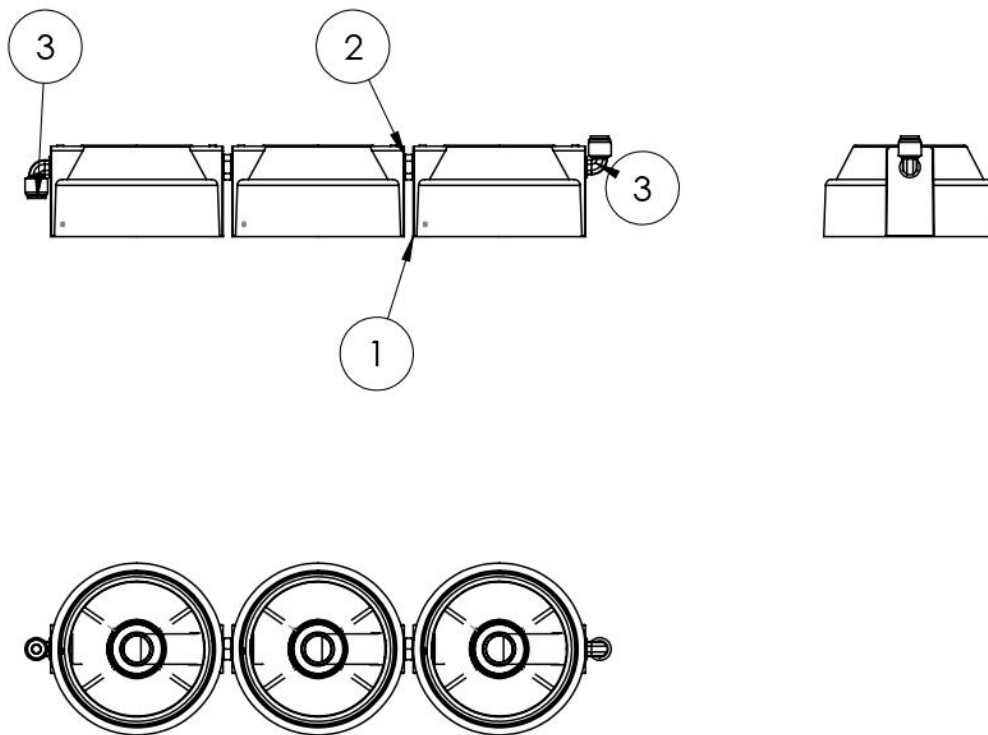
BOUAROUA OUSSAMA



Filter Housing Caps
Subassy, ROWFS

GANNA ISMAIL DHIYAEDDINE

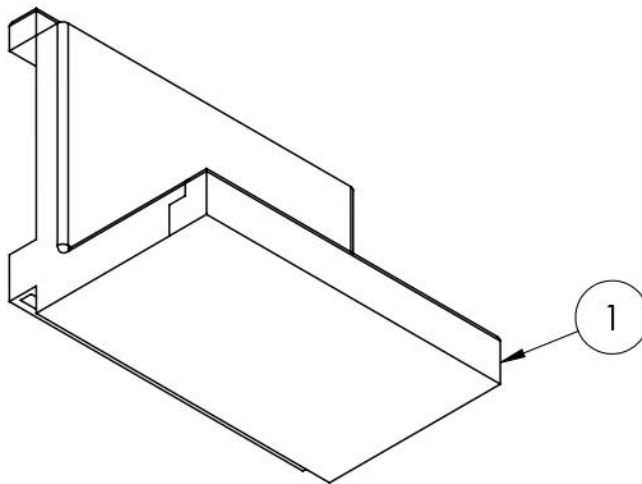
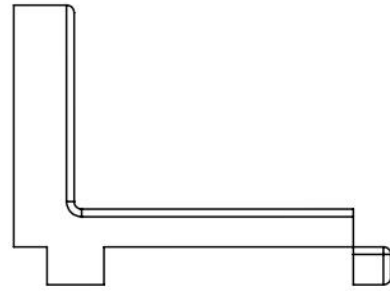
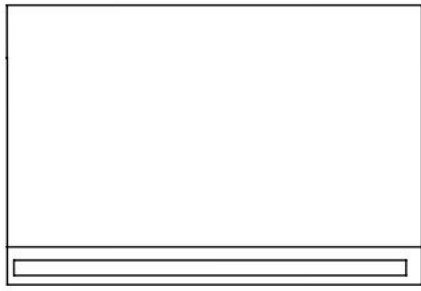
A4



No. ARTICLE	NUMERO DE PIECE	DESCRIPTION	QTE
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2	default		2
3	6.35 mm NPT to Quick Connect Coupling Subassy, FHCSA, ROWFS		2

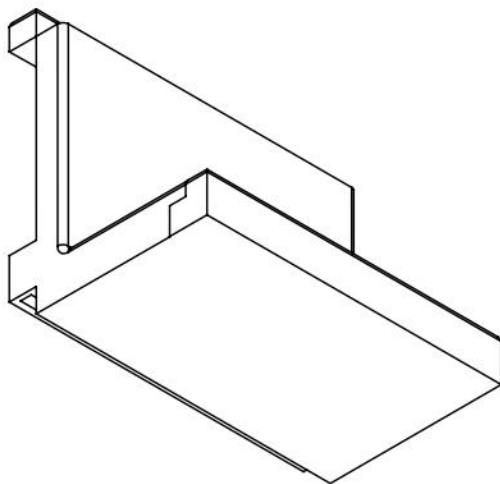
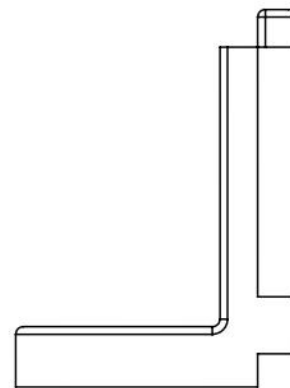
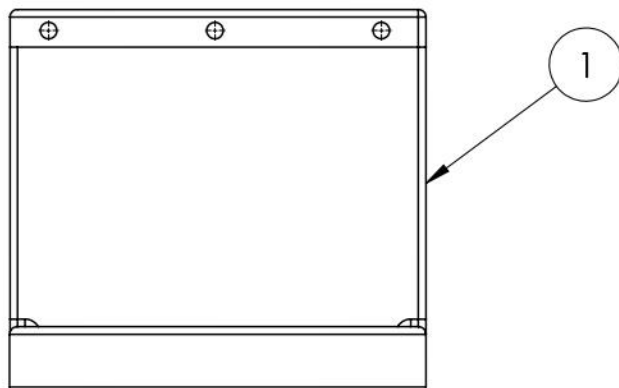
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1/3	Filter Housing Caps Subassy, ROWFS	BOUAROUA OUSSAMA
		GANNA ISMAIL DHIYAEDDINE
A4		



No. ARTICLE	NUMERO DE PIECE	DESCRIPTION	QTE
1	Wall Mount for RO System		1

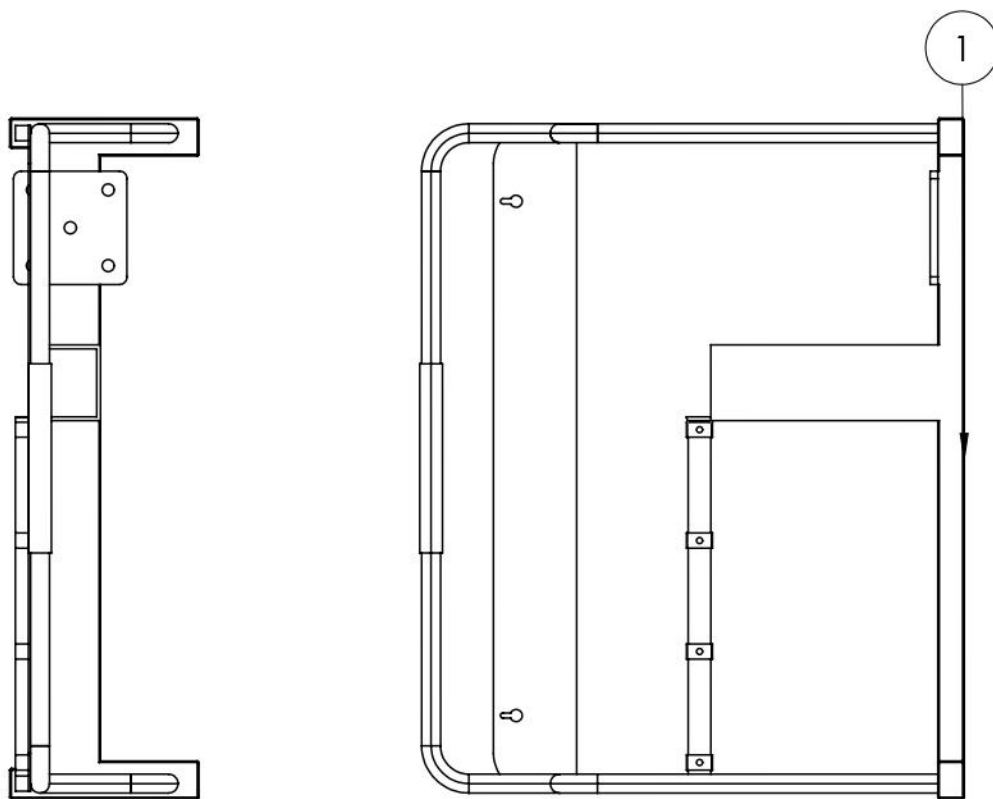
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1/3	Wall Mount for RO System	BOUAROUA OUSSAMA	
		GANA ISMAIL DHIYAEDDINE	
A4			



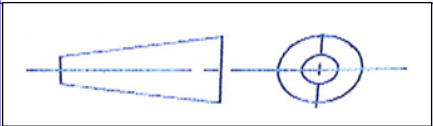
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1	Wall Mount for RO System		1

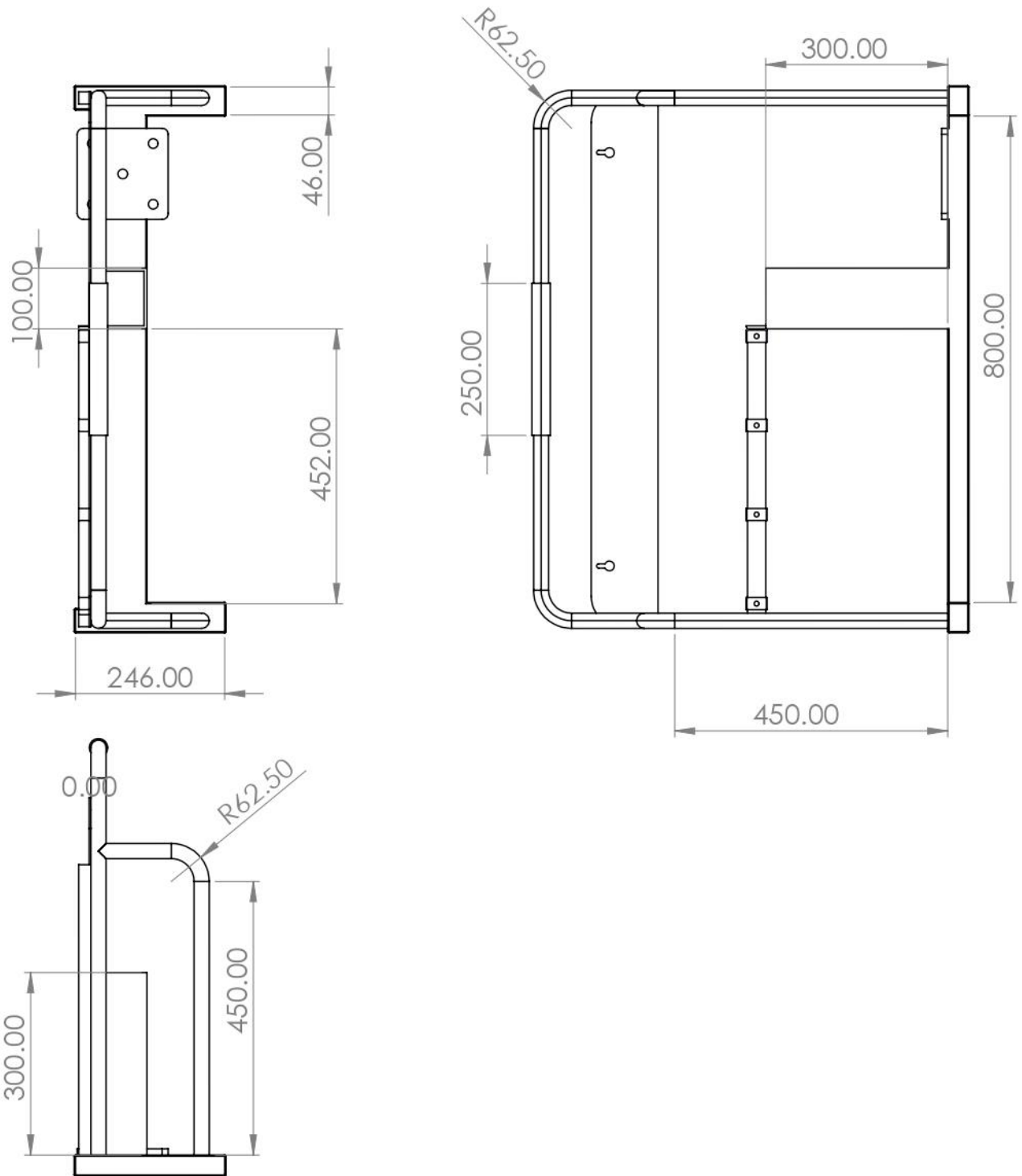
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1/3	Wall Mount for RO System	BOUAROUA OUSSAMA
		GANNA ISMAIL DHIYAEDDINE
A4		



No. ARTICLE	NUMERO DE PIECE	DESCRIPTION	QTE
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1/3	Body.step	Bouaroua Oussama	
		GANA Ismail dhiyaeddine	
A4			



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1/3

BOUAROUA OUSSAMA

GANNA ISMAIL DHIYAEDDINE

RO System Frame / Skid

A4