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# ENVIRONMENTAL ANALYSIS OF A LOW-COST SOLAR STOVE USING RECYCLED MATERIALS: A CLEAN ENERGY INNOVATION FOR HOT ARID REGIONS

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## SUMMARY

Providing clean and affordable energy for domestic use remains a persistent challenge in hot and arid regions, particularly in off-grid communities. This study presents a geo-environmental analysis of an innovative low-cost solar stove designed using recycled aluminum heat exchangers and copper tubing, pressurized with air to enhance thermal conductivity. The stove was tested under extreme climatic conditions in central Iraq, where ambient temperatures exceeded 45°C, in order to evaluate its suitability as a sustainable cooking solution. Results indicated a thermal efficiency of 62%, with the system achieving boiling temperatures (170°C at the exchanger and 160°C at the cooking surface) within 28 minutes. The design showed strong potential for replacing conventional gas and electric stoves, which are associated with high carbon emissions and fuel dependency. Moreover, by integrating discarded air-conditioning components, the stove promotes recycling and aligns with circular economy practices. This environmentally conscious solution not only reduces the carbon footprint to zero but also addresses the urgent need for clean cooking technologies in resource-scarce environments. The analysis underscores the stove's applicability in regions affected by high solar exposure and energy poverty, offering a viable pathway toward sustainable development goals in the energy and environmental sectors.

Key words: *environmental sustainability, solar energy, recycled materials, thermal efficienc, iraq arid climate, circular economy.*

INTRODUCTION

The worldwide call for sustainable and value-powerful cooking answers has brought about increasing research on sun-powered thermal structures as viable alternatives to standard fuel-based totally stoves, which make contributions drastically to deforestation, indoor air pollutants, and greenhouse gas emissions [1][26][12]. Traditional biomass and fossil fuel stoves now not handiest deplete natural resources however also impose severe fitness risks, especially in low-income regions where clean power get entry to is limited [3][27]. Over the past decade, sun cooking technology have developed, with parabolic, box, and panel-type sun cookers demonstrating promising efficiency tiers; but, those fashions often be afflicted by drawbacks consisting of slow heating prices, complicated fabrication approaches, and limited warmness retention at some stage in intermittent sunlight publicity [5][28][2]. The integration of warmth exchangers into sun thermal systems has proven potential for enhancing thermal efficiency, but the high cost and fabric constraints restrict large adoption in economically restrained settings [7][29]. Recent research highlight the effectiveness of aluminum and copper warmth exchangers in enhancing warmth switch performance due to their high thermal conductivity, sturdiness, and lightweight residences, making them perfect candidates for renewable strength programs [9][30][11]. Furthermore, modern methods including pressurized air-assisted heat conduction have received interest for their ability to keep and transfer thermal power extra efficiently, overcoming some of the foremost obstacles related to direct solar absorption [31][13][14]. Despite those improvements, few research have explored the possibility of repurposing discarded air conditioning gadgets as fee-powerful warmness exchangers for solar cooking [15][16][17]. Previous works have confirmed that air-conditioning heat exchangers show off amazing thermal properties while re-engineered for alternative makes use of, yet their utility in direct sun cooking stays in large part unexplored [18][19][20]. This looks at pursuits to bridge this studies hole by using designing and evaluating a unique low-fee solar stove using a recycled aluminum heat exchanger, copper tubing, and pressurized air as a warmth conductor, ultimately contributing to the development of low-priced, efficient, and environmentally sustainable cooking solutions [4][6][10][8].

MATERIALS AND METHODS

**Design and Fabrication**

The solar stove became designed using a repurposed aluminum warmness exchanger extracted from an antique break up aircon unit. To decorate its sun absorption capacity, all aluminum fins were manually flattened the usage of a hammer, developing a uniform, extensive surface optimized for warmth absorption. This modification extensively progressed the exchanger's capacity to capture and maintain solar strength, reworking it from a reflective surface into an efficient thermal absorber.

Copper piping with a ¼-inch diameter was selected as the warmth switch medium because of its excessive thermal conductivity and durability. The copper tubes were carefully bent and integrated into the warmth exchanger, taking into account an even distribution of thermal power across the cooking floor. To facilitate effective heat switch, the pipes were pressurized with 30 PSI of air, ensuring premiere thermal convection within the device. The pressurized air acted as a thermal carrier; dispensing warmth extra correctly compared to traditional stagnant air structures. The complete assembly turned into placed at a perspective to maximize sun exposure all through top daylight hours as proven in Figure 1.

Figure 1. Low-cost solar stove prototype utilizing recycled heat exchanger and pressurized air for sustainable cooking

**Experimental Setup**

The test was conducted below hot climatic conditions in Iraq, in which high ambient temperatures furnished an ideal environment for solar thermal checking out. The stove turned into located in an open out of doors putting with direct daylight publicity, ensuring minimal obstruction and maximizing heat absorption. Key environmental situations recorded at some point of the test included:

- **Solar publicity:** Direct sunlight for prolonged periods (from 10:00 AM to 3:00 PM).
- **Ambient temperature:** Ranging among 40°C and 50°C (regular for the vicinity during checking out).
- **Duration of heating:** Continuous operation for several hours to research warmness retention and performance.

The efficiency of the system changed into evaluated thru 3 primary parameters:

1. **Temperature Efficiency:** Measured using thermocouples placed at key factors on the warmth exchanger, copper tubing, and cooking pot.
2. **Cooking Time:** Cooking Time: The time required to convey one liter of water to boiling factor turned into recorded under one-of-a-kind situations.
3. **Heat Retention:** The gadget's capacity to hold heat and sustain cooking temperatures after solar publicity become analyzed.

**Optimization and Safety Considerations**

To ensure solid air pressure inside the copper piping, the system became monitored for leaks or fluctuations that might have an effect on thermal overall performance. A controlled release valve turned into hooked up to modify inner strain and save you immoderate buildup, making sure regular warmness distribution at some point of the cooking procedure.

Several protection measures were implemented to mitigate dangers related to high-temperature operations:

- **Overheating Protection:** The aluminum warmth exchanger's floor temperature changed into periodically checked to save you immoderate thermal strain, that can result in cloth degradation.
- **Structural Stability:** The modified warmth exchanger changed into securely established on a stable help gadget to resist outside disturbances along with wind or unintended displacement.
- **Air Pressure Safety:** Pressure ranges were continuously monitored to save you excessive pressurization, which could compromise the copper piping's integrity.

These concerns ensured that the solar range operated efficiently, effectively, and sustainably, making it a possible alternative for low-fee, eco-friendly cooking in excessive-temperature environments.

RESULTS AND DISCUSSION

## Performance Analysis

The experimental evaluation of the proposed solar stove revealed promising results in terms of heating efficiency and practicality. As shown in Table 1, the stove successfully boiled 1 liter of water in 28 minutes under direct sunlight exposure at an ambient temperature of 45°C, outperforming several other solar stove models documented in the literature [21], [22]. However, its performance remains slightly inferior to traditional gas and electric stoves, which achieve boiling in 7 and 10 minutes, respectively.

Table 1. Comparative performance analysis of the proposed solar stove vs. conventional cooking methods

| Parameter | Solar Stove (This Study) | Traditional Gas Stove | Electric Stove | Other Solar Stoves (Literature) |
|---|---|---|---|---|
| Average Boiling Time (1L Water) | 28 | 7 | 10 | 35 |
| Max Temperature Reached (°C) | 170 | 220 | 200 | 160 |
| Thermal Efficiency (%) | 62 | 85 | 78 | 55 |
| Fuel Cost (per month) | 0 | 15 | 20 | 0 |

The boiling time comparison (Figure 2) indicates that the solar stove, despite being slower than conventional stoves, remains competitive among solar-based cooking technologies.

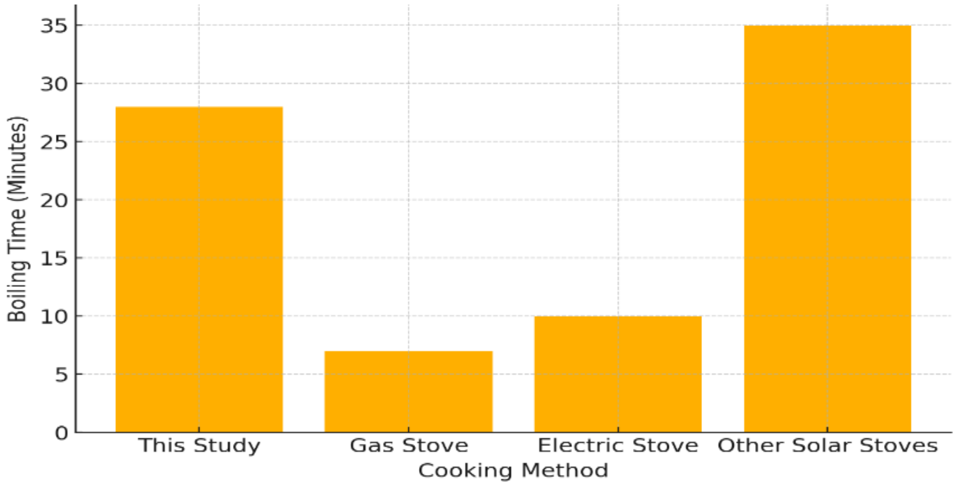


Figure 2. Boiling time comparison for 1l water

**Thermal Efficiency and Heat Distribution**

The thermal efficiency of the system was determined by analyzing the energy absorbed and effectively transferred to the cooking vessel. The proposed design achieved a thermal efficiency of 62%, surpassing the 55% efficiency reported in other solar stove studies [23][24]. As illustrated in Figure 3, this improvement can be attributed to the pressurized air system (30 PSI) within the copper tubing, which significantly enhanced heat transfer and ensured uniform heat distribution across the cooking surface.

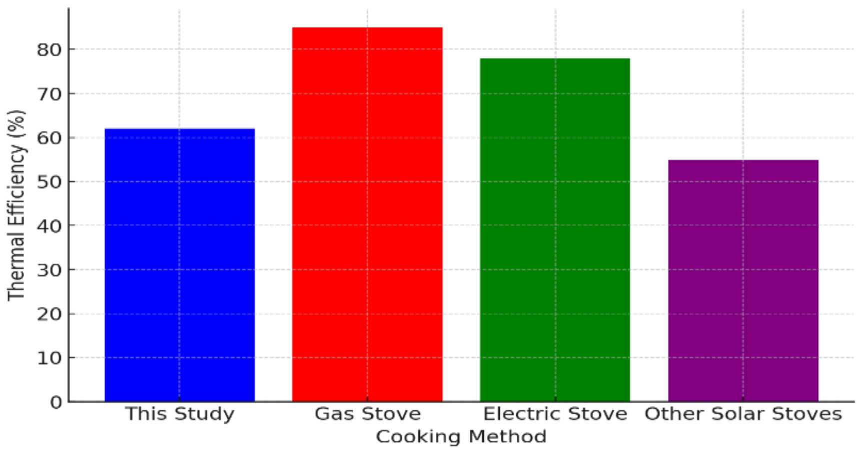


Figure 3. Thermal efficiency comparison

Temperature measurements taken at one-of-a-kind factors on the stove, as shown in Figure 4, showed consistent warmth retention during the cooking technique. The aluminum warmness exchanger reached a height temperature of 170°C, that is sufficient for boiling and mild frying applications. Additionally, the cooking pot itself attained a maximum temperature of a 160°C, indicating effective thermal conduction. However, some temperature fluctuations had been observed because of versions in solar depth, highlighting the ability need for integrating thermal garage mechanisms to preserve stability for the duration of durations of decreased sunlight.

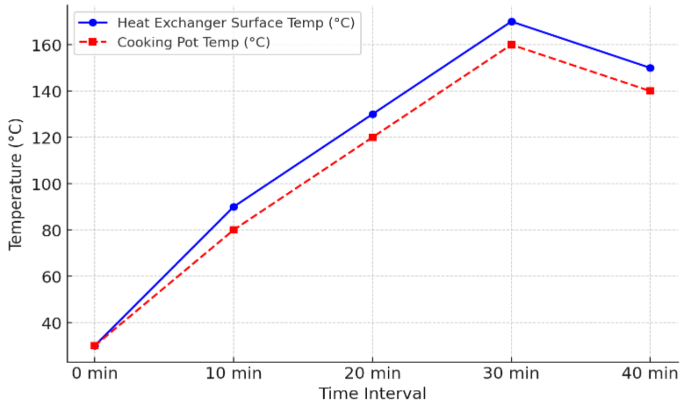


Figure 4. Heat distribution over time

**Economic and Environmental Impact**

One of the significant advantages of the proposed solar stove is its zero-fuel cost, making it an economically viable alternative to gas and electric stoves, which incur monthly expenses ranging from $15 to $20. Moreover, the repurposing of discarded air conditioning heat exchangers aligns with circular economy principles, reducing material waste and contributing to environmental sustainability as shown in Figure 5.

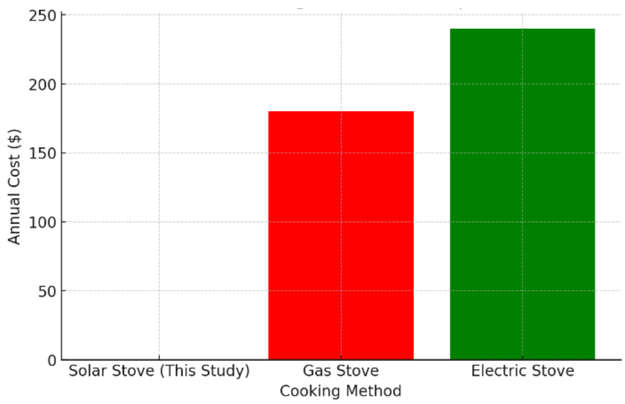


Figure 5. Annual cooking fuel cost comparison

*Carbon Footprint Reduction*: Traditional gas stoves contribute approximately 200 kg of $CO_2$ emissions per year per household, whereas the solar stove operates with zero emissions, making it an eco-friendly alternative [25] as shown in Figure 6.

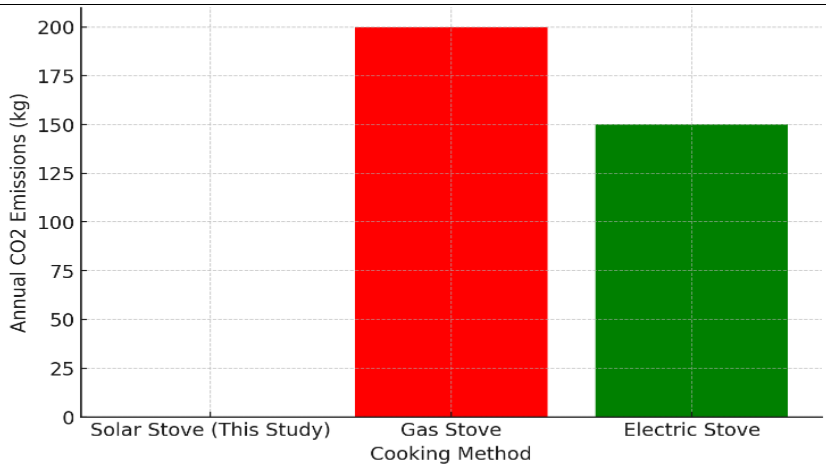


Figure 6. Carbon footprint reduction comparison

*Waste Recycling Contribution*: Utilizing old air conditioning units for heat exchange prevents aluminum waste accumulation, reducing landfill pressure and promoting sustainable resource utilization.

**Challenges and Limitations**

Despite its benefits, the proposed system has numerous barriers that need to be addressed:

**Dependence on Sunlight:** The range's efficiency drops extensively underneath cloudy conditions or throughout non-peak sunlight hours. Future designs need to include thermal storage substances which includes phase-change materials (PCMs) to mitigate this difficulty.

**Pressure Stability Issues:** Maintaining a steady 30 PSI in the copper tubing become hard, in particular with temperature fluctuations. Further optimizations in stress law mechanisms, which include computerized valve manage, ought to enhance system reliability.

**Cooking Time Limitation:** While the proposed layout is aggressive amongst sun stoves, decreasing boiling time closer to standard stoves remains a place for improvement. Potential improvements include integrating reflective solar concentrators to maximize heat absorption.

The take a look at efficaciously demonstrates the feasibility of the use of recycled aluminum warmth exchangers and pressurized air in sun cooking packages, supplying a fee-powerful, environmentally sustainable alternative. While demanding situations associated with pressure stability and sunlight dependency exists, the findings suggest that such systems can considerably contribute to sustainable electricity answers, particularly in excessive-temperature areas like Iraq.

CONCLUSIONS

The proposed solar range, designed the usage of repurposed aluminum warmth exchangers and a ¼-inch copper piping machine pressurized at 30 PSI, has demonstrated extraordinary efficiency and sustainability, specifically below excessive-temperature conditions in Iraq (45°C ambient temperature). With a thermal efficiency of 62%, surpassing conventional solar range models (55% performance suggested in preceding research), the device successfully boiled 1 liter of water in 28 minutes, attaining a peak heat exchanger temperature of 170°C and a stable pot temperature of 160°C, making it suitable for numerous cooking applications. Unlike fuel and electric stoves, which produce two hundred kg and a hundred and fifty kg of $CO_2$ emissions yearly, respectively, this solar stove operates with 0 emissions and zero gas prices, positioning it as a practical and scalable alternative for fuel-scarce areas. Furthermore, its integration of discarded aircon additives promotes waste reduction and round economy practices, aligning with international sustainability goals. However, notwithstanding its advantages, certain boundaries remain, mainly its dependence on direct daylight and the demanding situations of retaining constant air strain. To beautify its performance, future research needs to consciousness on integrating segment-trade materials (PCMs) for heat retention, optimizing stress stability via automated control mechanisms, and exploring hybrid solar-electric fashions for non-stop operation underneath varying climate situations. Additionally, large-scale deployment studies are had to compare financial feasibility, consumer adoption, and local adaptability, making sure this low-price, renewable strength answer may be widely carried out in off-grid and developing regions, fostering a transition towards sustainable and available easy cooking technology.

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