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Design and Fabrication of Thermal Insulated Overhead Water Tanks

Pravesh Chandra[1,*], Vardanshi Varma[2], Arun Kumar[2], Deepak Saini[2]

Abstract

Overhead water containers are essential for storing water in residential and commercial structures, but because of varying weather, they are sometimes subject to extreme temperature swings. During the summer, the average temperature regularly surpasses 50°C. In residential and commercial structures, above-water tanks are essential for water storage, but, due to changing climate conditions, they may be subjected to high temperature changes on a regular basis. The tanks are primarily situated on building roofs, where they are exposed to the sun's direct rays and lack insulation or shade. The material of the tank cannot lessen the impact of sunlight. This objective focuses on creating cutting-edge insulation devices that reduce temperature fluctuations and ensure that water remains at a comfortable and usable temperature throughout the year. By reducing thermal loss by at least 50% as compared to uninsulated tanks, the suggested insulating solution offers a practical and affordable method for preserving strength and improving water usability. A thorough examination of insulation materials, selection of a durable and climate-resistant solution, and design of a prototype specifically designed for overhead water tanks are all part of the task. The effectiveness of the device will be compared through rigorous testing in both summer and winter conditions. If it works, the solution might be scalable for a wide range of tank sizes, opening the door for massive deployment. An urgent need for green water and sustainable parking systems is addressed in this study.

Keywords: Thermal insulation, temperature regulation, weather-resistant materials, prototype design, innovation

INTRODUCTION

A common feature of both residential and commercial buildings is overhead water tanks, which are crucial components for water supply and storage. Even though the tanks are full-sized, they are frequently damaged by external weather, which results in undesirable temperature variations within the water that is saved. The water may get uncomfortably cold in the winter, but it will often get too hot in the summer. These extreme temperature swings are no longer the main source of customer annoyance, but they could impair the efficiency of water-saving heating or cooling systems. The pressing need for a reliable and environmentally friendly method to maintain water temperature balance in overhead tanks is addressed by this challenge. Since its invention, the tank's material has changed from wood to ceramics and then from steel to polyethylene. In Indian markets, water tanks are often composed of linear low-density polyethylene (LLDPE) [1]. This tank wall is made up of four LLDPE layers. Every layer has a specific purpose. UV radiation that could cause material deterioration is blocked by the outer layer. The tank becomes opaque due to the second layer, which is often black and stops microorganisms from growing [2]. Foam, the third layer, offers insulation. The innermost

*Author for Correspondence
Pravesh Chandra
E-mail: Praveshchandra96@gmail.com

[1]Assistant Professor, Department of Mechanical Engineering, Moradabad Institute of Technology, Moradabad, Uttar Pradesh, India
[2]Student, Department of Mechanical Engineering, Moradabad Institute of Technology, Moradabad, Uttar Pradesh, India

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layer prevents bacteria from developing or pollutants from building up within the tank. It is clear that the prefabricated tanks include an insulating system that reduces the temperature of the water within the tank relative to the surrounding air. For areas like India, this insulation is still insufficient. As Table 1 illustrates, India experiences extremely high levels of solar radiation, particularly throughout the months of April through October. The water in the water storage tank reaches quite pleasant temperatures throughout the day, which is one of the primary effects of the summertime solar radiation. During this time, it is not feasible either for showering or for other uses of the water. There is a considerable risk. At these points, household armor houses will burn if they are not treated very carefully [3]. To overcome this problem, there are various ways to store water in a bucket at night and allow it to be cooled for use later by the production of progressive insulation. This study deals with the goal of extremely mitigating temperatures and ensuring that the water remains within a narrow and usable range throughout the year. The proposed insulation layer can be designed to be cost-effective, durable, and climate-resistant, making it a realistic answer for various applications [4, 5]. Through established methods related to material research, prototype design, and rigorous testing under various climatic conditions, this challenge seeks to obtain at least 50% thermal loss reduction in comparison to uninsulated tanks [6]. The final purpose is to develop a scalable insulation system that may be tailored to different tank sizes and configurations, promoting energy efficiency and improving user comfort in water storage systems (Figure 1) [7, 8].

Figure 1. Glass fiber.

EASE OF USE

Human comfort is a priority in the design of the suggested insulating machine for overhead water tanks. A few essential components that demonstrate its usability are listed below:

a. *Easy Installation:* No specialized tools or technical knowledge are needed to put up the insulation layer. It is applicable to both new and existing installations because of its modular layout, which ensures compatibility with a variety of tank sizes and forms.
b. *Low Maintenance:* The chosen materials could be resistant to UV rays, dampness, and weathering, which reduces the need for frequent maintenance or replacements. In the event that it is necessary, owners or security personnel can easily do routine cleaning and inspection.
c. *Sturdy and Long-Lasting:* The machine's weather-resistant housing ensures that it maintains its strength in a variety of environmental circumstances, providing a longer carrier life. Because they are user-friendly and durable, these materials reduce the need for protection interventions.
d. *Lightweight Design:* The insulation reduces additional structural strain on the support system and tank because it is lightweight. This feature makes handling during installation and transportation easier [9].
e. *Economical Function:* The insulation lowers the need for external water heating or cooling systems by maintaining high water temperatures, which lowers power costs for consumers. Long-term financial savings in electricity and protection costs will make the initial insulating investment worthwhile.

f. *Environmental Benefits:* The machine minimizes the carbon footprint associated with water temperature regulation by reducing heat transfer, which is in line with green practices.
g. *Versatile Application:* To ensure broad applicability, the insulation can be applied to tanks made of a variety of materials, such as metal, concrete, or plastic, designed to meet the demands of different people and function properly in both residential and commercial settings. The suggested insulation machine ensures a hassle-free experience while simultaneously enhancing the functionality and performance of overhead water tanks by specializing in those person-centric aspects [10, 11].

Figure 2 shows the cutting process.

Figure 2. Cutting process.

MATERIALS USED

The choice of substances is essential to attaining the challenge`s goals, ensuring sturdiness, thermal efficiency, and cost-effectiveness. Below is an in-depth breakdown of the substances required:

a. *Insulating Material Purpose:* The purpose of the insulating material is to reduce the heat transfer and maintain a higher water temperature. Expanded polystyrene (EPS) is an option because of its high heat resistance and low thermal conductivity. It is easy to shape, lightweight, cost-effective, and widely available [12]. PUF (polyurethane foam) has superior thermal insulation qualities. It is resistant to moisture and long-lasting. It can be molded or sprayed for continuous use. Insulation Using Reflective Foil reduces the heat gain in the summer by reflecting radiant warmth. It is lightweight and easy to set up. Rock wool, or mineral wool, is non-flammable and resistant to fire. High-temperature protective outer layer is designed to prevent weathering, UV rays, and mechanical damage to the insulating material [13].
   Options:
   - Aluminium Foil or Sheet provides a long-lasting outer layer and reflects heat. It is resistant to corrosion when treated correctly.
   - Sheets of High-Density Polyethylene (HDPE) are weatherproof, UV-stabilized, flexible, and lightweight.
   - Fiberglass Reinforced Plastic (FRP) provides pressure and long-lasting protection. It is resistant to harsh environmental conditions.
b. *Weatherproof Coatings Purpose:* To enhance durability and protect against environmental damage.
   Options:
   - Elastomeric coatings provide waterproofing and UV protection. They remain flexible and durable over time.
   - Acrylic-based paint adds aesthetic value and additional UV resistance.
c. *Material Selection Criteria Thermal Performance:* Low thermal conductivity for powerful insulation. Weather Resistance: The ability to withstand UV rays, rain, and temperature extremes.

d. *Durability:* Long-lasting substances that require minimum maintenance.
e. *Cost-Effectiveness:* Affordable alternatives to keep the solutions economical.
f. *Ease of Application:* Materials that simplify the fabrication and installation process. By carefully selecting and combining these materials, the project aims to create a highly effective insulation system that meets all specified goals and may be scaled for practical implementation.

MATHEMATICAL MODEL

Analytical models were created to understand how solar radiation affects household water reservoirs. Therefore, the temperature rise in water tanks was explained using the concepts of management, convection, and radiation [14]. Modeling includes radiation heating operations from the sun to the outside area of the tank, natural convection heat transfer outside the tank, heat transfer through the walls of the tank, and natural convection heat transfer from the inside surface of the tank to water.

The following presumptions were used in the research:
1. Conditions are considered to be steady state.
2. The sun's radiation is assumed to be constant at all times.
3. It is believed that the tank's incident solar radiation is constant across all surfaces.
4. The water's and the tank's thermophysical characteristics remain constant.

The study area is located in Moradabad, the eastern city of Uttar Pradesh, India. The heat flow produced by the rays of the sun on the aquarium depends on the material and color of the tank [15]. As a result, the heat flow resulting from exposure to sunlight can be expressed as:

$$q'' = \mathrm{I}\ \frac{\mathrm{KWh}}{\mathrm{m^2\ day}} \times \frac{1}{24\ \mathrm{h}} \mathrm{day}\ \times \tag{1}$$

About 75% of the total irradiation incident on the tank is reflected by the material and color of the tank. Consequently, the heat flux resulting from solar radiation can be expressed as:

$$q''\ radiation = q'' - 0.75\ \times\ q'' \tag{2}$$

In addition to solar radiation, natural convection cooling occurs between the water storage and the ambient air. There, we can find the dimensionless number, the Grashof number, which is applied to the ratio of buoyancy to viscous liquid [16].

$$Gr_D = \frac{g\beta D^3 \Delta T}{v^2} \tag{3}$$

Here:

g: Acceleration due to gravity (m/s^2),
V: Motion viscosity of air (M^2/s),
ΔT: The temperature difference between the tank surface and the ambient air is marked with it (k),
d: Outer diameter of the tank (m), and
$\beta = \frac{1}{T_{Avg}} (K^{-1})$; "T $_{avg}$" is the average temperature between the air around the tank and its surface.

Therefore, we can obtain the modification (NUD) using the following empirical equation [17]:

$$Nu_D = 0.36 + \frac{0.518\ (Gr_D\ P_r)^{0.25}}{[\ 1 + \left(\frac{0.559}{P_r}\right)^{0.5625}]^{-0.444}} \tag{4}$$

Here,
P= Prandtl number for T_{avg} of air.

The following is the relationship between the Nusselt number and the natural convection heat transfer coefficient:

$$h = \frac{Nu_D\, k}{D} \tag{5}$$

As a result, the rate of natural convection cooling can be described as [18]:

$$q''_{convction} = h\,(\Delta T) \tag{6}$$

Thus, it can be used to express the net heat flow on the tank's surface:

$$q''_{net} = q''_{radition} - q''_{convction} \tag{7}$$

The following is a description of the connection between the tank's surface temperature, the net heat flux, and the surrounding circumstances:

$$q''_{net} = \sigma\,[\,T_{s,out}{}^{4} - T_{surrounding}{}^{4} \tag{8}$$

Here,

σ: is the constant of Stefan-Boltzmann (W/m^2k^4).

The water tank's outside surface temperature can be easily ascertained using Eq. (8).

Conduction heat transmission happens through the wall, and the heat conduction equation can be used to find the water tank's inner surface temperature. The conduction heat transfer rate for a cylindrical water tank can be calculated as follows:

$$q = \frac{2\pi L\,[\,T_{s,out} - T_{s,in}\,]}{\frac{\ln(d_{out}/d_{in})}{K}} \tag{9}$$

Here,

A: $\pi d_{out} L$ (m^2),
q: q_{net}'' x A (W),
$T_{s,out}$: The temperature of the outer surface (K),
$T_{s,in}$: The interior surface temperature (K),
K: the tank's thermal conductivity (W/m K),
L: is the wall's length in meters,
D_{out}: The water tank's external diameter (m), and
d_{in}: The water tank's internal diameter (m).

The water tank's interior surface temperature can be easily ascertained using Eq. (9). Heat transfer by natural convection takes place between the water tank's inner surface and the water that is being stored. Eqs. (3)–(6) can be used to easily determine the tank's water temperature while taking suitable tank dimensions and fluid characteristics into consideration. The physical and thermal properties of the tank are shown in Table 1. The surrounding conditions are explained in Table 2, and the results of the analytical calculations are shown in Tables 2 and 3. In particular, we performed analytical calculations for tanks exposed to solar radiation [19–21].

MODELLING AND ANALYSIS

Different types of prototype structures can be seen in Table 1.

Recommendations

Based on the project's objectives and scope, the following recommendations will ensure that an insulation system for overhead water tanks is designed, built, and installed effectively:

1. *Material Selection:* Due to its remarkable resistance to heat, moisture, and weight. The insulation core should be made of polyurethane foam (PUF). For long-term protection, weather resistance, and durability, select Fiber Reinforced Plastic (FRP) or UV-stabilized High-Density Polyethylene (HDPE) for the outermost line of protection.
2. *Sealants and Adhesives:* Use polyurethane adhesives for a sturdy binding and silicone sealants to ensure watertight seams.
3. *Design considerations:* Develop a modular insulating system that can be modified to fit various tank sizes and shapes. Use an easy-to-install technique (such as clamp-on or Velcro-based options) to increase user convenience. Incorporate reflective materials, such as coatings or aluminium foil, to reduce solar heat gain throughout the summer.
4. *Performance Evaluation:* Conduct controlled laboratory tests to assess thermal insulation's efficacy in winter and summer simulations. When putting the prototype in real-world environments for extended testing, use data loggers and temperature sensors to collect information. Compare tanks that are insulated and those that are not to guarantee that thermal loss is decreased by at least 50% (Figures 3 and 4).
5. *Cost optimization:* Give top priority to using readily available, reasonably priced materials without compromising functionality. To reduce production costs, look into buying goods in bulk.
6. *Implementation and Scalability:* The insulating system should be made to work with several types of tanks, including plastic, concrete, or metal, in order to guarantee wide applicability. Create scalable designs that facilitate mass production for both residential and commercial markets. Create scalable manufacturing procedures that facilitate mass production for both domestic and commercial markets. To reduce summertime solar heat gain, work with local water tank manufacturers to investigate the feasibility of adding insulating systems.
7. *Marketing and User Education:* To ensure proper usage and long-term efficacy, give end users simple installation instructions. To encourage adoption, highlight benefits including improved durability, energy savings, and water usability in marketing campaigns. By putting these recommendations into practice, the project will effectively address the challenges brought on by temperature fluctuations in overhead water tanks, offering a durable, efficient, and scalable insulation solution that meets user needs and sustainability goals.

Table 1. In this research, we used different types of prototype structures.

Prototype	P1	P2	P3
Materials	Epe foam	Pu foam	Thermocol
	Jute	Glass fiber	Clay + straw
		Epe foam	Glass fiber
			Light cardboard

Figure 3. Prototype 1.

Figure 4. Prototype 2.

RESULT AND DISCUSSION

The prototype is evaluated based on a number of criteria, including durability, cost analysis, convenience of use, thermal control, and material effectiveness. Additionally, improvements are being made for potential future uses. Figures 5 and 6 show the measured values, and Figure 7 shows the bar chart, which shows the winter and summer temperatures.

Table 2. Thermal regulation *in winters.*

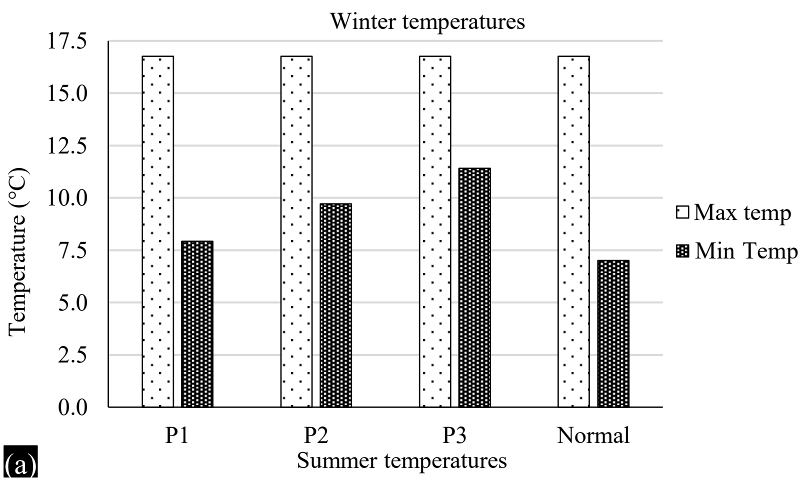
Prototype		**P1**	**P2**	**P3**	**Normal flask**
Initial temp. (°C)		19	19	19	19
Final temp. (°C)	Day 1	9	11	13	8
	Day 2	10	11	14	7
	Day 3	10	12	13	9
Avg		10	12	13	8

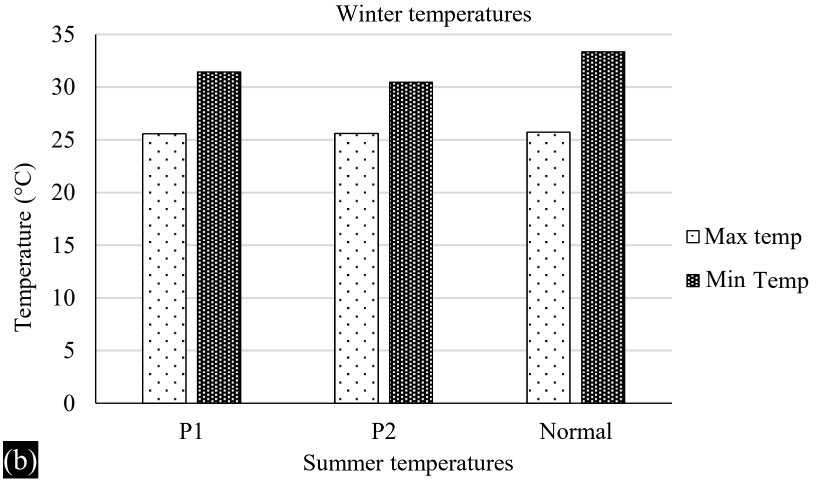
Table 3. Thermal regulation *in summer.*

Prototype		**P1**	**P2**	**Normal flask**
Initial temp. (°C)		27	27	27
Final temp. (°C)	Day 1	33	33	35
	Day 2	31	30	34
	Day 3	32	30	33
Avg		32	31	34

Figure 5. Measured value 035.

Figure 6. Measured value 036.





(b)

Figure 7. (a) and (b) Winter and summer temperatures.

CONCLUSION

This study examines how solar radiation affects home water storage tanks in India. India experiences more sun radiation in the summer because of its geographic location [18]. In the summer, this causes unwanted heating of household water storage tanks. Despite the fact that the residential and industrial communities are concerned about this issue, no such research has been documented in the literature that is currently available. The insulation system constructed for overhead water tanks met the study's objectives in terms of significant thermal control, durability, cost-effectiveness, and ease of installation. The results demonstrate how this system might be extended and altered for a variety of applications, providing benefits for the environment and the economy. Future research should focus on developing innovative materials to improve sustainability and optimizing designs for abrasive environments.

Standards and Guidelines

ASTM C518: Standard Test Method for Steady-State Thermal Transmission Properties using Heat Flow Meter Devices.

A benchmark for evaluating the thermal resistance of insulating materials.

Water Storage Tank Code of Practice, Bureau of Indian Standards (BIS), IS 2041:2009.

Indian regulations governing the design, building, and maintenance of water tanks.

Examples Include

The article "Application of Insulation Materials for Residential Water Tanks in Hot and Cold Climates" from the Energy and Buildings Journal (2021).

Online Resources

MatWeb (n.d.) is a resource for material selection.

Matweb.com offers "Material Property Data", a comprehensive database of material properties, including thermal insulation. Polyurethane foam is produced by Huntsman Corporation (n.d.). "Insulation Solutions" is available at www.huntsman.com.

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