

DEMOCRATIC AND POPULAR ALGERIAN REPUBLIC
MINISTERE DE HIGHER
EDUCATION AND SCIENTIFIC RESEARCH
KASDI MERBAH OUARGLA UNIVERSITY



Faculty of Applied Sciences
Department of Process Engineering
Master's Thesis for
the Academic Master's Degree
Field: Science and Technology
Sector : Petrochemical industries
Specialty: Petrochemical Engineering

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Theme:

**Solar Desalination using Parabolic trough concentrator :
selecting the optimal Oil as working fluid**

Publicly supported the: 09/06/2025

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Academic Year: 2025/2026

Acknowledgment and Thanks

First and foremost, I praise Allah, the Almighty, for giving me the strength, patience, and guidance to complete this work. Peace and blessings be upon His Messenger, Muhammad (PBUH).

I would like to express my deepest gratitude and sincere appreciation to my supervisor, **Lati Mokhtar and Benzaoui Asma**, for his/her invaluable guidance, insightful suggestions, and continuous support throughout the duration of this research. His/Her expertise and encouragement have been instrumental in the successful completion of this thesis.

I am also profoundly grateful to the members of the jury for their time and effort in reviewing and evaluating this work.

Furthermore, I would like to thank all the faculty members of the
Department of **Process Engineering** at **KASDI MERBAH**
OUARGLA UNIVERSITY

for providing the academic environment and resources necessary for my studies.

Finally, my thanks go to everyone who contributed, directly or indirectly, to the realization of this project. To all of you, I offer my sincere respect and gratitude.

Didication

I dedicate this modest work to my dear family, who never wavered in providing me with their endless support and encouragement throughout this journey.

To my esteemed professors, who enlightened my path with knowledge and guided me with their wisdom.

To all my colleagues and friends who accompanied me during my studies and were the best of companions.

To all of them, I dedicate the fruit of this research

ملخص

تهدف هذه الدراسة التجريبية والمخبرية إلى تحسين إنتاجية مقطر شمسي حوضي تقليدي عبر دمج مع مجمع القطع المكافئ الشمسي. تمحور البحث حول إجراء دراسة مقارنة وتقييم شامل لكفاءة مائعين مختلفين لنقل الحرارة، وهما زيت محرك جديد وزيت محرك مستعمل معاد تدويره وتنميته بيئياً. أظهرت النتائج الميدانية أن النظام المطور باستخدام الزيت الجديد تميز باستجابة حرارية سريعة أدت إلى تسريع وتيرة التبخر الصباحي ورفع الإنتاجية التراكمية، في حين أظهر الزيت المستعمل قدرة مميزة على تخزين الحرارة والعمل كمخزن طاقة حراري أسهم في تمديد فترة التقطير والإنتاج إلى غاية الفترات المسائية المتأخرة. أثبتت التحاليل الفيزيوكيميائية كفاءة وجودة عالية جداً للمياه المنتجة؛ حيث سجلنا انخفاضاً جذرياً وشاملاً في مؤشرات التوصيلية الكهربائية، والأملاح الذائبة الكلية، والملوحة، والعكارة مقارنة بمياه الحنفية الخام، مما يؤكد الحصول على مياه مقطرة نقية تماماً ومطابقة للمعايير القياسية دون تسجيل أي أثر للتلوث بالهيدروكربونات أو الزيوت.

كلمات مفتاحية: تحلية المياه، مجمع القطع المكافئ، زيت المحرك المستعمل، الإنتاجية التراكمية، الخصائص الثرموفيزيائية.

Abstract

This experimental and laboratory study focuses on enhancing the productivity of a conventional basin solar still by integrating it with a solar parabolic trough concentrator loop. The research evaluates and compares the heat transfer efficiency of two distinct working fluids: fresh motor oil and recycled, eco-friendly used motor oil. The field results revealed that the improved system operating with the fresh oil loop exhibited a rapid thermal response, which accelerated the morning evaporation kinetics and significantly boosted cumulative freshwater productivity. On the other hand, the used motor oil demonstrated an excellent capacity for localized thermal energy storage, acting as an efficient heat buffer that extended the active distillation process well into the late afternoon and evening hours. Physicochemical laboratory analyses validated the high purity and quality of the produced distillate. A drastic and comprehensive decline in electrical conductivity, total dissolved solids, salinity, and turbidity was recorded compared to the raw brackish tap water feed, confirming the production of safe, mineral-free water with absolute structural containment and no traces of hydrocarbon contamination. **Keywords:** Solar Desalination, Parabolic Trough Concentrator, Used Motor Oil, Cumulative Productivity, Thermophysical Properties.

Résumé

Cette étude expérimentale et de laboratoire se penche sur l'amélioration du rendement d'un distillateur solaire à bassin classique en le raccordant à un concentrateur solaire parabolique cylindrique. Le cœur de ce travail repose sur une étude comparative visant à évaluer l'efficacité de deux fluides caloporteurs différents : une huile moteur neuve et une huile moteur usagée, récupérée et valorisée dans le cadre de la protection de l'environnement. Les essais menés sur le terrain ont montré que le système fonctionnant avec l'huile neuve se distingue par une réponse thermique rapide qui accélère l'évaporation dès les premières heures de la matinée et augmente la production cumulative d'eau pure. De son côté, l'huile moteur usagée a prouvé une excellente capacité de stockage thermique, agissant comme un tampon d'énergie qui prolonge le processus de distillation et maintient la production d'eau même en fin de journée après le coucher du soleil. Enfin, les analyses physico-chimiques effectuées en laboratoire ont confirmé la haute pureté et la qualité de l'eau distillée produite. Une baisse radicale des indices de conductivité électrique, des solides dissous totaux, de la salinité et de la turbidité a été enregistrée par rapport à l'eau brute du robinet, ce qui prouve l'obtention d'une eau totalement saine, sans aucun risque de contamination par les hydrocarbures ou de fuite de résidus d'huile.

Mots-clés: Dessalement solaire, Concentrateur parabolique cylindrique, Huile moteur usagée, Productivité cumulative, Propriétés thermophysiques.

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List of Abbreviations and Symbols

Abbreviation	Full Description
CPF	Central Processing Facility
CSS	Conventional Solar Still
EPS	Expanded Polystyrene
FMO	Fresh Motor Oil
HTF	Heat Transfer Fluid
ISS	Improved Solar Still
LCA	Life Cycle Assessment
PCM	Phase Change Material
PTC	Parabolic Trough Concentrator
TDS	Total Dissolved Solids
TES	Thermal Energy Storage
UMO	Used Motor Oil
WHO	World Health Organization

List of Abbreviations and Symbols

Symbol	Description	Unit
λ	Molecular Thermal Conductivity	W/m.°C
C_p	Specific Heat Capacity	kJ/kg. °C
Q	Heat Flow Rate / Thermal Power	W
ΔT	Temperature Difference ($T_{\text{hot}} - T_{\text{cold}}$)	K or °C
Δt	Time Interval / Time Delta	<i>min</i>
<i>L or Δx</i>	Thickness of the Conduction Layer (Wall Depth)	<i>m</i>
A	Heat Transfer Cross-Sectional Area	m^2
I(t)	Solar Irradiance	W/m ²
T_{abc}	Absorber Tube Temperature	°C
T_{eau}	Water Temperature inside the basin	°C
T_{fin}	Inlet Fluid Temperature	°C
T_{fout}	Outlet Fluid Temperature	°C
T_v	Vapor Temperature	°C
D/d	Diameter	<i>m or Cm</i>
G	Global Solar Radiation Intensity	W/m^2

List of Abbreviations and Symbols

H_{fg}	Latent Heat of Vaporization	kJ/kg
m	Mass	Kg
R_{ml}	Daily Cumulative Distillate Yield	(ml or L/m ²)
V_{hourly}	Hourly Distilled Water Volume	mL/h
V_{total}	Total Daily Cumulative Yield	mL
V_{Improved}	Distillate Volume from the Improved Still	mL
V_{Conventional}	Distillate Volume from the Conventional Still	mL
Percentage_{Improvement}	Production Improvement Factor	%
pH	Potential of Hydrogen	
σ	Electrical Conductivity	uS/cm

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GENERAL INTRODUCTION

Algeria, particularly the Ouargla province, faces a major and growing problem with freshwater scarcity due to population growth, urban expansion, and industrial activity, where the annual per capita share of water has decreased significantly, requiring sustainable and practical solutions such as solar desalination [1]. Solar desalination is considered one of the best and most successful solutions to address water shortages in remote and desert areas due to its simple installation, low operating costs, and direct reliance on clean, renewable solar energy [1]. However, despite its many advantages, conventional simple solar distillation systems suffer from low daily water production, which prevents their widespread use [2]. Consequently, a lot of engineering research has focused on improving the thermal performance of solar stills by connecting them to auxiliary heating systems, such as Parabolic Trough Concentrators (PTC), and using advanced oils for heat transfer (HTFs) [3].

Within this framework, the thermal efficiency and economic success of concentrating solar power systems depend completely and strictly on the thermophysical properties of the oil used in the heat transfer loop, such as its specific heat capacity, thermal stability, and thermal conductivity [4]. Conventional commercial synthetic oils dedicated to heat transfer, despite withstanding high temperatures, are financially very expensive and cause serious environmental risks in the event of any leakage from the pipes [3]. Simultaneously, the continuous accumulation of used motor oils from routine car and factory maintenance has created a major environmental problem, as haphazard disposal leads to the pollution of soil and groundwater [5]. Therefore, reusing recycled used motor oil as a cost-free alternative to transfer and store heat in the solar system represents an innovative engineering idea that combines protecting the environment from pollution with increasing freshwater production efficiency [4].

Based on these engineering and environmental challenges, the primary objective of this experimental research is to study the success of connecting a parabolic trough collector to an active solar still. The core work focuses on conducting a real and direct comparison between the performance of fresh motor oil and recycled used motor oil to determine the best fluid that maximizes the amount of freshwater produced, while ensuring the safety of the still's engineering structure under the hot and dry climatic conditions of the Ouargla region [3, 4]. In terms of structure, this work in the thesis is divided into a comprehensive review of solar thermal applications and conventional distillation mechanisms [2], followed by laboratory

measurements and experiments to determine the properties of the oils used, and concludes with a detailed calculated discussion of the field results, tracking hourly water production quantities, along with a chemical and physical analysis to confirm the purity and quality of the produced distilled water [4].

Chapter I. Solar Energy and Desalination

I.1 Renewable Energy

Renewable energy sources, particularly solar thermal technologies, play a pivotal role in addressing global energy demands while mitigating climate change impacts, with Concentrating Solar Power (CSP) systems offering dispatchable generation through thermal energy storage [5, 6]. In Algeria, particularly within the hyper-arid region of **Ouargla**, solar resources exceed $2,200 \text{ kWh/m}^2$ year of Direct Normal Irradiance (DNI), enabling CSP viability for localized solar desalination and power co-generation, as evidenced by pilot projects achieving capacity factors above 40% [1]. These technologies reduce reliance on fossil fuels, directly aligning with Algeria's national renewable energy roadmap targeting 15 GW of green capacity by 2035 [6].

I.2 Solar Thermal Energy in Algeria

Algeria's Saharan climate provides exceptional solar thermal potential, with DNI values ranging from 1,900 to 2,600 kWh/m²/year in southern provinces like El Oued, surpassing global benchmarks for CSP deployment [5, 1]. Government initiatives, including the 2011 Solar Plan, have commissioned PTC-based power plants such as the 150 MW Khi Solar One hybrid, demonstrating thermal efficiencies of 20-25% [6]. Integration with desalination addresses regional water stress, where significant portions of Algerian aquifers are brackish, supporting hybrid systems for sustainable development [7].

I.3 Water Desalination Technologies

Desalination technologies span thermal processes like Multi-Effect Distillation (MED) and mechanical vapor compression (MVC), with solar thermal integration yielding gained output ratios (GOR) exceeding 12 in PTC-MED hybrids [8, 1]. Reverse osmosis (RO) dominates globally at 69% capacity, but thermal methods suit high-salinity brines prevalent in Algerian aquifers (TDS >5,000 mg/L) [8]. Solar-assisted MED achieves specific energy consumption as low as 50 kWh/m³ thermal, outperforming standalone RO in intermittent solar scenarios [9].

I.4 Concentrating Solar Power (CSP)

I.4.1 Principles of Parabolic Trough Concentrators (PTC)

Parabolic Trough Concentrators (PTC) employ curved mirrors to focus DNI onto linear evacuated receiver tubes, achieving geometric concentration ratios of 30-80 suns and fluid outlet temperatures of 350-400°C [5]. Single-axis tracking optimizes annual energy capture, with optical interception exceeding 90% under clear skies [1]. The system integrates HTF

circulation loops with storage tanks for baseload operation, critical for desalination continuity[6].



Figure I.4. 1Parabolic Trough Concentrators (PTC)

1.4.2 Optical and Thermal Efficiency

PTC optical efficiency incorporates reflectance ($\eta_{\text{refl}} \approx 93\%$), intercept factor ($\eta_{\text{int}} \approx 0.95$), and cleanliness ($\eta_{\text{clean}} \approx 0.98$), yielding net $\eta_{\text{opt}} = 72\%$ [3]. Thermal efficiency $\eta_{\text{th}} = 1 - (q_{\text{loss}} / q_{\text{in}})$ reaches 75% at moderate ΔT , limited by envelope conduction and convection losses ($U_L \approx 20 \text{ W/m}^2\text{K}$)[5]. Annual performance ratios of 1.5-2.0 are attainable with two-tank molten salt storage[10].

1.5 The Reference System (conventional)

In any experimental study, a "conventional" or reference system is essential to evaluate the effectiveness of the proposed modifications and improvements. In our research, the **Reference System** consists of the solar distillation unit operating under standard conditions, without the integration of the Parabolic Trough Concentrator (PTC) or the optimized heat transfer fluids (HTFs) [2, 11].

1.5.1 Definition and Role of the conventional solar still.

The reference system serves as the baseline for performance comparison. By measuring the distilled water productivity and the thermal gradient of a conventional solar still, we can quantitatively determine the "Efficiency Gain" provided by our improved PTC-coupled system [12]. This approach follows the standard experimental protocol used in thermal

engineering research to validate new designs, ensuring that any increase in yield is attributed directly to the technological enhancements [6, 9].

1.5.2 Characteristics of the Reference Setup

The reference system is characterized by:

- **Direct Heating:** The water is heated solely by the solar radiation hitting the basin liner through the glass cover [11].
- **Passive Operation:** No external pump or forced circulation of fluids is used, relying on natural convection for heat transfer [13].
- **Standard Insulation:** Uses basic insulation without the enhanced polystyrene layers or optimized heat transfer loops, reflecting the base-case thermal losses [14].

1.5.3 Comparative Parameters

To ensure a scientific comparison, the "Reference " is monitored using the same measurement tools (Digital Thermometers, Solarimeter) and under the same climatic conditions in Ouargla. The primary parameters recorded for the reference system include [12, 15]:

- **Teau (Reference):** Temperature of the water in a simple basin.
- **Tv (Reference):** Vapor temperature without external heat assistance.
- **Daily Yield:** The total volume of water produced by the natural greenhouse effect alone.

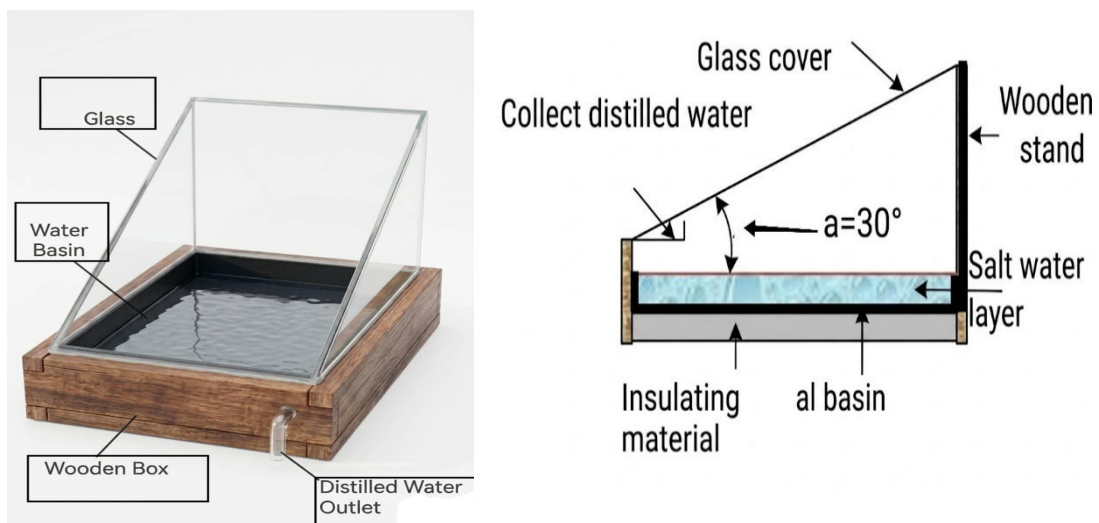


Figure I.5.3.1 Schematic of the conventional solar still

I.6 Thermal Mechanisms and Phase Change in Solar Distillation

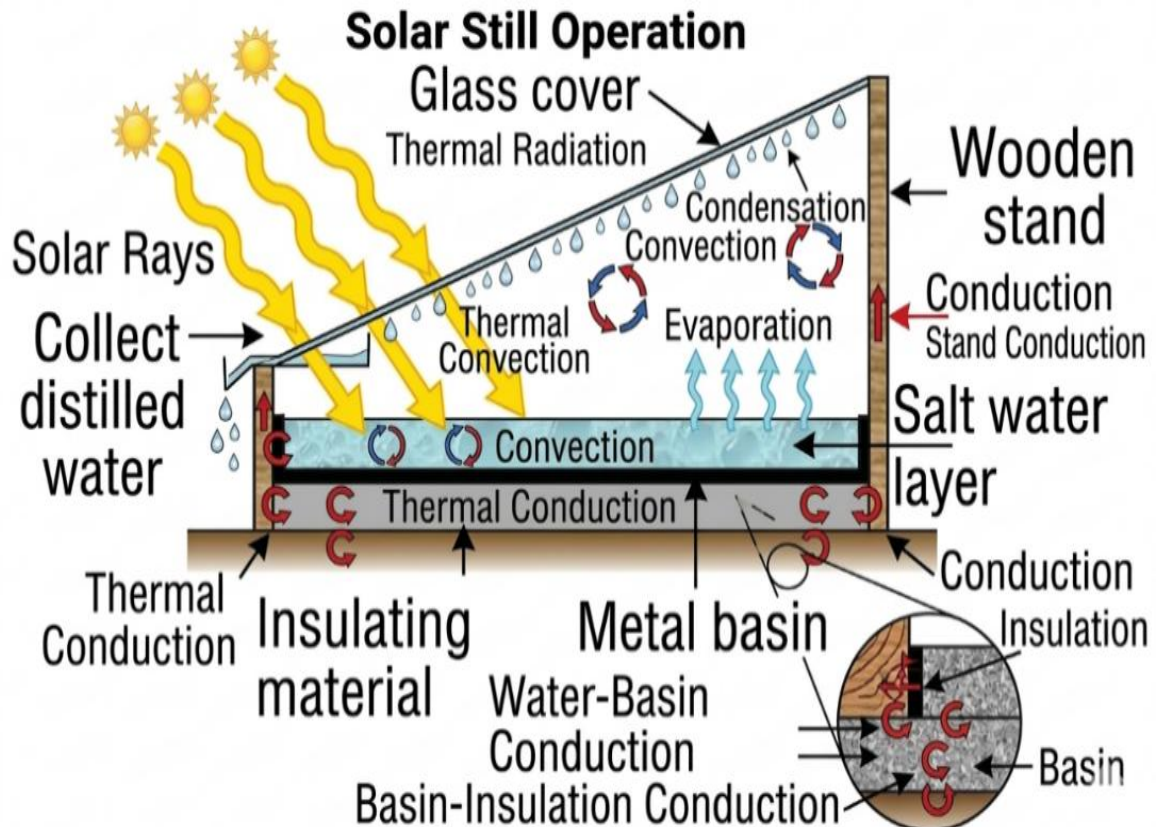


Figure I.5.3.1 Heat Transfer Mechanisms in a Single-Slope Solar Still

I.6.1 Thermal Radiation

Solar irradiance (short-wave radiation) transmits through the transparent glass cover of the solar still. While a minor fraction of this energy is lost to reflection at the boundary interfaces, the predominant portion is absorbed by the saline water layer and the black-coated basin liner. This absorbed radiative energy is subsequently converted into thermal energy, driving the temperature rise of the entire system [16].

I.6.2 Thermal Conduction

Thermal conduction governs the transfer of heat through direct molecular interaction and microscopic collisions within the stationary components of the still. Heat is conducted from the high-temperature metal basin to the underlying and peripheral insulation materials, as well as through the structural wooden/metallic frame. Consequently, utilizing insulation materials with minimal thermal conductivity (k) is vital to mitigate parasitic conductive heat losses to the ambient environment [17].

1.6.3 Thermal Convection

The internal thermodynamic environment of the solar still is highly influenced by buoyancy-driven free convection, which arises from temperature-induced density gradients. This convective transport operates through two distinct pathways [18]:

- **Internal Liquid Convection:** Fluid circulation within the saline water bulk itself, driven by the heating of the bottom water layers in direct contact with the basin.
- **Humid Air Convection:** The air-vapor mixture adjacent to the water surface absorbs heat and moisture. Due to its reduced density, this warm, buoyant mixture ascends toward the cooler glass cover, establishing a continuous convective loop that facilitates simultaneous heat and mass transfer [18].

1.6.4 Phase Change (Evaporation and Condensation)

The distillate yield of the solar still is fundamentally dictated by a continuous phase change cycle, shifting water across different thermodynamic states[2]:

- **Evaporation:** As the liquid water absorbs sufficient thermal energy to overcome intermolecular cohesive forces, it undergoes a phase transition into vapor. This process removes energy from the brine mass in the form of the *Latent Heat of Vaporization* (hfg).
- **Condensation:** Upon making contact with the cooler interior surface of the inclined glass cover, the saturated vapor rejects its latent heat. This causes it to transition back into the liquid phase, forming pure, mineral-free water droplets that slide down into the collection troughs due to gravity and the cover's tilt angle [2].

Chapter II . Heat Transfer Fluids (HTF) and Oil Selection

II.1 Role of Working Fluids in Solar Systems

Heat Transfer Fluids (HTF) constitute the cornerstone of concentrating solar power (CSP) systems, particularly Parabolic Trough Concentrators (PTC), by facilitating the efficient transport of concentrated solar thermal energy from absorber tubes to heat exchangers and steam generators in desalination plants[3]. These fluids must withstand extreme thermal gradients (typically 250-400°C), exhibit minimal thermal degradation during cyclic operation, and maintain low viscosity to reduce pumping power requirements, thereby optimizing overall cycle efficiency[5]. Conventional synthetic HTFs like Therminol VP-1 and Dowtherm A have dominated commercial applications due to their proven stability, but their high procurement costs (exceeding 20/L) and environmental persistence during spills underscore the urgency for sustainable alternatives derived from local resources[3]. In PTC-desalination hybrids, HTF performance directly influences gained output ratio (GOR) in multi-effect distillation (MED), where even marginal improvements in heat transfer coefficient can yield substantial freshwater productivity

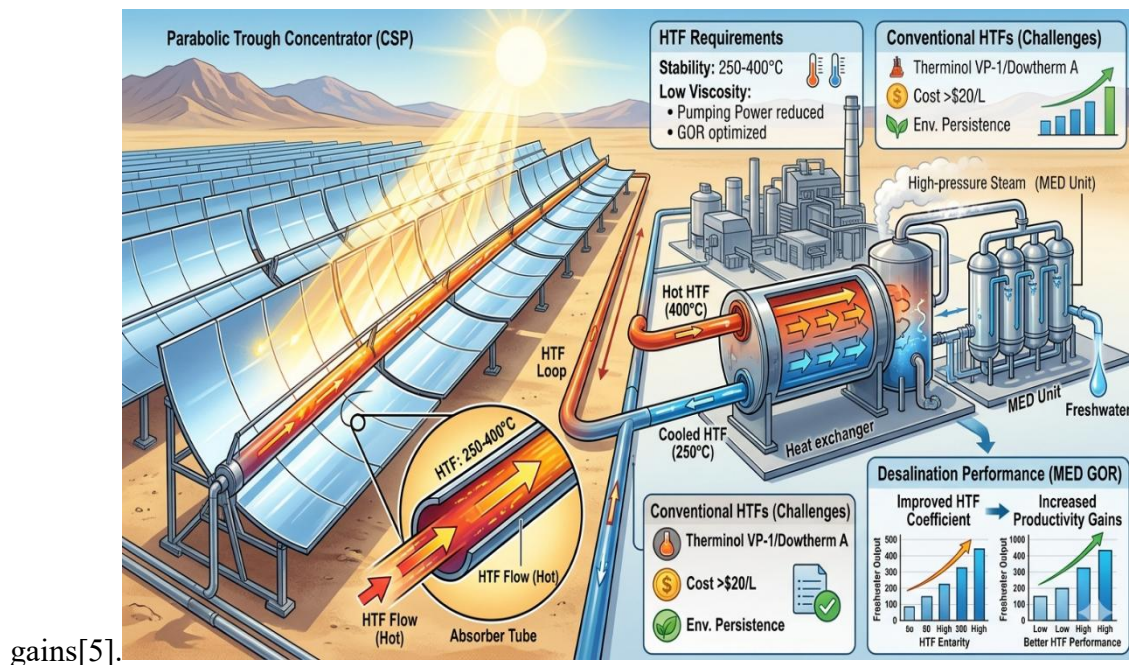


Figure I.6.4.1 Schematic diagram of a Parabolic Trough Concentrator (PTC) coupled with a Multi-Effect Distillation (MED) system showing HTF constraints. (Adapted by the author based on [3] and [19])

II.2 Thermophysical Properties of HTFs

The efficacy of HTFs in PTC systems hinges on a suite of interdependent thermophysical properties: thermal conductivity governs convective heat pickup from absorbers; specific heat capacity determines storage density; density and viscosity dictate pressure drop and pumping energy; and thermal stability defines operational limits[3]. Synthetic thermal oils typically maintain thermal conductivity between 0.10-0.15 W/m·K up to 400°C, while their viscosity escalation above 300°C necessitates careful loop sizing to avoid excessive parasitic losses [4]. Vegetable oils, though exhibiting promising heat capacities ($\approx 2.0\text{-}2.5$ kJ/kg·K), suffer from oxidative instability and polymerization at prolonged high temperatures, mitigated through antioxidant additives or vacuum degassing[5]. Critical performance metrics include the Prandtl number ($Pr = \nu/\alpha$) for laminar flow regimes in receiver tubes and the figure of merit for overall heat transfer enhancement, guiding nanofluid development where metal oxide nanoparticles boost conductivity by 10-30% without compromising stability[3]. For Algerian PTC-desalination applications, HTF selection must prioritize freeze protection (pour point $< -20^\circ\text{C}$ for nocturnal cooldown) alongside flash point $> 250^\circ\text{C}$ to ensure operational safety in remote installations [4].

II.3 Characterization of the Motor Oil

Fresh motor oil (API Group II/III base stocks, SAE 30/40 grades) establishes the performance benchmark in CSP with robust anti-oxidant packages (ZDDP, amines) ensuring oxidative stability beyond 400°C and excellent film strength for dynamic sealing [3]. Used motor oil (UMO), recovered from automotive service intervals, retains bulk thermal conductivity but exhibits 15-25% viscosity increase from soot agglomeration and base stock cracking, necessitating re-refining via vacuum distillation and hydrotreatment to restore API specification[5]. While fresh MO dominates commercial PTC fleets due to certified long-term reliability (degradation $< 1\%$ per 10,000 hours), re-refined UMO offers viable recyclability, though metal contaminants require chelation to prevent catalytic decomposition [4]. Both variants excel in lubricity critical for high-pressure HTF pumps, positioning motor oils as robust references against emerging bio-HTFs [3].

II.4 Comprehensive Evaluation and Comparative Analysis of Selected HTFs

Thermal efficiency and economic feasibility of Parabolic Trough Collector (PTC) systems. The performance of these fluids is governed by their thermophysical properties, such as

specific heat capacity (C_p), thermal stability, and viscosity, which directly influence the heat transfer coefficient within the receiver tube [4, 5].

In this study, two types of mineral-based oils—Fresh Motor Oil (FMO) and Used Motor Oil (UMO)—are evaluated to identify an efficient and sustainable medium for solar desalination in the Algerian context (specifically under Ouargla's climatic conditions). The following table provides a strategic comparison between the two remaining candidate fluids based on technical, economic, and environmental criteria:

Table I.6.4- 1 Comparative Matrix of the evaluated Motor Oils

Criteria	Fresh Motor Oil (FMO)	Used Motor Oil (UMO)
Thermal Stability	Excellent (Gold Standard)	Good (After proper filtration/treatment)
Economic Viability	Moderate to High Cost	Highest (Low cost/Recycled Waste)
Heat Transfer Efficiency	High Efficiency and Constant Flow [3]	Reliable (Slightly affected by carbon residues)
Environmental Impact	High Carbon Footprint (Mineral-based)	Highly Positive (Promoting Waste Recycling)
Operational Reliability	Maximum Reliability & Endurance	Moderate (Requires periodic check for degradation)
Availability (Algeria)	Commercial Market Dependent	Abundant Local Supply (Automotive Waste)

II.4.1 Strategic Synthesis and Recommendations

According to the comparative data presented in **Table II.3.2-1**, Fresh Motor Oil (FMO) serves as the technical benchmark (Gold Standard) for long-term industrial operations due to

its high chemical stability and superior degradation kinetics under authentic diurnal thermal cycling [3].

However, from a sustainable engineering and circular economy perspective, **Used Motor Oil (UMO)** emerges as a highly competitive and eco-friendly alternative for North African contexts. It effectively addresses environmental hazards associated with improper oil disposal in Algeria while maintaining a reliable heat transfer capacity. The slightly lower thermal stability of UMO can be economically mitigated through simple mechanical filtration and reprocessing protocols before integration into the PTC loop, making it an optimal candidate for cost-effective solar desalination units [4]..

Chapter III . Experimental Investigation and Performance Analysis

III.1 Experimental Strategy:

This chapter presents the experimental investigation conducted on the solar desalination system integrated with a Parabolic Trough Collector (PTC). The main objective of this experimental work is to evaluate and compare the thermal performance of two heat transfer fluids (HTFs), namely **Fresh Motor Oil (FMO)** and **Used Motor Oil (UMO)**, under the climatic conditions of Ouargla, Algeria.

The study focuses on examining the influence of the thermophysical properties of both fluids, including density, viscosity, specific heat capacity, and thermal conductivity, on the thermal behavior of the system and the productivity of the solar still. Particular attention is given to assessing the feasibility of reusing used motor oil as a sustainable heat transfer fluid in solar desalination applications.

III.2 Experimental Setup and Components:

The experimental prototype consists of a 2m cylindrical-parabolic concentrator designed to focus solar radiation onto a central absorber tube. The system includes a circulation loop, a heat exchanger, and a desalination unit (solar still).



Figure III.2- 1 Experimental setup of the solar desalination system featuring a parabolic trough and dual solar stills.

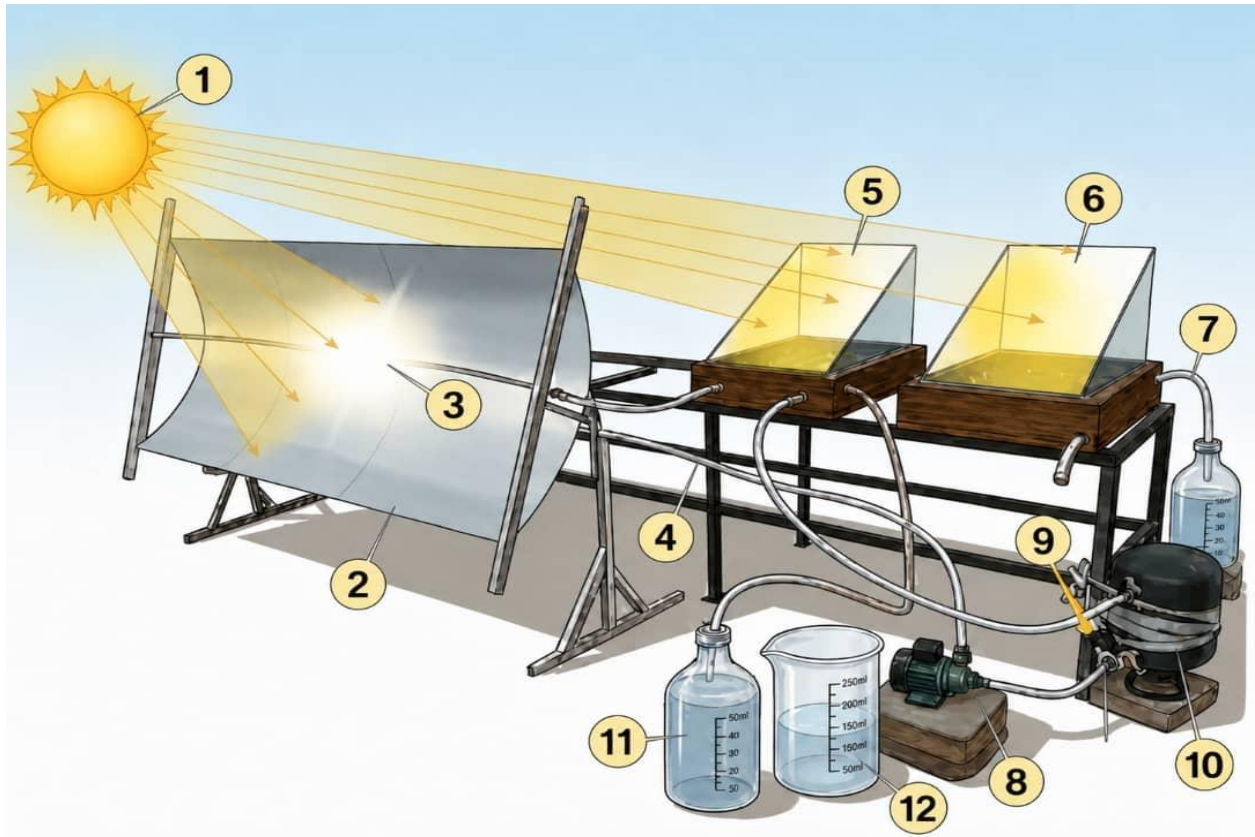


Figure III.2- 2 Schematic diagram of a solar water distillation system integrated with a Parabolic Trough Collector (PTC)

Tableau III.2 1 Components of the solar water distillation system integrated with a parabolic trough collector PTC

Number	Component Name
1	Sun (Solar Radiation Source)
2	Parabolic Trough Collector (PTC)
3	Receiver Tube (Absorber)
4	Hot Fluid Transport Pipe
5	Solar Still 1
6	Solar Still 2
7	Fresh Water Outlet
8	Fluid Pump
9	Pressure Gauge
10	Tank/Heat Exchanger

11	Distilled Water Collection Bottle
12	Measuring Beaker

This system represents a Hybrid Solar Desalination Plant that combines a Parabolic Trough Collector (PTC) with Solar Stills to maximize the efficiency of freshwater production.

III.2.1 Technical Description of the PTC-Coupled Solar Desalination System

This section details the operational components and mechanical interactions of the developed prototype, illustrating the transition from solar thermal collection to freshwater production.

III.2.2 Geometric Configuration and Oil Volume Calculations

III.2.2.1 Dimensions of the Copper Heat Exchanger Tube

To ensure optimal thermal transfer from the parabolic trough concentrator loop into the distillation matrix, a copper absorber tube was configured with the following precise geometric specifications:

- **Tube Length (L):** 11.53 m
- **Tube Outer Diameter (D):** 16 mm = 0.016 m
- **Tube Radius (R):** 8 mm = 0.008 m

III.2.2.2 Calculation of the Oil Volume

Mathematical Formulation:

$$V = \pi \cdot r^2 \cdot L$$

Where:

- V: Total volume of Oil (m^3).
- R: Core radius (m).
- L: Total descriptive length (m).

Numerical Application

Substituting the precise experimental values into the volume equation:

$$V = 3.1416 \times (0.008^2) \times 11.53$$

$$V = 3.1416 \times 0.000064 \times 11.53$$

$$V = 0.002318m^3$$

Converting the volumetric matrix from cubic meters (m^3) to Liters (L) to match the actual amount added to the tube:

$$V = 2.318liter$$

III.2.3 Parabolic Trough Collector (PTC) Loop (Thermal Harvesting Phase)

The parabolic reflective concentration sub-system serves as the primary thermal booster of the desalination plant:

- **Concentration Function:** The highly reflective curved surface focuses direct solar irradiance onto a central focal receiver pipe (absorber tube) running through the focal line of the collector.
- **Heat Transfer Mechanism:** The selected Heat Transfer Fluid (either FMO or UMO) is circulated through this absorber tube. Due to the high concentration ratio, the oil absorbs intense thermal energy, reaching elevated operating temperatures far exceeding conventional flat-plate configurations.
- **Thermal Injection:** The superheated oil acts as a thermal "booster," transferring its heat energy to the saline water basin via a dedicated heat exchange loop, drastically minimizing the thermal inertia of the system during morning startup.

III.2.4 Active Solar Still Units (Evaporation and Condensation Phase)

The distillation core consists of customized, glass-covered single-basin thermal structures operating in active mode:

- **Accelerated Evaporation:** Pre-heated saline water in the basins—assisted by the thermal energy delivered from the external oil loop—undergoes rapid vaporization. This process is further intensified by the greenhouse effect generated under the sealed glass covers.
- **Thermal Purification:** The phase change from liquid to vapor ensures absolute separation, leaving behind non-volatile compounds, dissolved salts, heavy metals, and biological contaminants at the basin liner.
- **Condensation Mechanism:** The rising vapor contacts the cooler internal surface of the tilted glass cover, losing latent heat and condensing into pure freshwater droplets.

These droplets flow by gravity along the inclination into the designated collection channels.

III.2.5 Fluid Circulation and Thermal Accumulation Sub-System

The lower section of the experimental setup manages the fluid dynamics and thermal stabilization of the prototype:

- **Circulation Pump:** A calibrated thermal pump maintains a constant volumetric flow rate of the HTF through the PTC receiver, preventing localized fluid overheating and ensuring steady thermal delivery to the distillation units.
- **Thermal Storage Tank (Accumulator):** This insulated vessel functions as a thermal buffer and pressure regulator. It stabilizes fluid temperature fluctuations caused by transient cloud cover and stores excess thermal energy to prolong operation during periods of low solar irradiance.

III.2.6 Distillate Collection and Quantitative Metrology

The final stage of the prototype focuses on product recovery and performance evaluation:

- **Freshwater Collection:** The high-purity distilled water is continuously drained from the collection troughs into sealed glass storage bottles to prevent ambient contamination.
- **Volumetric Measurement:** Graduated laboratory glassware (beakers and cylinders) is utilized to accurately quantify the daily cumulative yield ($R_{mlor} \text{ L/m}^2 \cdot \text{day}$). This parameter represents the primary empirical metric for evaluating the thermodynamic efficiency of the specific HTF protocol.

III.3 Data Acquisition, Monitoring Protocol, and Instrumentation

To ensure the precision and repeatability of the binary comparative study between the two evaluated HTFs (FMO and UMO), a rigorous data acquisition protocol was established. Environmental, thermal, and hydraulic parameters are systematically recorded every 30 minutes throughout a 10-hour daily cycle using calibrated laboratory instruments.

III.3.1 Thermal Monitoring Sub-System

The temperature gradients across the prototype represent the primary parameters for calculating the thermodynamic efficiency of the PTC loop and the solar still:

- **K-type Thermocouples:** Strategically positioned at the inlet and outlet of the parabolic receiver tube to measure the **Inlet Fluid Temperature (T_{f,in})** and **Outlet Fluid Temperature (T_{f,out})**. (Unit: °C)
- **Digital Thermometer:** Utilized for real-time tracking of the **Ambient Temperature (T_{abc})** and the **Saline Water Temperature (T_{eau})** inside the active solar still basin. These readings enable the calculation of the core thermal gradient (ΔT). (Unit: °C)



Figure III.3.1.1 Digital Thermometer Setup

III.3.2 Radiometric and Hydraulic Monitoring

The thermal power harvested by the mineral-based oils is directly governed by solar availability and fluid dynamics:

- **Solar Irradiance Meter / Pyranometer (MacSolar):** A specialized radiometric instrument used to capture and quantify the global **Solar Radiation Intensity (G)** hitting the aperture area of the concentrator. This parameter represents the raw energy input required to compute the optical and thermal efficiency of the collector. (Unit: W/m^2)



Figure III.3.2.1 MacSolar Solarimeter

- **Flowmeter:** Connected directly inline within the HTF loop to monitor and control the fluid movement through the absorber tube. This device is essential for maintaining and verifying a constant **Volumetric Flow Rate (dotV)** between the FMO and UMO experimental runs, as the flow rate directly dictates the residence time and the convective heat transfer coefficient of the oil inside the receiver. (*Unit: L/min or L/h*)



Figure III.3.2.2 Inline Flowmeter Setup

III.3.3 Productivity and Distillate Metrology

The definitive indicator used to judge the performance of each motor oil configuration is the volume of freshwater generated:

- **Graduated Measuring Cylinder:** A calibrated laboratory glass vessel used at the end of each hourly interval and after the completion of the 10-hour diurnal cycling to quantify the **Daily Cumulative Distillate Yield (Rml)**. This metric serves as the

baseline for evaluating the final desalination efficiency of the prototype. (Unit: ml or $L/m^2 day$)



Figure III.3.3.1 Graduated Measuring Cylinders for Daily Distillate Yield Quantification

III.4 Engineering details of solar still components(basins and glass sheets)

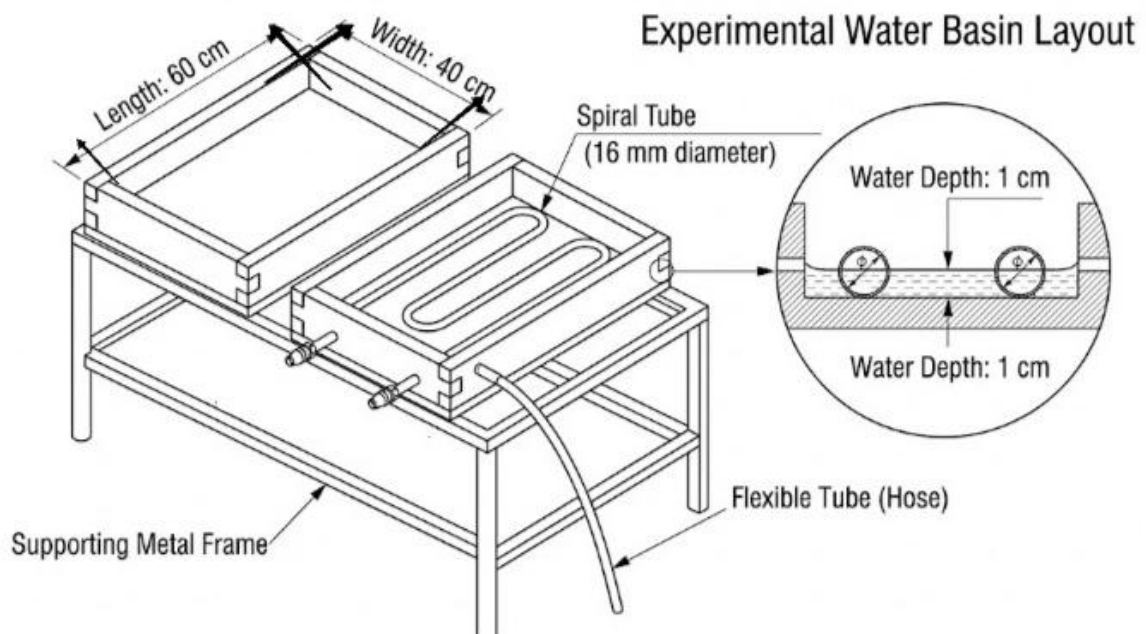


Figure III.3.3.1 Experimental water basin layout

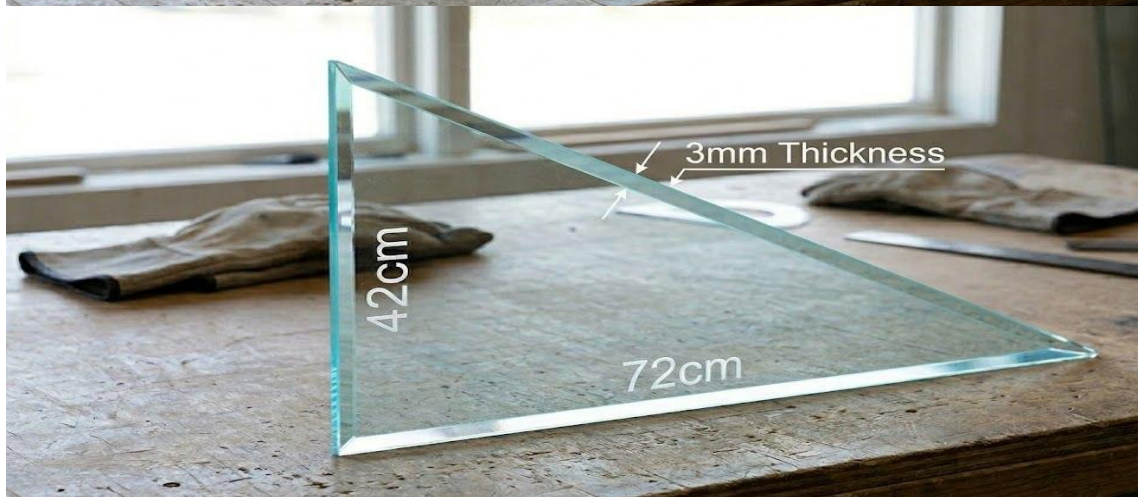
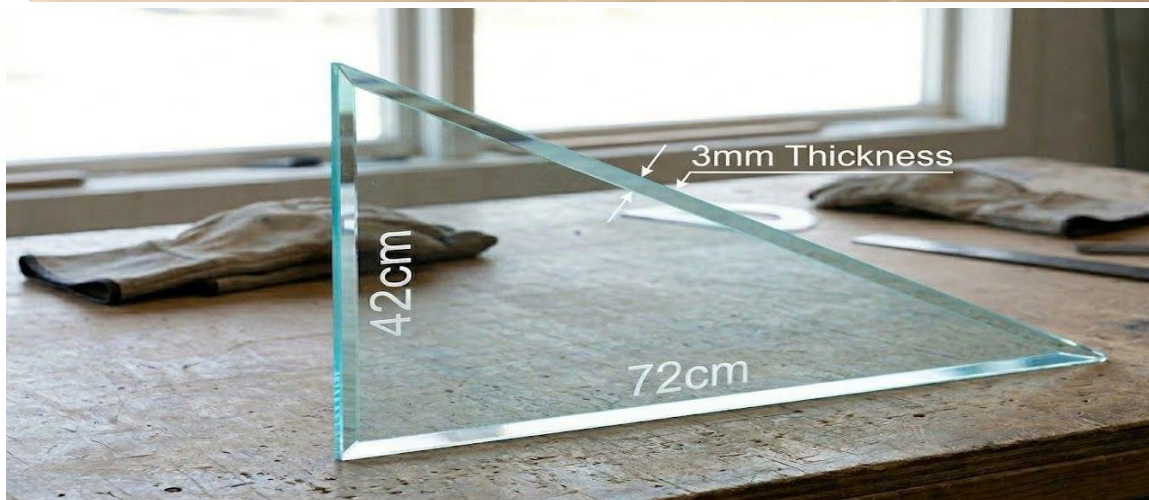




Figure III.3.3.2 Geometrical Specifications of the Water Basin and Glass Panel



Figure III.3.3.3 Solar stills

Wooden Frame Length: 69 cm Height of wooden frame: 49.7 cm

Wooden Frame width: 12.5 cm

1-Distillation Basin

2-Heat Exchanger / S-Pipe

3-Wooden Frame

4-Inlet Ports

5- Outlet Ports

6-Connecting Hose

A comparative study was conducted between the reference case and the enhanced case:



III.3.3.4 Enhancement/Active Element Case



Figure III.3.3.5 Reference/Base

Table III.3.3- 1 Performance Enhancement of Solar Distillation using a Parabolic Trough Collector: A Comparative Experimental Study

Feature	The Modified / Enhanced System	The Reference System (Conventional)
Definition	Refers to the solar still integrated with technical enhancements, Parabolic Trough specifically a Heat and a Collector (PTC) Exchanger coil	Represents the standard solar still operating without any external modifications. It relies solely on direct solar radiation to heat the basin water
Operational Mechanism	Dual-heating mechanism: Direct solar radiation + thermal energy harvested by the PTC and transferred via the heat exchanger	Natural evaporation driven by local solar flux
Primary Purpose	To demonstrate the enhancement in and the thermal efficiency distillate productivity increase in	to establish the baseline Acts as a natural performance and yield under specific local conditions
Role in Study	Validates the feasibility and performance gains of the integrated solar thermal system	Provides a comparative standard (Control) to evaluate the effectiveness of the proposed improvements

III.5 Experimental Results, Thermal Discussion, and Desalination Performance

III.5.1 Characterization and Thermophysical Properties of HTFs (FMO vs. UMO)

Before evaluating the dynamic system response, the baseline thermophysical properties of Fresh Motor Oil (FMO) and Used Motor Oil (UMO) were determined via laboratory testing. The measured and calculated parameters—density (ρ), kinematic viscosity (ν), specific heat capacity (C_p), and thermal conductivity (λ)

A- Viscosity & Density:



Figure III.5.1.1 Laboratory apparatus used for measuring HTF kinematic viscosity and density

Table III.5.1- 1 Thermophysical properties of new and used motor oils as heat transfer fluids (HTF).

Types of Motor Oil	dynamice Viscosity $mpa.s$	kinematic Viscosity mm^2/s	density g/cm^3
Fresh Motor Oil (FMO)	150.480	174.70	0.87024
Used Motor Oil (UMO)	86.279	100.70	0.86219

The experimental results indicate a significant reduction in both dynamic and kinematic viscosity for the Used Motor Oil (UMO) compared to the Fresh Motor Oil (FMO), dropping by approximately 42.6% and 42.3% respectively. This pronounced decline in viscosity—despite the slight decrease in density from 0.87024 g/cm^3 to 0.86219 g/cm^3 —is directly attributed to fuel dilution and the severe thermal shearing of long-chain polymer viscosity index improvers (VII) during engine service life. While carbon soot and metallic debris typically tend to elevate viscosity, the counter-acting effect of fuel contamination and chemical degradation of the oil base stock dominated the physical behavior, resulting in a

lighter fluid with enhanced hydraulic properties (lower pumping power) for the parabolic trough circulation loop

B- Specific Heat Capacity (Cp) Formulations: The sensible heat exchange rate (q) and the thermal balance within the calorimeter system were calculated using the following thermodynamic expressions:

$$q = \frac{m \cdot C \cdot \Delta T}{\Delta t}$$

$$C_p = \frac{q \cdot \Delta t (S)}{m \cdot \Delta T (^{\circ}C)}$$

$$C_{p, oil} = \frac{Q \cdot \Delta T}{m \cdot \Delta t}$$

Applying the exact experimental inputs from the trials, the operational equations yield:

$$C_{p_{eau}} = \frac{9.66v \times 2.25A \times 90s}{0.105kg \times 5.4.^{\circ}C} = 4186 \text{ J / Kg} \cdot ^{\circ}C$$

$$\Delta T_{eau}: T1 = 25 ^{\circ}C \text{ and } T2 = 30.4^{\circ}C$$

$$C_{p_{eau}} = 4.186 \text{ KJ / Kg} \cdot ^{\circ}C$$

For FMO: $\Delta T_{New}: T1=25^{\circ}C$ and $T2=40.06^{\circ}C$

$$C_{p_{new}} = \frac{11.66 \times 3 \times 90}{0.105 \times 15.06} = 1990.893 \text{ J / Kg} \cdot ^{\circ}C$$

$$C_{p_{new}} = 1.990 \text{ KJ / Kg} \cdot ^{\circ}C$$

For UMO: $\Delta T_{used}: T1 = 29.5^{\circ}C$ and $T2 = 40.2^{\circ}C$

$$C_{p_{used}} = \frac{9.66 \times 2.28 \times 90}{0.105 \times 15.06} = 1874.716 \text{ J / Kg} \cdot ^{\circ}C$$

$$C_{p_{used}} = 1.874 \text{ KJ / Kg} \cdot ^{\circ}C$$



Figure III.5.1.2 Laboratory apparatus and electrical circuit used for oil specific heat capacity (C_p) determination.

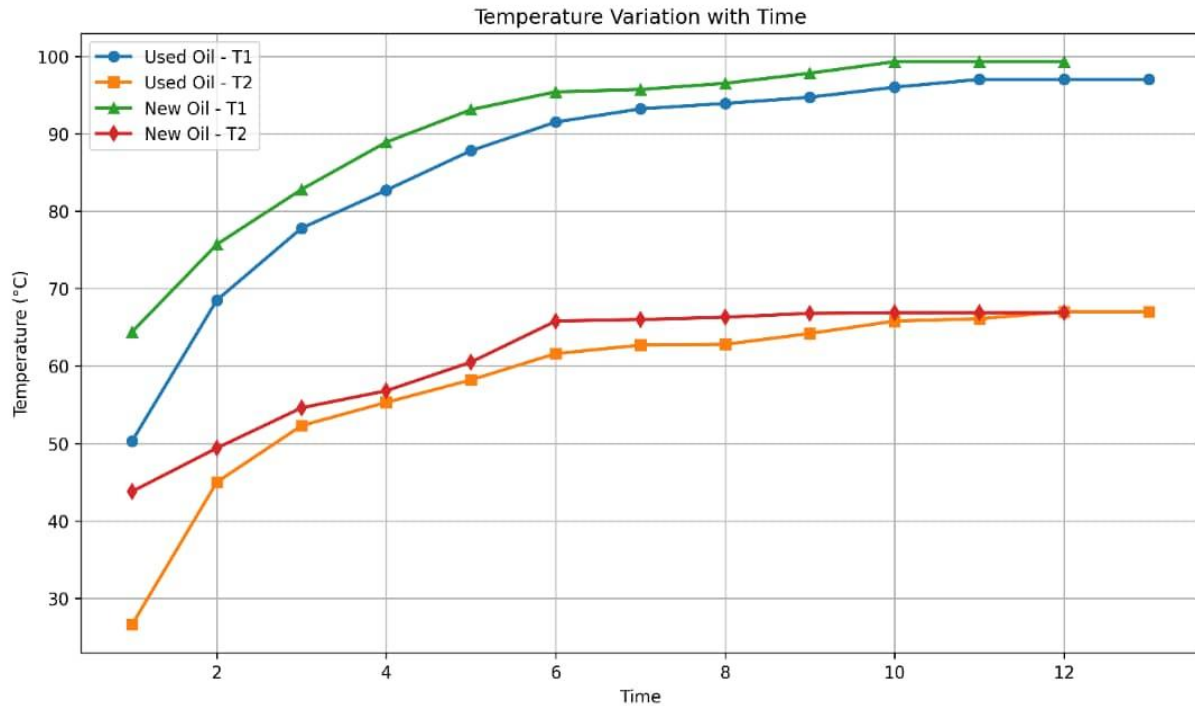
C Motor Oil -Thermal Conductivity (λ):

Figure III.5.1.3 Temperature-time graph for estimating conductivity

The rate of conductive heat transfer through the fluid layer was determined using Fourier's baseline adaptation:

Brief Analysis of the Temperature Curves

The graph shows the temperature variation of new oil and used oil at two measurement points (T1 and T2) over time.

For both oils, the temperature increases rapidly during the first few time intervals and then gradually approaches a stable value, indicating that the system reaches thermal equilibrium.

The new oil exhibits higher temperatures than the used oil at both T1 and T2 throughout the experiment.

At T1, the new oil reaches about 99–100°C, while the used oil stabilizes around 97°C.

At T2, both oils stabilize near 67°C, but the new oil reaches this temperature slightly faster.

The temperature difference between T1 and T2 is maintained during the experiment, showing a continuous heat transfer through the oil sample.

The faster temperature rise and higher final temperatures of the new oil suggest that it has better heat transfer characteristics (higher thermal conductivity) than the used oil.

Conclusion:

The new motor oil demonstrates more efficient heat transfer compared to the used oil, as evidenced by its faster heating rate and higher temperatures at both measurement points.

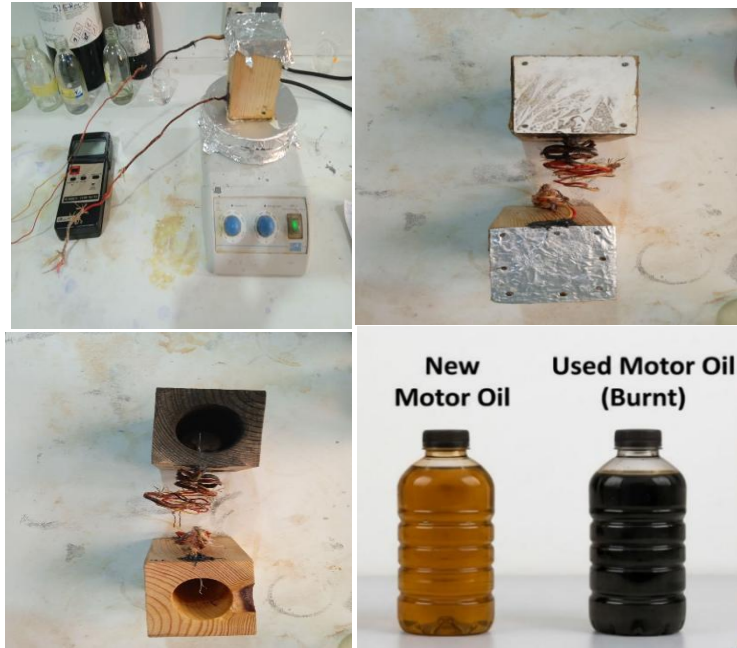


Figure III.5.1.4 The provided images illustrate a locally designed and fabricated experimental apparatus used to measure temperature differences(ΔT) and determine the thermal conductivity (λ) of the oil samples

Thermal Conductivity (λ):

Parameters and Nomenclature:

Cylinder Diameter(d):4cm = 0.04m

Cylinder Radius (r):d/2=2cm=0.02m

Cylinder Length / Thickness (Δx):8cm=0.08m

Heater Power (P or Q):630 W

Time (t): 1.5 hours = 5400s

Calculation of the Cross-Sectional Area (S):

$$S = \pi r^2 = \pi \times (0.02)^2 = 0.0012566m^2$$

Mathematical Formulation Rearranging Fourier's Law to solve for the thermal conductivity (λ):

λ : Thermal conductivity(w/m.k or w/m. °C)

Q: Heat power:(630w)

Δx : Length of the cylinder: (0.08m)

S: Cross-sectional are: (0.0012566m²)

ΔT : Temperature difference: (K or °C)

Temperature Difference for New Oil (ΔT): 30°C ($T_1=97^\circ\text{C}$ $T_2=67^\circ\text{C}$)

Temperature Difference for Used Oil (ΔT): 32.4°C ($T_1=99.3^\circ\text{C}$ $T_2=66.9^\circ\text{C}$)

$$\lambda = \frac{Q \times \Delta x}{S \times \Delta T}$$

$$\text{For FMO: } \lambda = \frac{630 \times 0.08}{0.001256 \times 30} = 1337.87 \text{ W/m} \cdot ^\circ\text{C}$$

$$\text{For UMO: } \lambda = \frac{630 \times 0.08}{0.001256 \times 32.41} = 1238.02 \text{ W/m} \cdot ^\circ\text{C}$$

Based on the laboratory investigations, the continuous heat input was optimized within the steady-state conduction regime. To avoid thermal convection currents and ensure pure conduction through the oil layer, the power input was finely tuned within the operational range of 0.5 W to 0.1 W.

The precise heat flow rate of $Q = 0.07 \text{ W}$ was successfully achieved by calibrating the electrical voltage (U) and current intensity (I) according to Joule's Law ($P = U \cdot I$):

$$Q(w) = P = U(v) \cdot I(A) = 0.07 \text{ V} \times 1 \text{ A} = 0.07 \text{ W}$$

The rate of conductive heat transfer through the fluid layer was determined using Fourier's baseline adaptation:

$$\lambda = \frac{Q \times \Delta x}{S \times \Delta T}$$

Used Engine Oil (Used Motor Oil): Substituting the specific values for the used engine oil ($\Delta T = 32.4^\circ\text{C}$):

$$\lambda = \left(\frac{0.07 \times 0.08}{0.0012566 \times 32.4} \right) = 0.1376 \text{ W/m} \cdot ^\circ\text{C}$$

New Engine Oil (Fresh Motor Oil):Substituting the specific values for the new engine oil ($\Delta T = 30^\circ\text{C}$):

$$\lambda = \left(\frac{0.07 \times 0.08}{0.0012566 \times 30} \right) = 0.1486 \text{ W/m} \cdot ^\circ\text{C}$$

Table III.5.1- 2 Thermophysical Properties of FMO and UMO at Baseline Conditions

Parameter	UMO used	FMO new	Unit
Density (at 25°C)	0.86219	0.87024	g/cm^3
Kinematic Viscosity (at 40°C)	100.70	174.70	mm^2/s
dynamice Viscosity	86.279	150.480	$\text{mpa} \cdot \text{s}$
Specific Heat Capacity (C_p)	1.874	1.990	$\text{kJ/kg} \cdot ^\circ\text{C}$
) λ Thermal Conductivity (	0.1376	0.1486	$\text{W/m} \cdot ^\circ\text{C}$

III.5.2 Thermal Performance and Yield Analysis of Used Motor Oil (UMO Loop)

This section assesses the desalination loop utilizing Used Motor Oil (UMO) as the external HTF, evaluated under identical solar conditions against a standard passive control still.

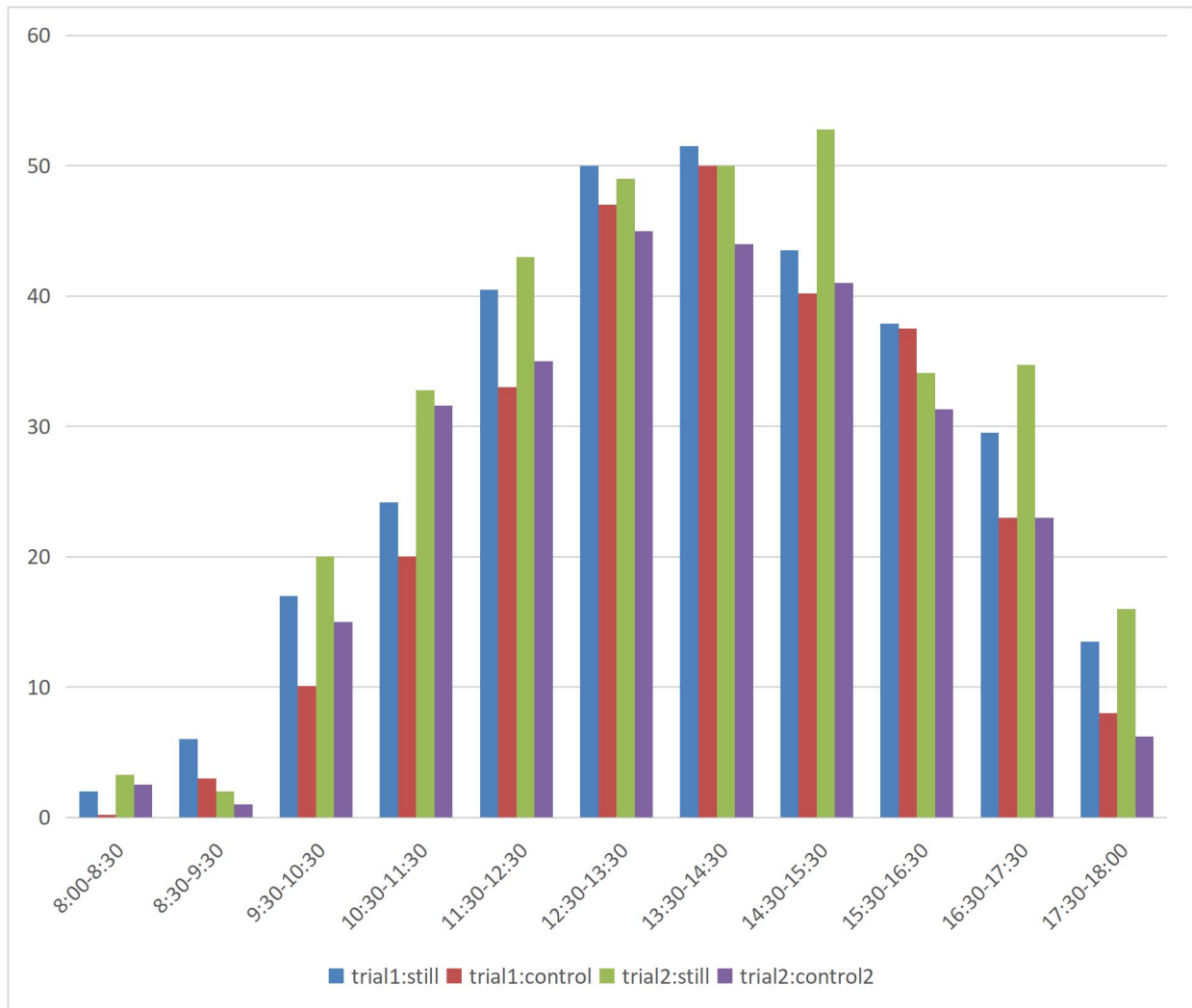
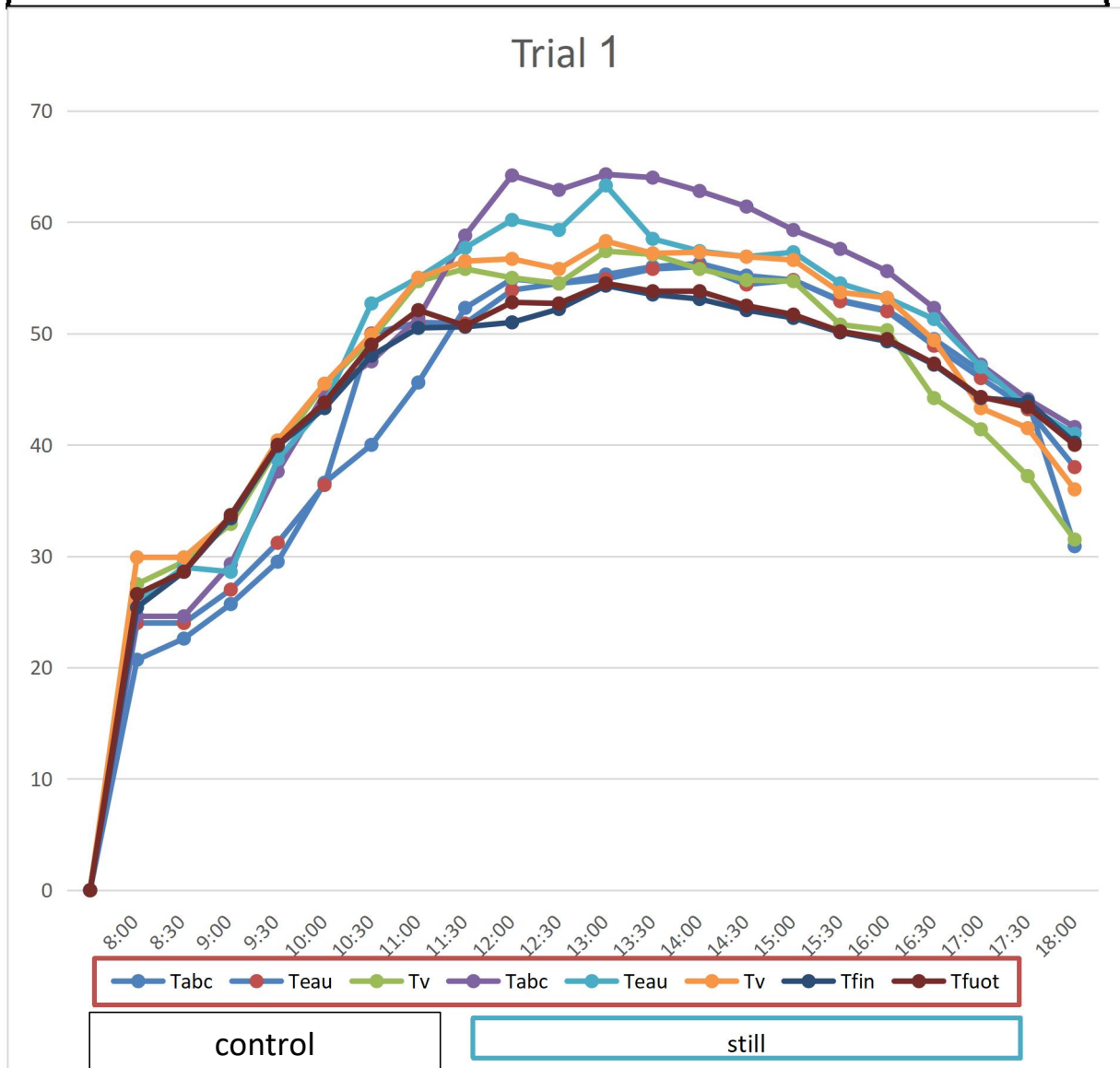
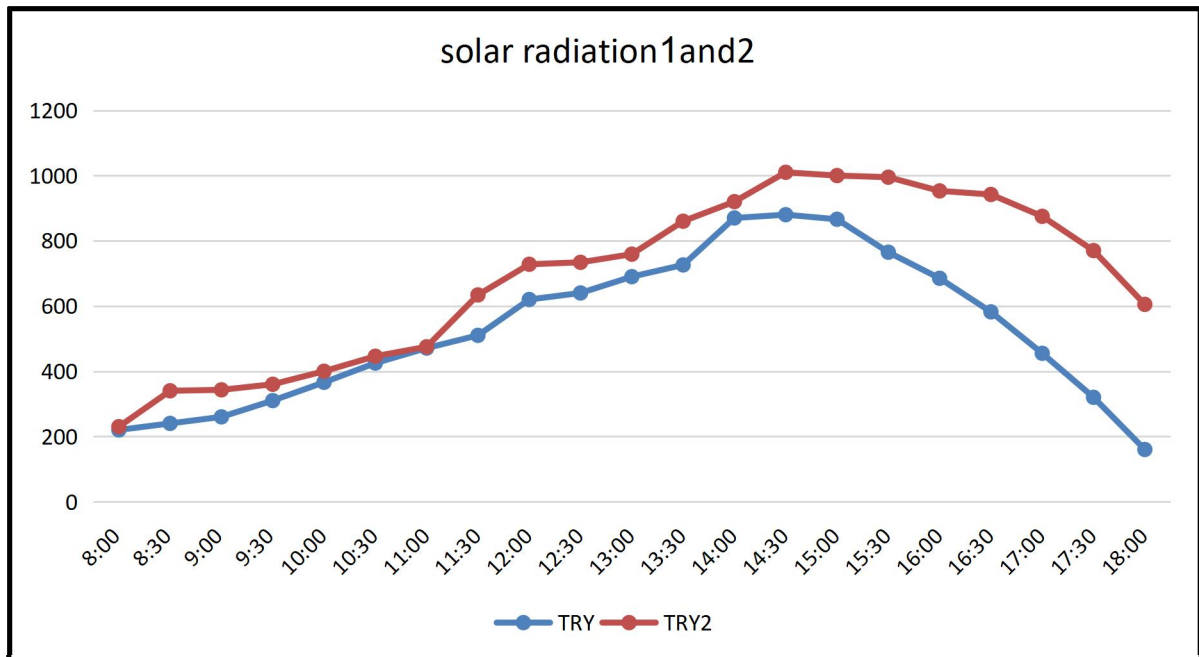


Figure III.5.2.1 Hourly distilled water productivity rates for the UMO thermal loop system versus the conventional solar still as a function of time.



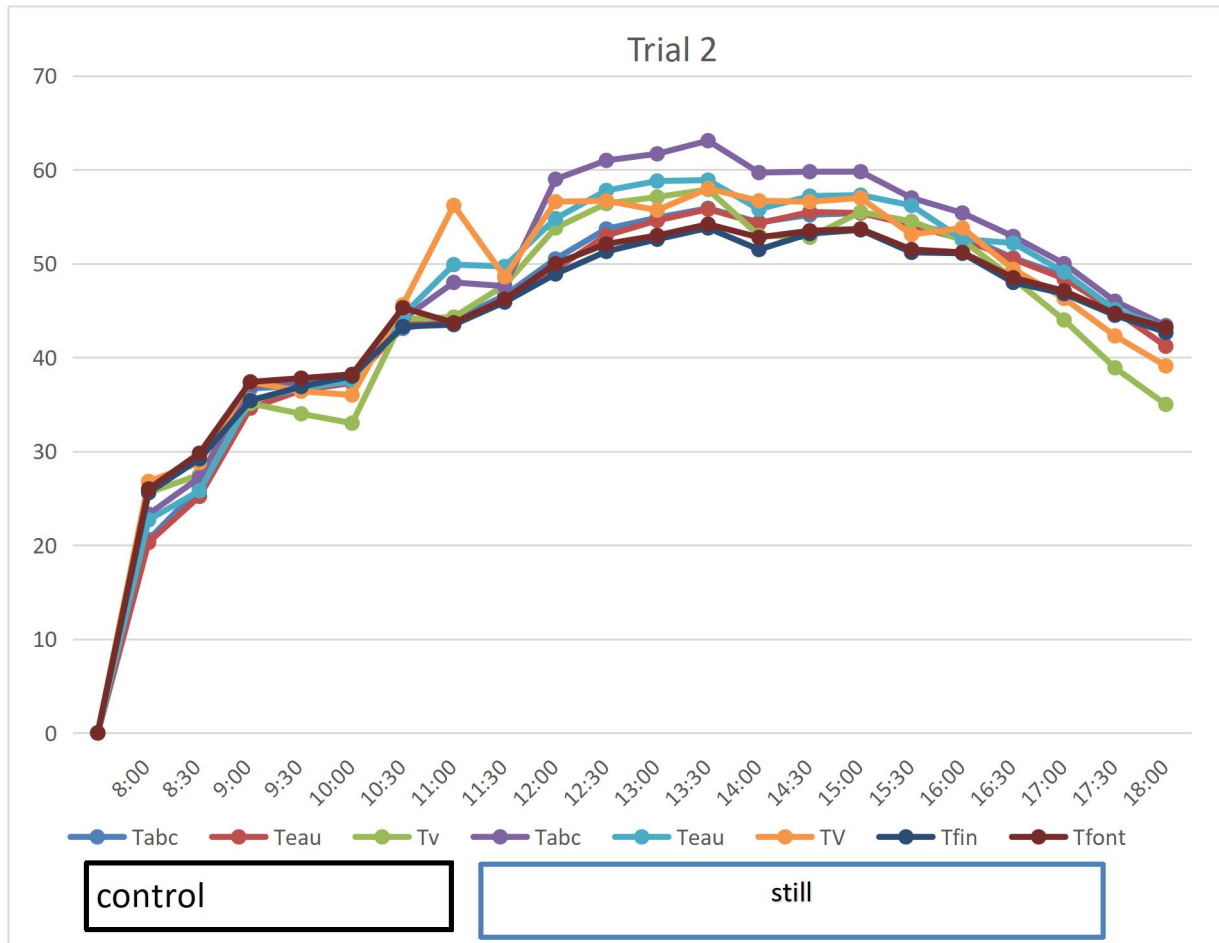


Figure III.5.2 Hourly and Cumulative Distilled Water Yield Curves for Used Motor Oil (UMO) Loop vs. Passive Control Still

UMO Desalination Discussion: As demonstrated by the empirical data in Figure III.5.2.1, the improved solar still incorporating the UMO thermal loop significantly outperforms the conventional solar still across all monitored intervals. During peak solar windows (11:30 AM to 02:30 PM), the hourly productivity of the improved solar still reached maximum operational thresholds of 51.5 mL/h in Trial 1 and 52.8 mL/h in Trial 2. This notable extraction enhancement is directly attributed to the integrated thermal loop, allowing the improved solar still to maintain higher basin temperatures compared to the passive conventional solar still. Furthermore, due to the calculated specific heat capacity and molecular thermal conductivity of the spent engine oil ($\lambda_{\text{used}} = 0.1376 \text{ W/m.C}$ and $C_p = 1.874 \text{ kJ/kg.C}$), the circulating fluid efficiently stores and transports sensible heat, acting as a localized thermal storage medium. This allows the improved solar still to extend its evaporation cycle and sustain distillation kinetics during early evening hours when solar irradiance declines sharply, yielding 13.5–16.0 mL at 18:00 PM, whereas the conventional solar still experiences rapid cooling and drops to a minimal output of only 6.2–8.0 mL.

III.5.3 Performance Analysis of the Fresh Motor Oil (FMO) Loop

The quantitative distillation output records for the primary active framework utilizing pristine Fresh Motor Oil (FMO) as the heat transfer medium are detailed in.

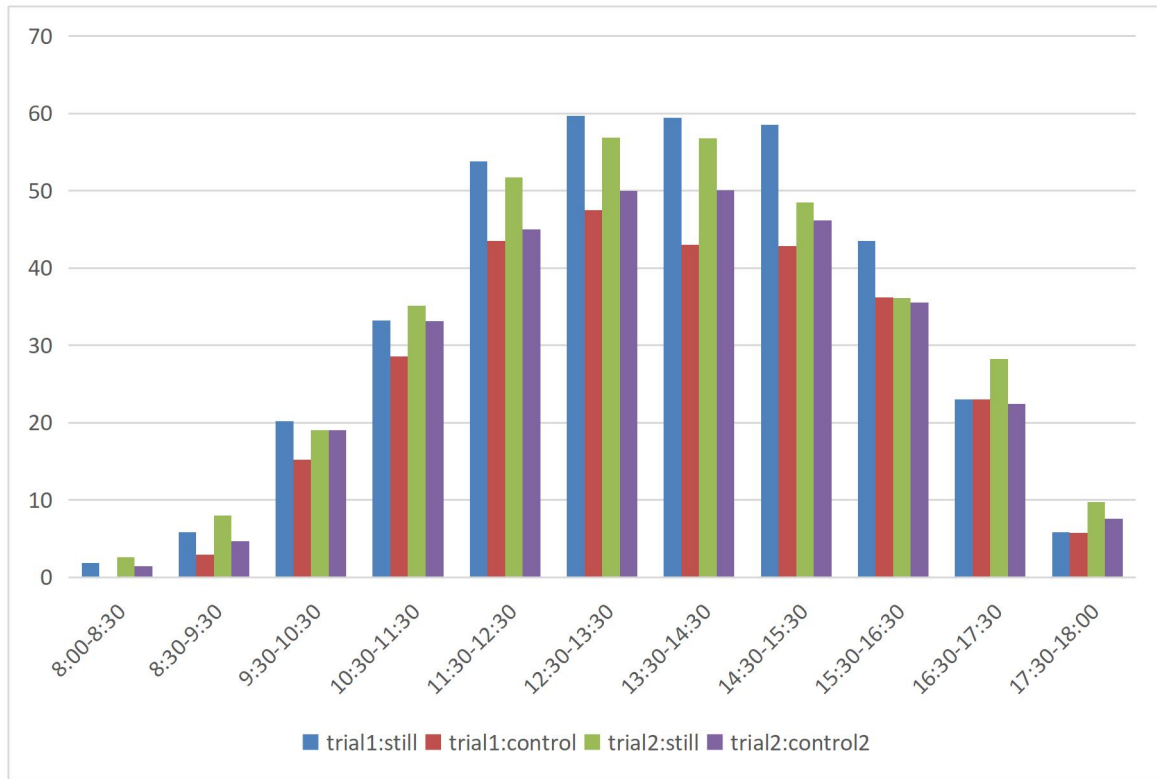
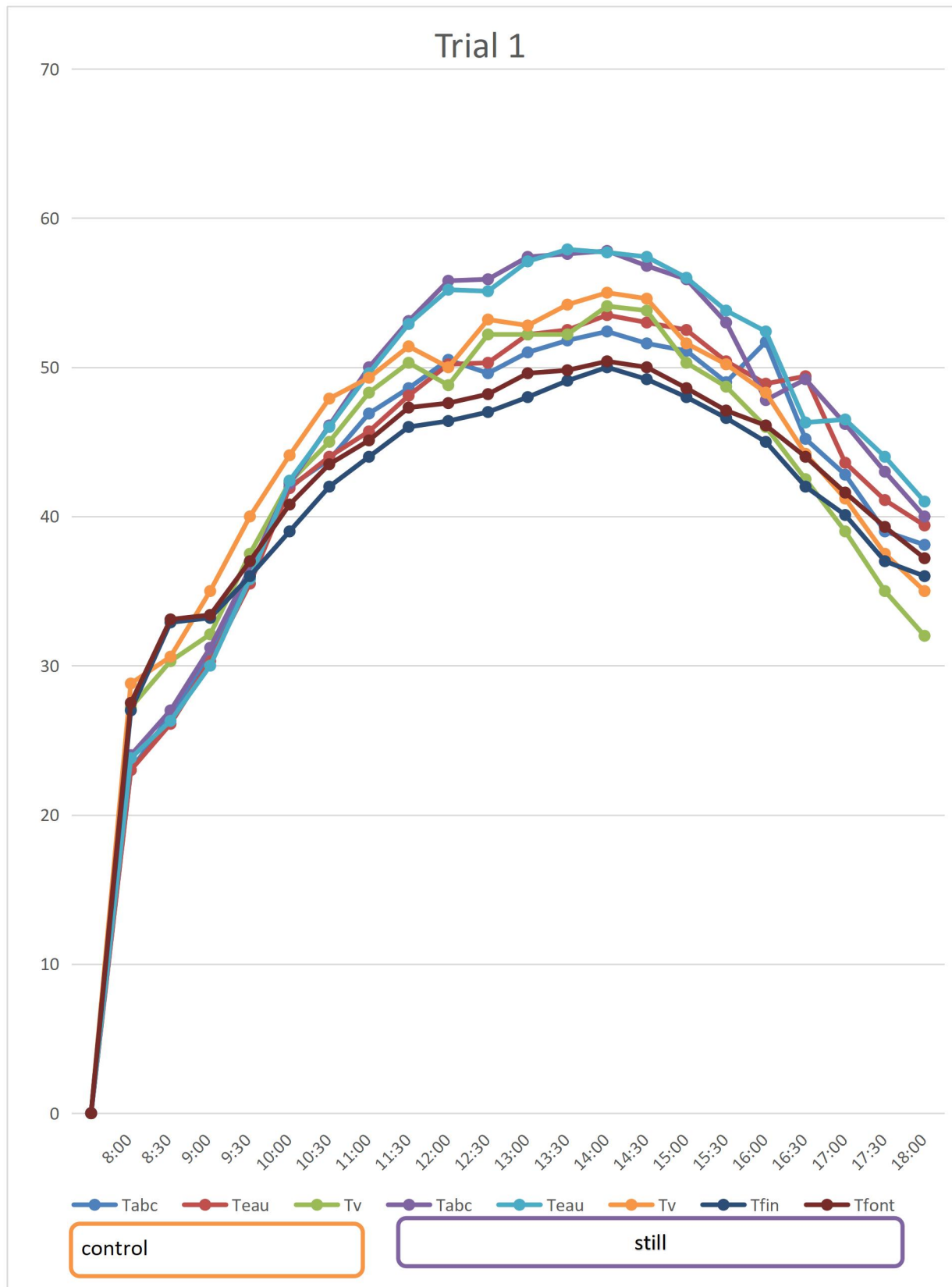


Figure III.5.3.1 Hourly distilled water productivity rates for the FMO thermal loop system versus the conventional solar still as a function of time.



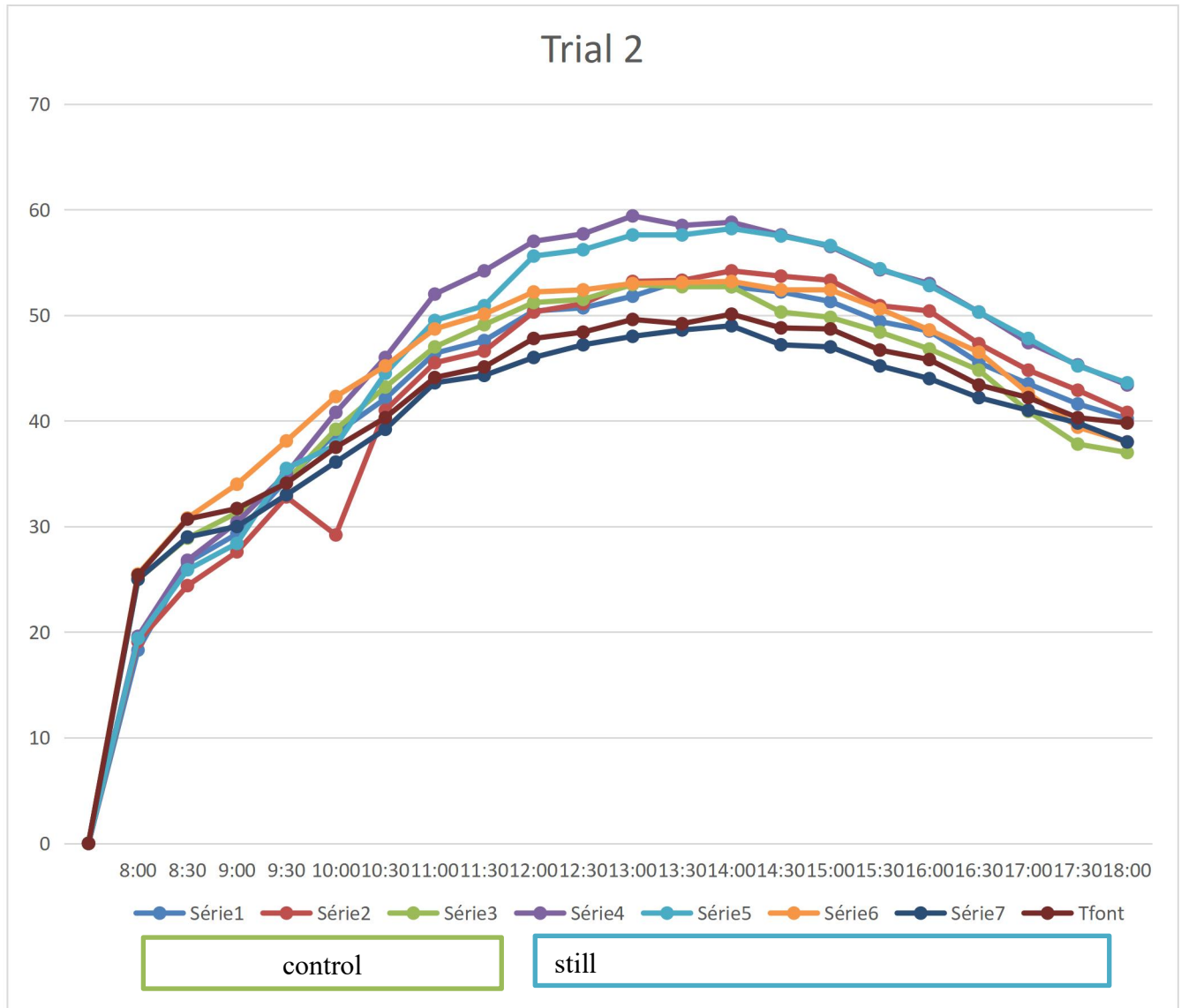


Figure III.5.3.2 Hourly Distilled Water Yield Curves for Improved Solar Still (FMO) vs. Conventional Solar Still

FMO Desalination Discussion: The thermal behavior of the FMO setup yields an accelerated phase-change response early in the day. Due to its higher molecular thermal conductivity ($\lambda_{\text{new}} = 0.1486 \text{ W/m.C}$), the fresh oil rapidly transmits thermal energy from the parabolic trough focus into the distillation basin matrix. Consequently, the evaporation chamber quickly reaches steady-state activation across both experimental runs. This drove the peak hourly distillation rate of the improved solar still up to 59.7 mL/h in Trial 1 and 56.9 mL/h in Trial 2 between 12:30 PM and 01:30 PM, significantly outperforming the conventional solar still which reached its respective peaks at 47.5 mL/h and 50.1 mL/h. The presence of the Expanded Polystyrene (EPS) base isolation underneath the basin ensures that conductive loss to the frame is heavily prevented, maximizing the total daily distillate conversion factor safely for both trials MO) Loop vs. Passive Control Still

III.5.4 Comparative Production Improvement Analysis

A. Mathematical Formulations:

Daily Cumulative Yield (V_{total}):

$$V_{total} = \sum V_{hourly}$$

Production Improvement Percentage ($Percentage_{improvement}$)

$$Percentage_{improvement} = \left(\frac{V_{improved} - V_{conventional}}{V_{conventional}} \right) \times 100\%$$

Where:

- $V_{improved}$: Total daily distillate volume from the improved solar still (mL).
- $V_{conventional}$: Total daily distillate volume from the conventional (control) solar still (mL).

B. Numerical Application

1. Used Motor Oil (UMO) Loop vs. Conventional Still

Production of improved distillate = 327.9 mL

Production of the witness distillate = 274.3 mL

$$Percentage_{improvement} = \frac{327.9 - 274.3}{274.3} \times 100\% = 19.54\%$$

2. Fresh Motor Oil (FMO) Loop vs. Conventional Still

Production of improved distillate = 364.6 mL

Production of the witness distillate = 288.4 mL

$$Percentage_{improvement} = \frac{364.6 - 288.4}{288.4} \times 100\% = 26.42\%$$

Table III.5.4- 1 Summary of Daily Water Yield and Improvement Percentages

Experimental Case	Improved Still Yield (mL)	Conventional Still Yield (mL)	Net Production Increase (%)
UMO Loop	327.9	274.3	19.54%
FMO Loop	364.6	288.4	26.42%

C. Discussion of Improvement Efficiency

The calculated results explicitly prove the thermodynamic advantage of integrating an external oil thermal loop. The improved solar still recorded a maximum production improvement of **26.42%** when utilizing Fresh Motor Oil (FMO) in Trial 1, which correlates directly with its higher thermal conductivity ($\lambda_{\text{new}} = 0.1486 \text{ W/mC}$), and up to **19.54%** when using recycled Used Motor Oil (UMO). This enhancement is directly linked to the steady thermal supply from the parabolic trough concentrator, which increases the baseline basin temperature and maintains active vaporization kinetics well above the performance limits of the passive conventional solar still.

III.5.5 Physicochemical Quality of Produced Distillate

To verify purification efficiency and ensure absolute containment, the generated distillate was analyzed. The comparative physicochemical properties are summarized in Table III.5.5-2.

Table III.5.5- 1 Comparative Physicochemical Properties of the Produced Distillate

Parameter (Unit)	Improved Still FOM	Improved Still UOM	Conventional Still
pH at 27°C	6.82	6.05	7.82
Dissolved Oxygen (mg/L)	7.82	7.24	6.5
Electrical Conductivity (μ S/cm)	63	93	1450
Total Dissolved Solids (mg/L)	32	47	928
Salinity (PSU)	0.03	0.04	0.93
Turbidity (FNU)	2.1	2.4	4.5

- ✓ pH Level: Both the new and used distillates are slightly acidic to neutral (6.82 and 6.05, respectively) compared to tap water, which is slightly alkaline at 7.82.

Dissolved Oxygen (mg/L): The new distillate contains the highest level of dissolved oxygen (7.82 mg/L), followed closely by the used distillate (7.24 mg/L), while tap water has the lowest amount (6.5 mg/L).

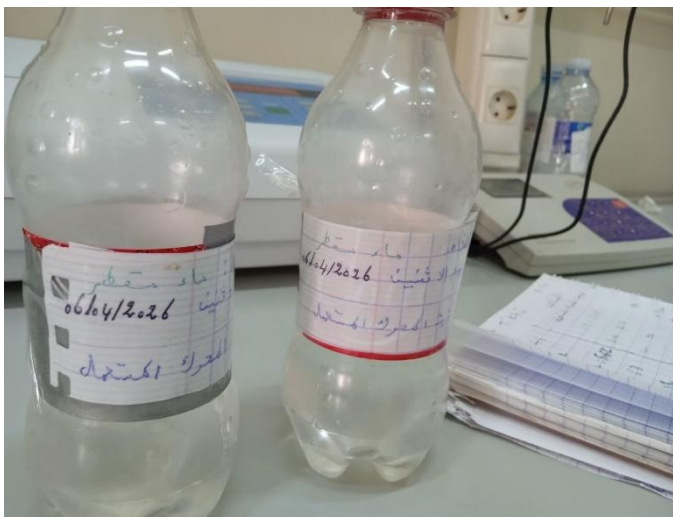
- ✓ Electrical Conductivity ($\mu\text{S}/\text{cm}$) & Total Dissolved Solids (mg/L): There is a massive difference here. Tap water has extremely high conductivity (1450 $\mu\text{S}/\text{cm}$) and TDS (928 mg/L). In contrast, the distillates show very low values, with the new distillate being the purest (63 $\mu\text{S}/\text{cm}$ and 32 mg/L).
- ✓ Salinity (PSU) & Turbidity (FNU): Tap water exhibits the highest salinity (0.93 PSU) and turbidity (4.5 FNU). The distillates have negligible salinity (0.03–0.04 PSU) and significantly lower turbidity levels, indicating high clarity and successful filtration.
- ✓ The comparison clearly demonstrates that the distillation process successfully purifies the water. Both distillate samples (new and used) show drastically lower levels of dissolved solids, conductivity, salinity, and turbidity compared to standard tap water, confirming high purification efficiency.



Figure III.5.5.1 Physio-Chemical Characterization Device for Distilled Water



Figure III.5.5.2 Produced Distilled Water / Distillate



GENERAL CONCLUSION

This experimental and laboratory study successfully demonstrates the feasibility and efficiency of coupling a Parabolic Trough Concentrator (PTC) with a solar desalination system utilizing motor oils within an external thermal loop for heat transfer and energy storage. By establishing a rigorous comparative framework between Fresh Motor Oil (FMO) and recycled Used Motor Oil (UMO), several key engineering and thermodynamic conclusions have been drawn:

Heat Transfer and Thermal Dynamics: Laboratory characterizations revealed a relative advancement for the Fresh Motor Oil due to its higher thermal conductivity ($\lambda_{\text{new}} = 0.1486 \text{ W/m}\cdot^{\circ}\text{C}$), which triggered an accelerated thermal response and allowed the system to achieve a peak focus temperature of up to 100°C . Conversely, the recycled Used Motor Oil displayed highly competitive and stable thermal performance, supported by its thermal conductivity $\lambda_{\text{used}} = 0.1376 \text{ W/m}\cdot^{\circ}\text{C}$ and specific heat capacity ($C_p = 1.874 \text{ kJ/kg}\cdot^{\circ}\text{C}$). This thermal inertia allowed the UMO loop to act as an effective thermal storage buffer, sustaining the evaporation kinetics well into the late afternoon hours.

Distillation Yield Performance: The distinct thermodynamic properties of the tested working fluids directly influenced the cumulative freshwater volume. The FMO circuit recorded the highest daily output improvement, achieving a 26.42% increase in cumulative yield compared to the passive conventional solar still. Meanwhile, the UMO circuit delivered a highly successful performance, securing a substantial production improvement of 19.54%.

Purification Quality and Structural Safety: Physicochemical analyses validated the outstanding deionization and mineral rejection capacity of the dual-loop setup. Total Dissolved Solids (TDS) plummeted from a highly saline baseline of 928 mg/L in raw tap water down to minimal trace levels of 32 mg/L for the FMO system and 47 mg/L for the UMO system, representing exceptional salt rejection rates of 96.55% and 94.93%, respectively. Furthermore, the stable pH range, low conductivity, and significantly reduced turbidity ($2.1\text{--}2.4 \text{ FNU}$) provided ultimate scientific proof regarding the structural integrity of the boundaries. The Expanded Polystyrene (EPS) and copper physical layouts completely prevented any volatile oil cross-contamination or chemical leakage into the produced freshwater.

Recommendations and Future Perspectives

To further expand the operational limits, scalability, and performance of PTC-coupled solar desalination systems, the following future research pathways are highly recommended:

- **Dynamic Flow Rate Optimization:** Investigate the impact of integrating a variable-speed circulation pump to optimize the oil mass flow rate within the copper absorber tube, minimizing localized thermal stress and maximizing convective heat transfer coefficients.
- **Advanced Thermal Energy Storage (TES):** Evaluate the integration of Phase Change Materials (PCMs), such as specialized paraffin waxes or metallic matrices, directly beneath the distillation basin to capture excess heat during mid-day and sustain distillation throughout the night.
- **Corrosion and Fouling Mitigation:** Conduct long-term durability assessments of the copper heat exchanger tube and basin coatings under high salinity conditions to prevent chemical scaling and electrochemical corrosion.
- **Economic and Environmental Feasibility:** Perform a comprehensive life-cycle assessment (LCA) and thermo-economic analysis to determine the precise cost-per-liter of freshwater produced on a large-scale industrial decentralized network.

Références

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