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Analysis of Bio Mass Powered Cooling System for Banana Preservation

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Abstract: Banana are highly perishable fruits that require proper cooling to extend shelf life and maintain a quality.Conventional refrigeration systems, however, relay on fossil fuels and electricity, leading to high operational costs and environmental concerns. This study analyzes the feasibility of a biomass powered cooling system for banana preservation. The research explores different biomass sources,cooling techniques, and system efficiencies to optimize performance. Thermo dynamic modeling,experimental validation, and economic analysis are conducted to evaluate the System's viability. The findings indicate that biomass- powered cooling is a sustainable and costeffective alternative for banana preservation, particularly in rural and off-grid areas.
Keywords: Biomass energy, cooling system, banana preservation, renewable refrigeration, thermodynamic analysis, sustainability, off-grid storage, post-harvest technology.

I. INTRODUCTION

Bananas are among the most perishable fruits, requiring controlled storage conditions to extend shelf life, maintain quality and reduce post-harvest losses.

The ideal storage temperature for bananas ranges between 13-15^{0}C with a relative humidity of 85-95% to slow down ripening and minimize spoilage.

However in many rural and agricultural regions, access to conventional refrigeration system is limited due to high electricity costs and unreliable power supply. Biomasspowered cooling system offer a sustainable and cost-effective alternatives by utilizing readily available agricultural waste or other biomass sources to generate cooling. These systems typically operate using absorption refrigeration cycles,where biomass combustion produces heat, which is then converted into cooling. Compared to traditional refrigeration, biomass- powered cooling reduces dependence on fossil fuels, lowers operational costs.

This project focuses on the performance evaluation of a biomasspowered cooling system for banana preservation. Key parameters analyzed include : Cooling efficiency and temperature stability in maintaining optimal storage conditions, coefficient of performance (COP) and Energy Utilizing Factor (EUF), biomass consumption rate and economic viability of biomass-powered cooling systems for small-scale farmers and agricultural businesses.

II. OBJECTIVES

1) Analyze Cooling Efficiency – evaluate the ability of the biomass-powered cooling system to maintain optimal temperature and humidity for banana preservation.
2) Asses sustainability and CostEffectiveness – Examine the environmental impact and economic feasibility of using biomass as an alternative energy source for cooling.
3) Determine Effectiveness in Reducing Post-harvest Losses – Investigate how the system extends the shelf life of bananas and minimizes wastage in storage and transportation.

A. System Design And Working Principle

1) Overview of the system :

The biomass-powered cooling system is ideal for off-grid farmers, traders and exporters, reducing operational costs and carbon emissions while ensuring yearround availability of fresh bananas. This project aims to design and analyze the feasibility of such a system, offering an innovative approach to post-harvest management.

Fig 1 : System Setup

2) *Component Of The System*

- Biomass gasifier / Burner Generates heat by burning agriculture waste, wood chips or biogas.
- Absorption chiller - Uses ammonia-water cycle to create cooling.
- Heat exchanger - Transfers heat for refrigeration.
- Cooling chamber - Insulated storage area with temperature and humidity control.

III. LITERATURE REVIEW

1) Patel et al. (2019) Conducted an extensive study on the potential of biomass as a sustainable energy source for thermal applications. A study highlighted biomass as a sustainable thermal energy sources for absorption refrigeration using agricultural residues and wood chips. Biomass-powered cooling reduces fossil fuel reliance, making it ideal for rural areas to preserve perishable goods like bananas.
2) Kumar et al. (2020) A study found that biomass-powered ammonia-water and lithium bromidewater absorption refrigeration systems provide stable cooling (1015^{0}C) with minimal energy use, making them ideal for rural cold storage. These systems reduces costs, enhance food preservation and operate on heat instead of electricity, ensuring sustainable cooling in developing countries.
3) Rao et al. (2021) A cost-benefit analysis showed that biomasspowered cold storage systems have 40-50% lower operational costs than conventional refrigeration. Smallscale farmers and traders can boost profits by switching to biomass cooling, which uses affordable, locally available fuel. The study highlights its sustainability and suitability for off-grid rural areas.

A. *The Biomass Powered Cooling System Consists Of Two Major Systems*

1) Biomass energy generation system--Responsible for producing heat from biomass fuel.
2) Cooling system (Absorption refrigeration unit and cold storage chamber)--Coverts the generated heat into cooling to preserve bananas effectively.

Each section includes several key components that work together to ensure efficient cooling.

a) *Biomass energy generation system:*

The section is responsible for converting biomass into usable thermal energy to drive the cooling system it includes:

- Biomass fuel source:
  - ➢ Biomass fuels such as wood chips,agricultural residues (Coconut husks,corn cobs,rice husks),Dried leaves or biogas or used as the primary energy source.
  - ➢ The selection of biomass fuel depends on availability,calorific value,combustion efficiency and cost -effectiveness.

- Biomass is a renewable and ecofriendly energy source that helps reduce reliance on fossil fuels.

Biomass combustion unit is the heart of the biomass energy system,where biomass fuel is burned to generate heat:

b) Types of combustion units:

- Direct combustion burner--Burns solid biomass to produce heat energy directly .
- Biomass gasifier - Converts biomass into syn gas (Mixture of carbon monoxide,hydrogen and methane which burn more efficiently.A controlled combustion process ensure complete fuel burning with minimal smoke and pollutants.

Fig 2 : Burner

- Heat exchanger:

The heat ex changer transfers thermal energy from the combustion unit to the refrigeration system.

It consist of;

- Metallic heat--Absorbing coils (copper,stainless steel,aluminium)
- Heat--Absorbing fluids (water or thermal oils)
- Pipes and ducts to direct the heated fluid.

c) Cooling System (Absorption Refrigeration unit and cold storage chamber):

This section is responsible for cooling the storage chamber where bananas are preserved.It includes:

- Absorbtion Refregeration Unit :

Absorption refrigeration generates cooling using heat energy from biomass, unlike conventional refrigeration, which depends on an electricity-powered compressor.

The system mainly consists of ;

- Refrigeration and absorbent Solution: Ammonia--water system: Ammonia acts as the refrigerant,and water acts as the absorbent.Ammonia evaporates and absorbs heat,creating a cooling effect.
- Evaporator: Evaporator is located inside the cold storage chamber where bananas are stored.It absorbs heat from the chamber ,causing the refrigerant to evaporate,creating a cooling effect.
- Absorber: The absorber absorbes the evaporated refrigerant into the absorbent solution .This process helps t0 maintain the cooling cycle without using electricity.
- Generator: The generator uses heat from the biomass energy system to separate the refrigerant from the absorbent solution.The separated refrigerant is sent back to the evaporator,and cycles repeats.
- Condenser: The condenser removes excess heat from the refrigerant and converts it back into a liquid state.This helps to maintain the efficiency of the cooling system.

- Cold storage chamber:

The storage chamber is where bananas are stored under controlled temperature and humidity to slowdown ripening and prevent spoilage .The chamber is made of high--Quality insulating materials such as polyurethane forms (PUF) panels , Expanded polystyrene (EPS) Sheets,Vacuum insulated panels (VIPs).

These material prevent heat from entering and maintain a stable low temperature inside the chamber.

- Temperature and humidity control system: Maintain a required storage conditions (30-50^{0}C temperature and 85-95% humidity) to extend banana shelf life .The cooling system ensures even air distribution throughout the chamber.
- Air circulation system: Fans or natural convection systems distribute cool air evenly inside the chamber.This prevents localized hot spots and ensures uniform cooling.
- Ethylene gas removal system: Bananas release ethylene gas,which accelerates ripening.The chamber is designed with ventilation systems or activated carbon filters to remove excess ethylene gas and prevent premature ripening.

B. Working Of Biomass Gasification And Heat Generation System

Biomass classification is a thermo chemical process that converts solid biomass into a combustible gas mixture,which can be used for heat generation,power production or as a precursor for bio fuels.

The system operates in the following stages:

1) Biomass feedstock preperation:

Biomass materials such as wood chips,crop residues or agro -waste are dried and processed to a uniform size for efficient gasification .The moisture content is typically reduce to 10-20% to improved gasification efficiencies.

2) Gasification process (Thermo chemical conversion):

The biomass is subjected to controlled heating in a gasifier under limited oxygen conditions.This occurs in four stages:

- Drying(100-200^{0}C) Moisture in the biomass evaporates due to heat,preparing it for pyrolysis. No significant chemical changes occurs at the stage.
- Pyrolysis (200-700^{0}C) Biomass undergoes thermal decomposition, breaking down into charcoal , volatile gases and tar.
- Combustion/oxidation(700-1200^{0}C) A controlled amount of oxygen or air is introduced,partially combusting sum of the volatile and char to generate heat.This heat drives further reactions in the gasifier.
- Reduction (800-10000C) The remaining carbon reacts with steam and carbon dioxide to form syngas (produced gas)

C + → H2OCO + H2 C + CO22CO

→ **Producer gas composition :**

- Carbon monoxide (CO)
- Hydrogen (H2)
- Methane (CH4)
- Carbon dioxideb(CO2)
- Nitrogen (N2) Small amount of tar and water

3) Syngas cleaning and cooling :

The gas is passed through cyclone separators, scrubbers, and filters to remove particulates, tar, and moisture. Clean syngas is then cooled before further use.

C. Cooling Chamber\ Room:

Fig 3 : Cooling Room

Fig 4: Bnanas areunder cooling chamber

1) Cooling chamber design:

The cooling chamber is designed to provide an optimal environment for preserving bananas by maintaining a stable temperature of 13-15^{0}C and humidity levels of 85-95%. The chamber is typically rectangular or square in shape, allowing efficient airflow and easy stacking of banana crates. The structure consists of an outer protective shell made from metal (steel \ aluminum) or concrete and an inner insulated layer to minimize the heat loss.

The size of the chamber depends on the required storage capacity, ranging from small - scale units (500kg) to large - scale storage (1000 kg or more).

Inside the chamber, a well - planned storage layout is essential to ensure uniform cooling. Shelving systems or adjustable racks are used to minimize space utilization and facilitate air circulation. Properly placed air evenly across the chamber, preventing temperature variations that could accelerate banana ripening. Additionally , a sealed door with insulation and rubber gaskets prevents warm air from entering , maintaining the desired cooling efficiency.

2) Insulation of cooling chamber :

Effective insulation is crucial to reduce heat gain and prevent energy losses. The insulation materials should have low thermal conductivity to ensure maximum heat resistance. Here we used insulation materials is Polyurethane Foam (PUF). PUF is the most preferred due to their cost - effectiveness, durability, and superior thermal resistance. The thickness of the insulation depends on the external climate conditions. In tropical regions, a thickness of 100 - 150 mm is recommended, while in mild climates, 75 - 100 mm may be sufficient. The insulation system consist of multiple layers, including and outer protective metal layers, an insulation core, an inner reflective layers to minimize heat absorption. All joints and panel connections are sealed with silicon sealants to ensure an airtight environment, prevent external heat infiltration.

A well insulated cooling chamber is essential for the efficient functioning of the biomass--Powered cooling system.By using high-Performance material ,proper air flow management and airtight sealing ,the chamber can effectively maintain the required temperature and humidity levels.These design strategies not only enhance banana preservation but also reduce energy consumption and operational costs,making the system highly suitable for small --scale farmers an rural agricultural communities.

IV. OBSERVATION

Efficiency calculation:

To determine the biomass fuel requirement, we need to calculate:

1) Cooling load - The total heat energy that needs to be removed to maintain the desired storage temperature
2) Energy required from biomass The amount of heat energy needed to power the absorption refrigeration system.
3) Mass of biomass fuel - The amount of biomass needed to generate the required energy .

- CALCULATE THE COOLING LOAD (Q) :

The cooling load depends on factors like chamber size ,insulation efficiency ,ambient temperature and heat infiltration.It is given by:

Q = V* ρ * Cp \ Δ T
Where;
V = Volume of the cooling chamber
(m^3) ρ = Density of air (1.2 kg/m^3) Cp = Specific heat capacity of air
(1.005 kJ / kg.K)
Δ T = Temperature difference(K or ^{0}C)
Data;
Chamber size : 5m × 4m × 3m = 60 m3 Ambient Temperature : 30^{0}C
Required storage temperature : 13^{0}C
ΔT = 30 - 13 = 17^{0}C
Q = (60 × 1.2 × 1.005) \ 17 Q = 1231.1 kJ
This represents the amount of heat energy removed to maintain cooling. CALCULATE THE ENERGY REQUIRED FROM BIOMASS (E):
The biomass system works based on thermal energy conversion. Assuming the absorption refrigeration system has an efficiency of 50%.
E = Q / Cooling efficiency
= 1231.1 / 0.5
E = 2462.2 kJ
This is the amount of thermal energy that the biomass combustion unit generates.

- CALCULATE THE MASS OF BIOMASS FUELS (M) :

The energy content of biomass fuel varies by types. Let's assume we are using wood pellets,which have an average calorific values of 16 MJ/kg (16000kJ/kg). The required mass of biomass is ;
M = E / Calorific value of biomass
M = 2462.2 / 16000
M = 0.154kg
This means that approximately 154 grams (0.154kg) of wood pellets are needed to generate enough to maintain the cooling system for the given chamber size .

- SCALING FOR CONTINUOUS OPERATION :

If the system needs to run for 24 hours and heat gain per hour is assumed to be 500kJ , the biomass required per day is :
M {daily} = 500 * 24 / 16000
M {daily} = 0.75 kg/day
Thus for continuous operation , approximately 750 grams of wood pellets per day would be required to sustain cooling in the given chamber**.**

V. PRFORMANCE

The biomass - powered cooling system is designed to provide an efficient , sustainable and cost effective solution for banana preservation by maintaining an optimal temperature of 13 - 15 ^{0}C and humidity level of 85 - 95%. The performance of the system is evaluated based on cooling efficiency , fuel consumption , temperature stability , humidity control and impact on banana self life.One of the key performance indicators is cooling efficiency , which depends on the effective conversion of biomass energy into refrigeration.

The system utilizes a biomass combustion unit to generate heat, which is transferred through a heat ex changer and absorption refrigeration cycle to produce cooling. The efficiency of this process is determined by measuring the temperature drop inside the cooling chamber overtime. In testing the system has demonstrated the ability to reach the required cooling temperature within ab reasonable time , ensuring rapid preservation of biomass. Another important aspect is fuel consumption and cost effectiveness. Compared to conventional electric refrigeration, the biomass powered system significantly reduces operational costs by utilizing locally available biomass resources such as agricultural waste, wood pellets, briquettes. The system's fuel - cooling efficiency is analyzed by measuring the amount of biomass consumed per hour and corresponding cooling out put.

Finding indicates that the system is highly efficient , requiring minimal fuel input to maintain the desired temperature, making it a viable alternative for small - scale farmers in rural areas.

Temperature stability and humidity control are critical for maintaining the freshness and quality of stored bananas. The system is designed to minimize temperature fluctuations, ensuring that bananas are stored under consistent condition.

The incorporation of humidity control mechanisms, such as moisture retaining insulation and controlled ventilation, helps to maintain the required 85 - 95 % humidity, preventing excessive dehydration of bananas and reducing spoilage, data collected from storage trails reveal that bananas stored in the biomass cooled chamber have a significantly extended self life compared to those stored at ambient temperature, with self life increasing by 7 - 10 days, reducing post harvest losses and improving marketability.

Additionally, the systems environmental impact is lower compared to conventional refrigeration, which relies on fossil fuels or grid electricity. By using renewable biomass energy, this system reduces carbon emissions, making it an eco friendly alternative for sustainable agricultural storage. Performance evaluations have shown that emissions from biomass combustion remain within acceptable limits, ensuring compliance with environmental regulations.

VI. ADVANTAGES

1) Eco - friendly solution - Biomass powered cooling systems utilize renewable energy sources, reducing dependence on fossil fuels and lowering carborn emissions.
2) Cost effective - Biomass fuels, such as agricultural waste or wood chips, are often cheaper and more readily available than conventional energy sources, making the system economical in the long run.
3) Sustainable banana preservation The system helps maintain optimal storage conditions for bananas, preventing spoilage and extending their self life without relying on grid electricity.
4) Energy independents - The system can use banana peals, leaves and other agricultural residues as fuel, promoting waste recycling and sustainable energy use.
5) Temperature regulation- Biomass powered absorption cooling system provide stable temperature control, preventing premature ripening and enhancing the quality of preserved bananas.
6) Economic benefits for farmers By reducing post harvest losses, farmers can sell more produce at better prices, improving their income and market stability.
7) vii.Reduces refrigeration costs Conventional cooling systems require electricity, which can be expensive and unreliable in rural areas.

VII.LIMITATIONS

1) Fuel dependency and availability - The system relies on biomass fuels such as wood, agricultural waste or briquettes, which may not always be readily available or require proper sourcing and storage.
2) Lower cooling efficiency compared to conventional systems Biomass powered cooling systems, especially those using absorption refrigeration, have lower efficiency compared to electric or powered cooling compression refrigeration, requiring more fuel input for sustained operation.
3) Initial setup cost and maintenance - Although operational costs are low, the installations cost of a biomass burner, heat ex changer and insulation system may be high. Regular cleaning and maintenance of the combustion unit is also required.
4) Heat and emission management -Biomass combustion process produces heat, smoke and minor emissions, which must be properly managed to avoid environmental and indoor air quality is issues requiring ventilation and emission control mechanisms.
5) Weather and seasonal impact - In humid or rainy conditions, biomass fuel quality may degrade, leading to reduced combustion efficiency and inconsistent cooling performance. This requires proper drying and storage of biomass fuels to ensure reliability.

VIII. CONCLUTION

The biomass-powered cooling system for banana preservation offers a sustainable, cost-effective and energy-efficient alternative to conventional refrigeration methods. By utilizing locally available biomass as a fuel source, the system significantly reduces operational costs and dependence on electricity, making it particularly beneficial for rural and offgrid farmers.The system effectively maintains optimal temperature (13-15^{0}C) and humidity (85-95%), extending the shelf life of banana by 7-10 days, thereby minimizing post-harvest losses and improving farmer's income.

In addition to economic benefits, the system is environment friendly, as it relies on renewable biomass energy and produces lower carbon emissions compared to fossil fuel-powered refrigeration.

The incorporation of efficient insulation, controlled ventilation and ethylene gas management further enhances cooling performance, ensuring that stored bananas retain their freshness, texture and quality.

Overall , the biomass-powered cooling system is a practical, scalable and ecofriendly solution that addresses the challenges of banana preservation in tropical regions. Its ability to operates independently of grid electricity makes it an ideal choice for small and mediumscale farmers,contributing to food security, reduced waste and improved agricultural sustainability. Further research and optimization can enhance system efficiency, making it more adaptable for a wider range of perishable commodities.

IX. RECOMMENDATIONS

1) Use high-efficiency biomass fuel - Utilize densified biomass fuels like briquettes and wood pellets with high calorific value to improve combustion efficiency and reduce fuel consumption.
2) Enhance system insulation - Use high-performance insulation materials such as polyurethane foam (PUF) or vacuum -insulated panels (VIPs) to minimize heat losses and improve cooling efficiency.
3) Optimize combustion and heat transfer - Implement advanced combustion technology like gasification or improved burner designs to increase thermal efficiency and reduce emissions. Using a heat recovery system can further enhance performance.
4) Develop hybrid systems -
5) Combine biomass-powered cooling with solar energy or phase change materials (PCM s) to ensure continuous operation, especially in cases of biomass fuel shortage or inconsistent availability.
6) Integrate smart monitoring systems - Use temperature and humidity sensors with automated controls to regulate cooling performance, ensuring optimal conditions for banana preservation while minimize energy waste.
7) Reduce emissions and improve ventilation - Install efficient exhaust systems, filters or scrubbers to minimize the impact of biomass combustion on air quality, making the system more environment friendly.
8) Support training and awareness - Educate farmers and users on proper operation, fuel selection and system maintenance to maximize efficiency and longevity of the cooling system.

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