"Design and Fabrication of Portable Solar Air Heater for Raisins"

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Abstract

Solar air heating technology utilizes solar thermal energy by capturing solar isolation (insolation) using an absorbing medium to directly heat air. This renewable energy solution is highly suitable for building heating/air conditioning and process heat applications, often proving to be the most cost-effective among solar technologies, especially in commercial and industrial settings. The typical configuration involves drawing ambient air, passing it through the collector where it is warmed by conduction from the absorber plate, and then supplying the heated air to a dehydration chamber using a fan or blower. The system investigated featured an absorber plate constructed from a Tin alloy metal and coated with a jet black paint to maximize absorption. Performance was assessed under various climatic conditions, demonstrating that the system is affordable and portable. The device successfully raised the air temperature from an inlet of 40^0C to an outlet of 70^0C. The measured thermal efficiency of the solar air heater was found to be 42.12%, with the potential for further improvement through minor design modifications.

Keywords: Solar air heater, Thermal storage, Blower, Absorber plate, Tin alloy, Collector, Thermocouple.

1. Introduction

Solar air heating (SAH) is a solar thermal technology that harnesses the energy from the sun (insolation) via an absorbing medium to warm air. As a renewable energy technology, it is employed for diverse applications, including the crucial need for food preservation (fruits, vegetables, and other foods) to extend shelf life and prevent quality deterioration. SAH systems can provide necessary ventilation and process air heating globally, leveraging solar energy as a free and accessible resource.

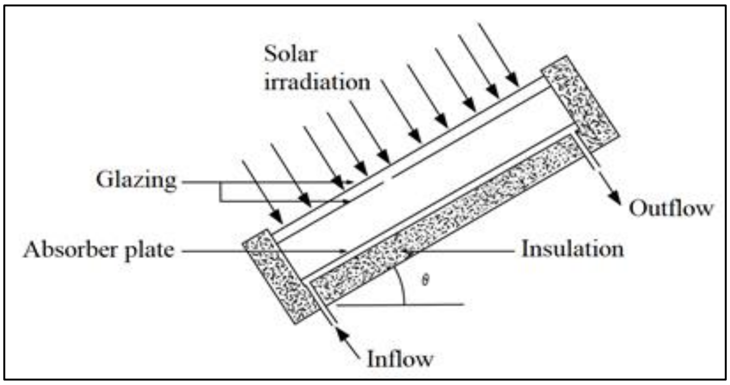

Fig: -3.1 Solar Air Heater

The primary factors limiting the wider adoption of solar products are often efficiency and cost. However, solar thermal technology is rapidly gaining traction in agriculture due to its abundance, inexhaustibility, and non-polluting nature, positioning it favourably against alternatives like wind or shale energy. Solar air heaters are straightforward devices used to heat air using solar energy for applications requiring low to moderate temperatures (typically below 80^0C), such as crop drying and space heating.

Food Preservation and Drying

Fruits and vegetables constitute a significant portion of food crops, particularly in developing nations. Drying is a fundamental preservation technique used to remove moisture until the product reaches its equilibrium moisture content. This process not only achieves an extended storage life but also enhances quality, simplifies handling, and prepares the product for further processing.

Conventional Solar Air Heater Design

A conventional solar air heater operates fundamentally as a flat plate collector incorporating an absorber plate. The collector assembly is typically tilted and oriented to maximize solar radiation absorption during the season of use. Key structural components include a transparent cover (glazing) on top and insulation at the bottom and sides, all enclosed within a casing. Optimal stationary orientation in the Northern Hemisphere is due south, and due north in the Southern Hemisphere. For this specific work, the solar collector was oriented facing south and tilted at 45^0 to the horizontal to facilitate maximum radiation capture, water runoff, and air circulation.

Challenges in Raisin Production

Fresh grapes undergo rapid deterioration, typically within two months, necessitating prompt processing to mitigate postharvest losses in both quantity and quality. A common raisin production technique in India involves dipping grape bunches in an emulsion (usually 2.5% potassium carbonate and 1.5% ethyl oleate) for 2–4 minutes, followed by shade drying in an open tier system. The presence of certain enzymes can trigger a browning reaction in the grapes during the drying process.

Modern Methods to Overcome Drying Challenges

To address the challenges of traditional drying, several modern grape drying techniques have been researched:

- Solar Drying: The traditional method where grapes are spread in direct sunlight until the target dehydration level is achieved.
- Shade Drying: Grapes are placed in a dark, open area, shielded from direct sun exposure, but maintained in a proper airflow condition, usually provided by the ambient environment.
- Hot Air Drying (Tray Drying): This method uses hot air as the medium to create a temperature gradient between the air and the grapes, simultaneously removing moisture.
- Microwave Drying: Electromagnetic waves from a magnetron cause water molecules to vibrate, generating thermal energy that quickly evaporates the moisture from the grapes.
- Vacuum Drying: Air is removed from a closed chamber using a vacuum pump, resulting in lower pressure. This artificially increases the water vapour pressure difference between the product and the surrounding atmosphere, speeding up the drying process.
- Infrared Drying: Heat is transferred from a hot element to the food via radiation.

Principle Concept of the Solar Air Heater

A solar air heater functions as a device that transfers energy from a radiant source (the sun) to air. These systems are applicable for various uses, including crop drying, space heating, and maintaining comfortable indoor environments, particularly during winter. The operational principle is based on two steps: Absorption of solar radiation by a solid body (the absorber plate), causing the body temperature to rise; and Convection of heat from the heated solid body to the air flowing across its surface.

Major Components of a General Solar Air Heater

The key components of a solar air heater are depicted in the fig.3.2:

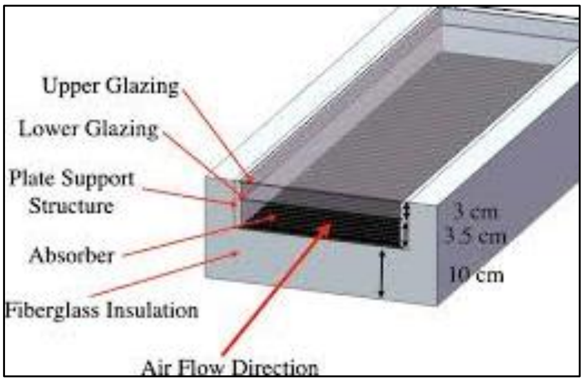

Fig: -3.2 Components of Solar Air Heater

1. Absorber Plate: This is the critical component responsible for absorbing incident solar radiation and facilitating convective heat transfer to the air. The absorptivity of a typical aluminum plate ranges from 0.85 to 0.95 when coated with matte black paint.
2. Inner Box: Constructed from wood (a poor heat conductor), the inner box establishes a fixed path for the air to flow inside the heater. Wood's high fire point (above 300^0C for dry wood) also makes it suitable.
3. Outer Box: Also constructed from wood, its primary function is to prevent heat loss. A layer of insulation is placed between the inner and outer boxes.
4. Glazing or Glass Plate: This transparent cover is essential for creating a greenhouse effect within the solar air heater, which is necessary for achieving the required temperature rise.
5. Insulation Wall: Provided to minimize total heat loss from the side walls and the base of the inner box. As the internal temperature increases, heat loss accelerates, making insulation vital.
6. Inlet and Outlet Duct: These channels are required to maintain a uniform flow of air throughout the air heater.
7. Blower or Exhaust Fan: A blower or exhaust fan is needed to generate a pressure difference between the inlet and outlet ducts, forcing air through the system.
8. Glass Chamber: A 5 mm glass chamber was selected for the drying application (Sapota fruit). Glass was used here to benefit from the combination of natural drying and forced drying.

Scope

Global energy demand is rising, emphasizing the need for clean, renewable energy sources, with solar energy being a prime candidate. Future modifications to this technology could include the use of heat pipes to absorb solar energy and evacuated tubes to minimize convective heat losses. Implementing limited collector tracking could potentially increase the system's efficiency. Incorporating a selective absorber coating on the inner surface of the evacuated tube and using a solar flux meter to measure incoming solar radiation are also recommended. Experiments in this field have shown that using an evacuated tube with a heat pipe achieved a maximum thermal efficiency of 35%.

Objectives

The primary objectives of this project were to:

- Study the thermal performance of the flat plate solar air heating system.
- Determine the outlet temperature of the air.
- Calculate the efficiency of the system.

2. Literature review

In recent years, researchers across the world have explored different ways to improve solar air-heating and drying systems, focusing on increasing efficiency, enhancing heat storage and improving system reliability. The journey begins with the conceptual development of an integrated collector-storage solar air heater designed for a 9.9 m^2 building. This early study demonstrated that even a simple, well-designed system could achieve a significant environmental impact by reducing nearly 5.8 tons of carbon emissions over its lifetime, highlighting the potential of solar-powered heating systems to support sustainability goals [1].

As understanding of solar air systems grew, researchers discovered the critical role of solar insolation on system performance. One study clearly showed that the daily amount of sunlight had a far stronger influence on heating efficiency compared to the ambient air temperature. Even when temperatures changed slightly, the system performance remained stable, but higher solar radiation consistently improved output. This emphasized the need for optimal placement and regional solar suitability when designing solar-powered floor heating systems [3].

Researchers then turned their attention towards working fluids and heat pipe technologies. An experimental investigation examined how different filling ratios (30–60%) and two refrigerants, R22 and R134a, affected the thermal efficiency of coaxial heat pipe solar collectors. The results were striking—thermal efficiency increased by up to 67% under an optimal flow rate of 0.009 kg/s, and both refrigerants displayed very similar behavior, simplifying design choices for engineers [2].

This motivated the development of more innovative collector designs. A unique flat-plate solar air collector featuring micro-heat pipe arrays (MHPA) was introduced. Its special architecture allowed heat collection and heat transfer to be separated, making the process more efficient and improving air heating performance. This structural innovation became a milestone for lightweight and compact solar air collectors [4].

Further advancements focused on integrating heat recovery into solar drying systems. One notable study designed and evaluated a heat-pipe evacuated tube solar dryer using water as both the working and recovery fluid, while air served as the heat-transfer medium inside the dryer. This setup demonstrated high thermal performance as well as a more efficient way to utilize recovered heat within the drying process [5].

At the industrial level, researchers proposed a system capable of delivering air temperatures between 150°C and 230°C using a combination of simplified compound parabolic concentrators (CPC) and evacuated tube collectors. The design utilized 30 collector units, each equipped with a copper concentric tube heat exchanger and a stainless-steel mesh for enhanced heat conduction. This configuration aimed to support high-temperature industrial processes with clean, solar-based heating [7].

Drying agricultural crops has always been an important application of solar technology. A comparative study designed and tested a solar dryer equipped with evacuated tube collectors, both with and without gravel heat storage. When drying chili, the dryer with storage reduced moisture from 87.36% to 3.4% in just 10 hours, whereas natural sun drying required 32 hours. The drying efficiencies of 34.23%, 22.03%, and 9.32% for the three respective methods demonstrated the clear advantage of using solar dryers with thermal storage under Indian climatic conditions [6].

To further extend operating hours beyond sunshine periods, a solar air collector integrated with latent heat storage was developed. The system used acetamide as a phase change material (PCM) and maintained an impressive temperature difference of 37°C during sunlight and 20.2°C even without sunlight, enabling operation after sunset. Interestingly, high air flow rates significantly boosted efficiency, showing that proper control of flow dynamics can improve thermal performance [8].

In another study, an evacuated tube solar air collector was used as the primary heat source for drying agricultural products such as apples, carrots and apricots. The warm outlet air reached temperatures suitable for drying without requiring external preheating, forming the foundation for a new convective, indirect solar dryer design [12].

Researchers also explored enhancing thermal performance by adding copper oxide (CuO) nanoparticles to methanol when used in vacuum tube heat pipe collectors. The energetic and exergetic analyses under different air velocities showed how Nano fluids can significantly improve heat transfer characteristics, presenting a new pathway for next-generation solar air heaters [10].

Efforts to combine heat collection and storage continued with the development of an air collection-storage thermal system (ACSTS) using flat micro-heat pipe arrays (FMHPA) and lauric acid as PCM. Experiments showed that higher air flow rates enhanced collector efficiency and storage charging speed, while an outlet air flow rate of 60 m^3/h provided stable temperatures during discharging. The system achieved 4210–4300 kJ of cumulative heat transfer, demonstrating high reliability for continuous air heating [11].

The concept evolved further with the introduction of a CPC solar air collector integrated with FMHPA, having a concentration ratio of 1.8. By combining an evacuated tube, micro-heat pipe arrays, and CPC reflectors, the system significantly improved thermal performance. Both theoretical and experimental analyses confirmed the efficiency of this integrated heat-collecting unit [10].

Finally, a novel solar air heating system utilizing FMHPA, an evacuated tube heater and a latent heat storage unit was proposed. The researchers developed a systematic evaluation method based on heat-flow behaviour, allowing a detailed analysis of system efficiency and dynamic performance. This comprehensive approach contributed to better engineering optimization for solar air systems [9]. A follow-up study on FMHPA-based heaters reported that the system could achieve a stable thermal efficiency of up to 70%, with a favourable time constant and acceptable pressure drop, marking it as one of the most efficient solar air heating technologies available [8].

LITERATURE FINDING

From the above research papers, we have observed that in passive solar air heating systems, hot air is generated at different places and directed to end use. Heat storage materials are commonly utilized in active Solar air heater to generate hot air during off day time. On other hand passive Solar air heaters are generally utilized during daytime. From another perspective, Solar air heaters may be classified according to the number of air passes into single-pass and double-pass with or without heat storage [5–6].

In single-pass air solar heater, air flows in one way either above the absorber plate or below it from the air inlet to outlet. While in double-pass air solar heater, air flows in two passages, which may be either counter or parallel. Solar air heaters consist mainly of air flow duct and absorber plate. To reduce heat losses from both bottom and sidewalls, thermal insulation with low thermal conductivity is used.

Many researchers have fabricated their experimental test-rigs to study the effect of modifications which may be done in the main components of the Solar air heaters. Therefore, the main objective of the present paper is to find the scope and to study the different design configurations of solar air heaters.

3. Methodology

STEP 1: PROBLEM DEFINITION

Drying is one of the best methods to preserve food, as lots of food is wasted due to poor storage condition. Due to the increasing greed of the raisins producers and to get more product in less number of time the producers are using unconventional methods of production. As far as now the drying of grapes is done by using the chemicals such as Sulphur, potassium meta bisulphide (KMS), potassium hydroxide (KOH), sodium hydroxide (NaOH), potassium carbonate (K_2CO_3) etc. These kinds of chemicals cause a large impact on human health. To overcome this problem a portable solar air heater is introduced which can be more affordable than available in markets and it can easily achieve the desirable efficiency after doing some modifications.

STEP 2: DATA COLLECTION

Data collection plays an important role in methodology of the project. The data collection was carried out by going through various research papers regarding various processes of raisins production, various concepts of solar air heater, also by doing market surveys of different types of solar air heaters available in the markets.

STEP 3: DATA ANALYSIS

Revising the data collected from the market survey and field research, the data are analysed and the decisions regarding proper design and fabrication of the solar air heater are confirmed.

STEP 4: DESIGN PARAMETERS

The required parameters for generating the design were concluded by doing the data analysis in which we have given priority to affordability and portability.

STEP 5: DESIGN MODEL

Based on the parameters obtained from the data analysis all the requirements were considered and the basic model was created over the software named “AUTO-CAD version 23.1” and “CATIA V3”.

STEP 6: PROPOSED DESIGN

The final design was created by doing some minor changes which were done in order to make the model more effective, creative and user friendly.

STEP 7: FABRICATION

Fabrication process was carried out at workshop by undertaking all the standard considerations and safety precautions. For fabrication the raw material was procured from the local market at cheaper rates.

STEP 8: TESTING

Testing was carried out at different locations where the true potential of the project was examined. The thermal efficiencies of the solar air heater were examined with different time period and at different locations.

4. Materials, Design and Fabrication

4.1 Selection of Design

The design of the proposed solar air heater (SAH) was finalized based on established findings from earlier studies. Several researchers have demonstrated that modifications in absorber geometry, flow arrangement, and the inclusion of porous or metallic structures significantly enhance thermal performance. For instance, Filiz Ozgen et al. [6] experimentally investigated a flat-plate double-pass SAH integrated with aluminium cans arranged in three absorber configurations. Their results indicated that the zigzag arrangement provided the highest collector efficiency at an air mass flow rate of 0.05 kg/s. Similarly, Sopian et al. [7] reported that introducing porous media into the second pass of a double-pass SAH improved heat transfer characteristics, enabling the system to achieve a typical thermal efficiency of 60–70%, with strong agreement between theoretical and experimental observations.

Further enhancement strategies were identified by Zomorodian and Zamanian [8], who examined a flat-plate SAH equipped with a slatted glass cover and absorber plates of varying thickness and porosity. They found that the thicker and more porous absorber plate, combined with higher air mass flow rates, yielded a maximum thermal efficiency of 0.88. These findings confirm that absorber surface modifications significantly improve the heat transfer rate and overall performance.

Drawing from these insights, the present study adopts a zigzag aluminium-can absorber configuration, similar to the design used in [6], to enhance the convective heat transfer area and promote better airflow turbulence. The geometric dimensions for the constructed SAH were also guided by Ozgen et al. [6], who utilized a collector length of 73 cm, width of 45.5 cm, and a thickness of 17 cm. The selected design is suitable for typical applications such as agricultural product drying, space heating, seasoning of timber, curing plastics, and regeneration of dehumidifying agents—common use-cases of solar air heaters documented in literature.

4.2 Materials Used

Given the variety of solar air heating systems, material selection plays a crucial role in thermal performance, durability, and fabrication feasibility. For the present prototype, materials were chosen based on thermal properties, availability, structural strength, and cost-effectiveness. The materials used for constructing the solar collector chamber and drying chamber include:

- Plywood sheets (6×3 ft) – used for the external frame
- Tin sheet (3×2 ft) – used as the absorber plate
- Flexible plastic pipe (Ø 2 inches) – for interconnecting chambers
- Glossy black paint (Hex Code #252324) – coating for the absorber to maximize solar absorptivity
- Solar plate (XURUI 9V, 100 mA) – to power airflow-supporting components
- 12V DC battery – energy storage for the fan system
- Stainless steel mesh (2×4 ft) – used in the dehydrating chamber as the drying platform
- Transparent 4 mm glass plate – glazing layer for the collector

- Digital thermometer (LR44, 1.5V) – for real-time temperature monitoring
- 12V DC fan (2800 rpm) – for forced convection airflow

4.3 Design Specifications

4.3.1 Main Solar Heat Collector Chamber

- Material: Plywood frame (12 mm thick), coated in black paint
- Absorber Plate: Tin sheet, painted black
- Dimensions:
    - Length: 3 ft
    - Breadth: 2 ft
    - Height: 5 inches

4.3.2 Dehydrating Chamber

- Material: Plywood frame (12 mm thick)
- Drying Platform: Stainless steel net
- Dimensions:
    - Length: 2 ft
    - Breadth: 2 ft
    - Height: 1 ft

4.3.3 Auxiliary Components

- Glossy black paint (#252324) for maximum heat absorption
- 12V DC fan and battery system
- Plastic pipe (Ø 2 inch) for airflow coupling
- Solar panel for renewable power supply
- Digital thermometer for temperature tracking

4.4 CAD Model

CAD modelling was performed for all three primary components of the system—the solar collector chamber, the dehydrating chamber, and the airflow channel.

Figure 4.7 illustrates the individual CAD models, while Figure 4.8 shows the fully assembled configuration, ensuring appropriate alignment of flow channels and thermal components.

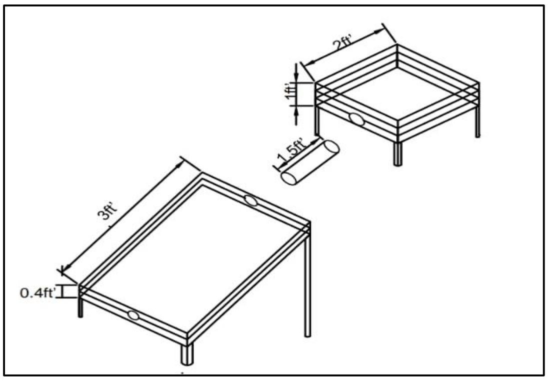

Fig.4.7 CAD model of all three components

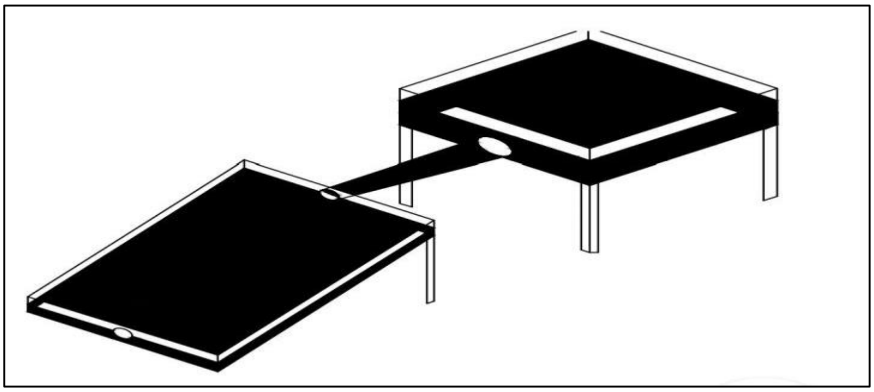

Fig.4.8 Cad model of all three components assembled

4.5 Fabrication Procedure

The fabrication of the solar air heating and drying system followed a structured sequence to ensure mechanical stability, thermal efficiency, and reliable operation. The process was divided into material preparation, structural assembly, surface treatment, component integration, and system validation.

Step 1: Cutting and Preparation of Structural Components

The wooden sheets required for the main collector chamber and the dehydrating chamber were cut according to the design specifications. Manual cutting tools were used to achieve clean edges and uniform sections suitable for airtight assembly.

Step 2: Assembly of the Wooden Framework

The prepared components were assembled to form the two independent chambers. A combination of wood adhesive and nails provided mechanical strength and ensured that the structure could withstand operational loads. Care was taken to maintain proper alignment to facilitate smooth airflow through the system.

Step 3: Surface Coating and Absorber Preparation

The internal surfaces of both chambers and the metallic absorber plate were coated with a high-absorptivity black paint to enhance solar energy absorption. The outer surfaces were also painted to improve durability and provide environmental protection. A transparent glass cover was installed over the collector to function as glazing, reducing convective heat losses and improving greenhouse trapping within the collector.

Step 4: Integration of Thermal and Electrical Components

Once the chambers were prepared, they were connected using a flexible duct to enable the transfer of preheated air from the collector to the drying chamber. A DC-powered airflow fan was installed at the outlet of the collector chamber to support forced convection and maintain a steady air stream during operation. The fan was powered by a rechargeable DC battery coupled with a solar panel, enabling off-grid and continuous operation during daylight.

5. Data Collection and Analysis

The performance evaluation of the developed solar air heater was carried out under real outdoor conditions. The experimental procedure involved initiating airflow through the system and monitoring the thermodynamic behavior of air as it passed through the collector. An air blower was used to draw atmospheric air into the system, supplying it through the lower air channel of the heater. The velocity of the incoming air was continuously measured using a vane anemometer to ensure consistent flow conditions during testing.

As solar radiation was incident on the absorber plate, the plate transferred heat to the air flowing through the lower channel. The heated air then moved upward into the upper channel, flowing in a counter-directional path, where it underwent an additional heating cycle due to recirculation within the chamber. This dual-pass flow arrangement enhanced the overall heat transfer and improved the temperature rise of the air exiting the system.

The temperature at the inlet and outlet of the heater was measured using calibrated thermocouples, and readings were recorded at 60-minute intervals throughout the test duration.

Readings:

Table 7.1 presents the observed temperature data for each interval of measurement.

Table 7.1. Hourly Temperature Measurements of Solar Air Heater

Sr. No.	Time	Inlet Temperature (°C)	Outlet Temperature (°C)
1	10:30 AM	34	51.9
2	11:30 AM	38	55.2
3	12:30 PM	40	67.2
4	01:30 PM	41	68.1
5	02:30 PM	42	70.0

A graphical representation of the inlet and outlet temperatures as a function of time is shown in Fig. 7.1. The chart clearly indicates a progressive rise in both inlet and outlet air temperatures with increasing solar intensity during midday hours. The maximum outlet temperature of **70°C** was observed in the early afternoon, corresponding to the peak solar radiation period.

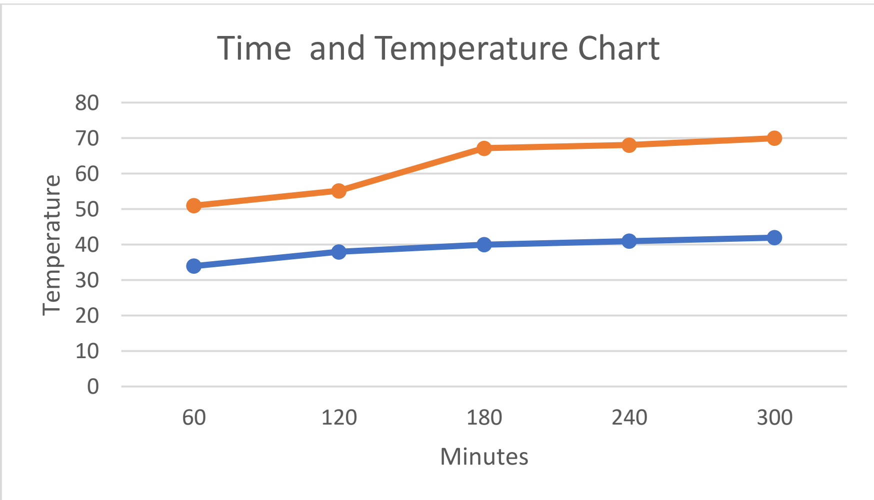

Fig.7.1 Time vs Temperature chart.

Thermal Efficiency Evaluation

The thermal efficiency (η) of the solar air heater was determined based on the useful heat gain by the air and the total solar radiation incident on the absorber surface.

1. Calculation of Efficiency (η)

The formula for efficiency is given by:

η = [M * c_p * (T_o - T_i)]/ (I * A}

- Formula Presented (Numerical Form, assuming c_p is 1):

η = [10.6*(70^{0}C - 40^{0}C)]/ (1361*0.5547)

- **Variable Definitions:**
  - M: mass flow rate of air (kg/sec)= 10.6 kg/sec, calculated with vane anemometer
  - I: solar irradiance at Earth's atmosphere is 1361 W/m^2
  - A: area of absorber plate is 0.5547 m^2
  - T_o: Output temperature (70^{0}C)
  - T_i: Input temperature (40^{0}C)
- Result:

Therefore, **η = 42.12%**

2. Amount of Moisture Content (M_c)

The formula for the amount of moisture content is:

M_c = [100*(M_i - M_f)]/M_i

- Formula Presented (Numerical Form):

M_c = (100*(250 - 60)]/250

- **Variable Definitions:**
  - M_i: Initial mass (wet)
  - M_f: Final mass (dry)
- Result:

Therefore, **M_c = 76%**

3. Amount of Moisture to be Expelled (M_w)

The formula for the amount of moisture to be expelled is:

$M\_w = M\_p *[(M\_i - M\_f)/(100 - M\_f)]$

- **Variable Definitions:**
  - M_w: Amount of moisture to be expelled
  - M_p: Initial mass of product (Kg)
  - M_i: Initial moisture content (%)
  - M_f: Final moisture content (%)
- **Safe Storage Requirement:**
  - For safe storage moisture content should be 10%
- Formula Presented (Numerical Form):

$M\_w = 0.25 * [(76 - 10)/(100 - 10)]$

(Note: M_p = 0.25 Kg and M_i = 76% from calculation 2, and M_f = 10%)

- Result:

M_w = 0.1833 kg

4. Useful Heat Collected (Q)

Useful heat collected for an air-type solar collector (solar air heater) can be expressed as:

$Q = M * c\_p * (T\_ao - T\_ai)$

- Formula Presented (Numerical Form):

$Q = 10.6 * 1.00 * (70 - 40)$

(Note: The term c_p for air is used as 1.00 which likely represents 1.00 kJ/kg^{0}C.)

- **Variable Definitions:**
  - M: mass flow rate of air (10.6 kg/sec)
  - c_p: Specific heat of air (1.00 assumed value/unit)
  - T_ao: Air output temperature (70^0 C)
  - T_ai: Air input temperature (40^0 C)
- Result:

Q = 318 joules

This efficiency calculation provides insight into the heater's ability to convert incoming solar energy into useful thermal output. The recorded temperature rise across the heater confirms the feasibility of the system for low-temperature applications such as drying, space heating, and preheating of air for thermal processes.

6. Conclusion

The present study successfully demonstrates the development and performance evaluation of a portable solar air heater equipped with a tin-based absorber plate. The system effectively harnesses solar energy to generate hot air, confirming its suitability for low-temperature thermal applications such as drying and space heating. Experimental results show that the fabricated heater is capable of increasing the air temperature from approximately 40°C to 70°C under clear-sky conditions. The recorded thermal efficiency of 42.12% indicates a satisfactory level of heat transfer for a low-cost, lightweight, and easily transportable system.

The simplicity of construction, low operational cost, and minimal maintenance requirements further enhance the practicality of the device. As a renewable energy-based heating solution, the system offers an environmentally friendly alternative to conventional fuel-based drying and heating methods.

7. Future Scope

India’s geographical location provides significant potential for harnessing solar energy, and systems such as the proposed solar air heater can play a vital role in promoting sustainable thermal applications. The current design, while effective, presents several opportunities for further improvement. Enhancing the absorber material—such as replacing tin with copper to improve thermal conductivity—could substantially increase the system’s overall efficiency.

Additionally, integrating automation into the collector chamber, particularly by enabling dynamic adjustment of the collector angle using light sensors, can ensure optimal solar tracking and maximize heat gain throughout the day. The system can also be adapted for specific agricultural applications, such as grape drying or other post-harvest processing operations, where uniform heating and controlled airflow are essential.

Future developments may also include incorporating phase change materials (PCM) for thermal storage, optimizing airflow pathways, and scaling the design for industrial or community-level drying applications. These advancements can contribute to a more robust, efficient, and user-friendly solar air heating system suitable for diverse climatic conditions.

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