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Thermal Performance Evaluation of Coconut Coir Fiber Multi-Layer Insulation in Elevated Water Storage Tanks

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Abstract: Elevated water storage tanks in tropical climates are susceptible to significant heat gain, leading to elevated water temperatures and reduced utility. This study experimentally evaluates a coconut coir Fiber-based multi-layer insulation system comprising an inner virgin plastic tank, coconut coir Fiber, polyurethane foam, and an outer protective plastic layer. Two identical 15-liter tanks—insulated and non-insulated—were monitored under ambient summer conditions with hourly temperature measurements. Results demonstrate that the insulated tank significantly mitigates peak temperature rise, enhancing thermal stability. The combination of coconut coir Fiber and polyurethane foam provides effective thermal resistance while maintaining cost-efficiency and sustainability. This system offers a practical, eco-friendly solution for controlling heat gain in elevated water storage tanks.

Keywords: Coconut coir Fiber, multi-layer insulation, elevated water storage tanks, thermal performance, heat gain mitigation, polyurethane foam

I. INTRODUCTION

Elevated water storage tanks are commonly employed in both residential and industrial settings, yet regulating water temperature remains difficult under extreme environmental conditions. During hot periods, exposure to solar radiation raises the water temperature, limiting its suitability for domestic use. Conversely, in colder climates, low water temperatures can affect comfort. Such temperature variations often lead to greater dependence on energy-intensive heating and cooling systems.[8]

To address these challenges, researchers have been focusing on efficient and sustainable insulation solutions. Conventional materials, while effective, are often expensive and environmentally unsustainable. Natural Fibers such as bamboo and banana Fiber have therefore attracted considerable attention due to their low thermal conductivity and eco-friendly properties. Building on this concept, alternative Fibers like coconut coir offer potential for practical, cost-effective, and environmentally responsible insulation in elevated water storage systems, providing an opportunity for further experimental investigation.[2],[4],[14]

This study investigates a multi-layer insulation system using coconut coir Fiber, polyurethane foam, and virgin plastic to reduce heat gain and maintain stable water temperature in elevated water storage tanks. Effective insulation enhances energy efficiency, minimizes dependence on heating or cooling systems, and improves tank durability by limiting thermal stress.[6]

Eco-friendly materials like coconut coir Fiber provide a sustainable alternative to conventional synthetic insulation, effectively reducing heat gain and maintaining stable water temperatures under varying environmental conditions.[4],[7]

Selecting insulation materials requires balancing thermal efficiency, durability, and cost. While conventional materials like fiberglass and PU foam are effective but costly and less sustainable, natural Fibers offer an eco-friendly alternative. This study investigates a multi-layer system using coconut coir Fiber, PU foam, and virgin plastic to enhance thermal resistance while remaining cost-effective.[3],[14]

A. Objectives

The primary aim of this study is to design, fabricate, and evaluate a multi-layer insulation system for elevated water storage tanks using coconut coir Fiber, polyurethane foam, and virgin plastic. The specific objectives are:

1) To develop a cost-effective and environmentally sustainable insulation system.
2) To assess and compare the thermal performance of insulated and non-insulated tanks under real-time climatic conditions.
3) To examine the impact of insulation thickness and material combinations on water temperature stability and energy efficiency.
4) To evaluate the long-term durability and sustainability of coconut coir Fiber as an insulation material.

II. LITERATURE REVIEW

Maintaining stable water temperatures in elevated water storage tanks has become increasingly important due to growing energy demands and extreme climatic conditions. Studies show that conventional plastic and metal tanks are susceptible to significant heat gain from solar radiation, leading to elevated water temperatures and greater dependence on mechanical cooling systems [8]. Therefore, effective insulation is essential to minimize thermal fluctuations and improve energy efficiency.

Recent research emphasizes the increasing focus on sustainable and eco-friendly insulation materials. Natural Fibers, such as bamboo, banana, and coconut coir, are favoured for their renewability, biodegradability, and low thermal conductivity [2],[4],[14].

Coconut coir Fiber provides excellent thermal resistance, is lightweight, and offers good structural durability. Polyurethane foam, widely used in commercial insulation, exhibits very low thermal conductivity, making it highly effective in reducing heat transfer [3],[6].

Multi-layer insulation combines materials with complementary thermal properties, enhancing resistance and durability. Incorporating coconut coir with synthetic layers and a protective plastic outer layer effectively reduces solar heat gain and stabilizes water temperature.[5],[8]

Although previous research has explored individual insulation materials, few studies have examined cost-effective multi-layer systems for elevated water storage tanks under real-time conditions. Additionally, the combined thermal performance and sustainability of coconut coir Fiber integrated with polyurethane foam remain underexplored.

III. METHODOLOGY

A. Materials Used

Three materials were employed in the study:

Material	Thermal Conductivity (W/m·K)	Specific Heat (J/kg·K)	Density (kg/m³)
Virgin Plastic	0.33	1900	950
Coconut Coir Fiber	0.045	1500	120
Polyurethane Foam	0.021	1500	30

B. Experimental Setup

Two identical 15-liter elevated water storage tanks were prepared:

- Model 1: Non-insulated (Control)
- Model 2: Multi-layer insulated (Coconut coir Fiber + PU foam + virgin plastic)

Both tanks had the same dimensions: **30.56 cm × 25 cm**.

(Water Tank Before Insulation)

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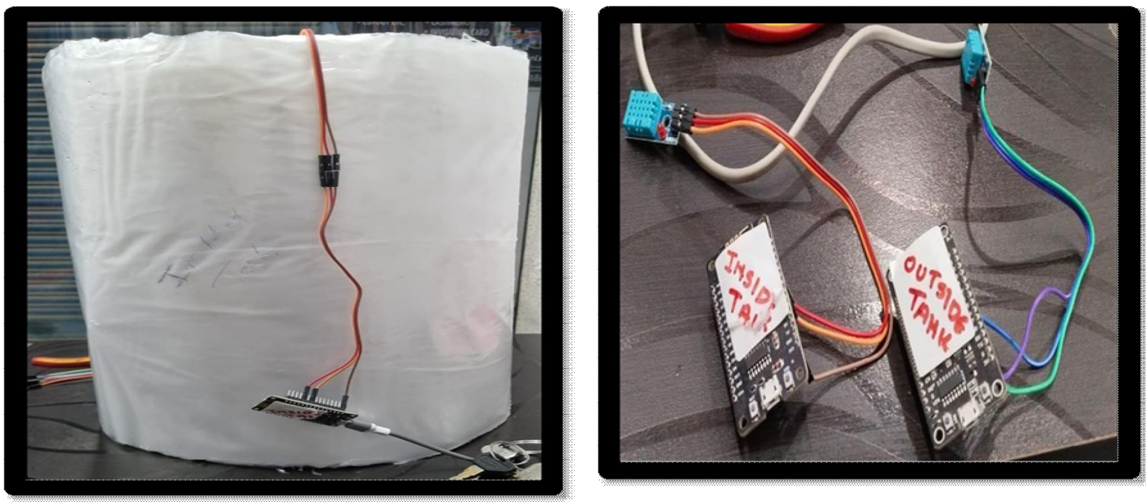
IV. INSULATION LAYER DESIGN

The insulated tank consisted of:

1) Inner Virgin Plastic Layer – 3 mm
2) Coconut Coir Fiber Layer – 10 mm
3) Polyurethane Foam Layer – 25 mm
4) Outer Virgin Plastic Layer – 7 mm

V. IOT MONITORING SYSTEM

Temperature sensors (DHT11) were installed inside and outside both tanks to measure internal and ambient temperatures. The data was transmitted through an **ESP8266 Wi-Fi module** to the **Adafruit IO cloud platform**, enabling real-time monitoring and storage of temperature data.



(Experimental Setup)

VI. DATA COLLECTION

Temperature was recorded hourly over 24 hours under summer conditions.

A. *Observations*

1) Non-insulated tank peak: 42°C
2) Insulated tank peak: 30°C
3) Temperature difference: up to 12°C

B. *Heat Transfer Analysis*

Heat transfer rate was calculated using:

1) *Single-Layer Conduction*

For a single homogeneous layer, the heat transfer rate is calculated using **Fourier's law**:

$$Q = \frac{k \cdot A \cdot (T_{\text{ambient}} - T_{\text{water}})}{d}$$

Where:

- Q= Heat transfer rate through the wall (W)
- k= Thermal conductivity of the material (W/m·K)
- A= Surface area of the wall (m²)
- $\Delta T = T_{\text{ambient}} - T_{\text{water}}$= Temperature difference across the layer (K)
- d= Thickness of the wall (m)

2) Multi-Layer Insulation

For a multi-layer system, each layer offers a separate thermal resistance (R_{th}). The overall heat transfer can be calculated as:

$$Q = \frac{\Delta T}{\sum_{i=1}^{n} R_{\mathrm{th},i}}$$

Where:

- $R_{\mathrm{th},i} = \frac{d_i}{k_i \cdot A}$ is the thermal resistance of the i^{th} layer
- d_i= Thickness of the i^{th} layer (m)
- k_i= Thermal conductivity of the i^{th} layer (W/m·K)
- A= Wall surface area (m²)
- n= Number of layers in the insulation system

C. Thermal Resistance

1) Thermal Resistance of Materials

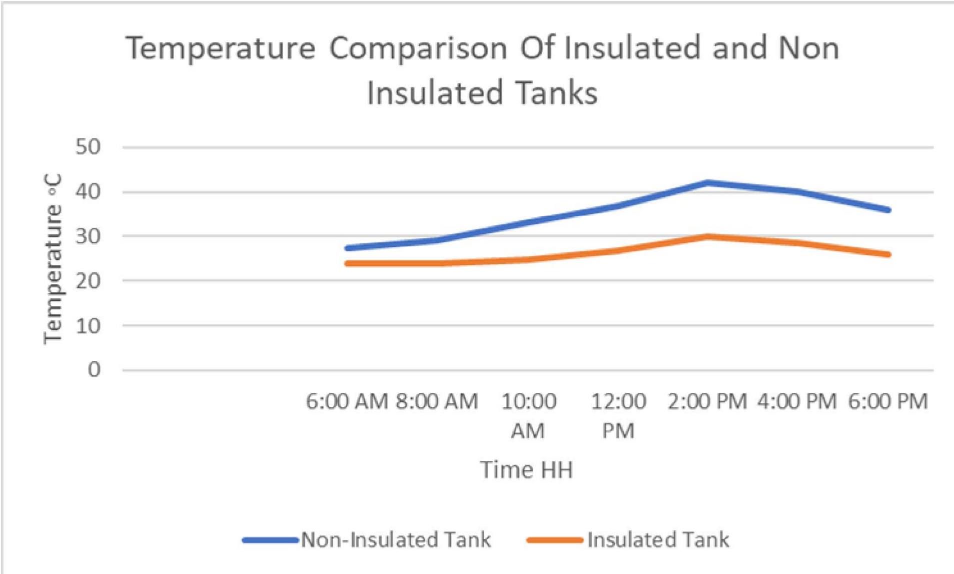
Material	Thermal Resistance (Rth, °C/W)
Virgin Plastic Tank (3mm)	0.044
Coconut Coir Fiber (10mm)	0.657
Polyurethane Foam (25mm)	2.475
Virgin Plastic (7mm)	0.104

2) Heat Transfer Results

Model	Heat Transfer (W)	Thermal Resistance (°C/W)
Non-Insulated	16 W	0.044
Insulated	3.66 W	3.28

3) Temperature Comparison

Time (HH)	Non-Insulated	Insulated	Temperature Difference
06:00 AM	27.5	24	3.5
08:00 AM	29	24	4
10:00 AM	33	24.8	8.2
12:00 PM	37	26.8	10.2
02:00 PM	42	30	12
04:00 PM	40	28.5	11.5
06:00 PM	36	26.1	9.9



The insulated tank maintained 7.5–12°C lower temperature during peak hours.

VII. RESULTS

The multi-layer insulation system significantly reduced heat transfer. Coconut Coir Fiber provided natural insulation while polyurethane foam enhanced resistance due to low thermal conductivity.

The combined insulation improved thermal resistance from 0.044 °C/W to 3.28 °C/W, resulting in:

1) 78% reduction in heat transfer
2) Stable water temperature
3) Improved thermal efficiency

VIII. CONCLUSIONS

The study confirms that a multi-layer insulation system using banana fiber and polyurethane foam effectively reduces heat absorption in overhead water tanks. The insulated model showed a maximum temperature reduction of 14.4°C during peak hours and reduced heat transfer rate by approximately 78%. This eco-friendly and cost-effective solution can be implemented in residential water storage systems in tropical regions.

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