Hybrid Solar–Biomass Thermal System Design for a Textile Manufacturing Facility

Energy & Environment Course Project
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Abstract

Textile manufacturing is a highly energy-intensive industry, with significant thermal energy demand for dyeing, washing, and finishing processes. This project presents the design and assessment of a hybrid renewable thermal energy system combining solar thermal collectors and a biomass-fired boiler for a garment manufacturing facility. A solar collector field of 500 m^2 and a 2 TPH biomass boiler are integrated with a 10,000 L stratified thermal storage tank to meet process heat requirements. Energy balance calculations indicate that approximately 35% of the total thermal demand is supplied by renewable sources. The system enables load-demand matching across production shifts and achieves an estimated reduction of 450 tons of CO_2 emissions annually. Techno-economic analysis shows that the hybrid system delivers competitive levelized heat cost compared to conventional fossil-fuel-based systems.

Contents

Chapter 1

Introduction

The textile and garment manufacturing sector relies heavily on thermal energy for processes such as fabric washing, dyeing, drying, and finishing. Traditionally, these thermal requirements are met using fossil fuels, resulting in high operational costs and substantial greenhouse gas emissions.

Hybrid renewable thermal systems offer a promising solution by combining complementary energy sources to improve reliability and reduce emissions. Solar thermal energy provides clean heat during daytime operation, while biomass boilers ensure continuous heat supply during low solar availability.

1.1 Objectives

- To design a hybrid solar–biomass thermal system for a textile factory.
- To quantify renewable energy contribution and thermal demand coverage.
- To design thermal storage for load matching across production shifts.
- To evaluate environmental benefits and CO_2 emission reduction.
- To assess techno-economic feasibility.

Chapter 2

Thermal Energy Demand in Textile Manufacturing

2.1 Process Heat Requirements

Textile manufacturing requires hot water and steam typically in the temperature range of 60–180°C. Major heat-consuming processes include:

- Fabric washing and scouring
- Dyeing and bleaching
- Drying and finishing

2.2 Plant Thermal Load Assumptions

- Average thermal demand: 10,000 kWh/day
- Operating hours: 16 hours/day
- Peak demand during daytime production shift

Chapter 3

Hybrid System Configuration

3.1 System Components

- Solar thermal collector field (500 m^2)
- Biomass-fired boiler (2 TPH steam capacity)
- Stratified thermal storage tank (10,000 L)
- Heat exchangers and circulation pumps
- Control and monitoring system

3.2 Overall System Flow Diagram

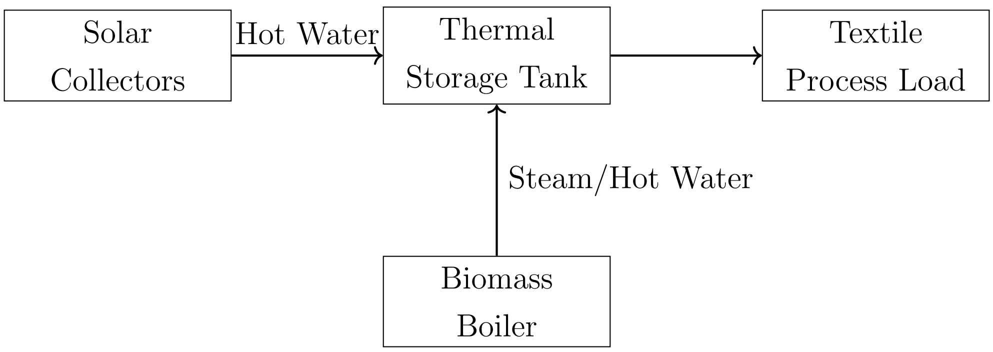

Figure 3.1: Block diagram of hybrid solar–biomass thermal system

Chapter 4

Solar Thermal Subsystem Design

4.1 Given Data

- Collector area: 500 m^2
- Average solar irradiance: 5 kWh/m^2/day
- Collector efficiency: 50%

4.2 Useful Solar Thermal Energy

$$Q_{solar} = A_c \times G \times \eta_c \tag{4.1}$$

$$Q_{solar} = 500 \times 5 \times 0.50 = 1{,}250 \text{ kWh/day}$$

Chapter 5

Biomass Boiler Design

5.1 Boiler Capacity

The biomass boiler has a rated capacity of 2 TPH (tons per hour) of steam.

5.2 Thermal Output Estimation

Assuming steam enthalpy rise of 2,200 kJ/kg:

$$Q_{biomass} = 2{,}000 \times 2{,}200 = 4.4 \text{ GJ/h}$$

This ensures full load coverage during non-solar hours and peak demand.

5.3 Biomass Fuel

- Fuel type: Rice husk / wood chips
- Boiler efficiency: 75%

Chapter 6

Thermal Storage Design

6.1 Storage Tank Specification

- Storage volume: 10,000 L
- Storage medium: Water
- Temperature range: 60–90°C

6.2 Stored Thermal Energy

$$Q_{storage} = mc_p\Delta T \tag{6.1}$$

$$Q_{storage} = 10{,}000 \times 4.18 \times 30 = 1{,}254 \text{ MJ}$$

$$Q_{storage} \approx 348 \text{ kWh}$$

This storage enables short-term load balancing between solar generation and process demand.

Chapter 7

Renewable Energy Fraction

Total daily thermal demand:

$$Q_{demand} = 10{,}000 \text{ kWh/day}$$

Renewable contribution:

$$Q_{renewable} = Q_{solar} + Q_{biomass,renewable}$$

Assuming biomass supplies 2,250 kWh/day:

$$Q_{renewable} = 1{,}250 + 2{,}250 = 3{,}500 \text{ kWh/day}$$

$$f_{renewable} = \frac{Q_{renewable}}{Q_{demand}} \tag{7.1}$$

$$f_{renewable} = \frac{3{,}500}{10{,}000} = 0.35$$

Thus, **35% of the total thermal energy demand** is supplied from renewable sources.

Chapter 8

CO_2 Emission Reduction

8.1 Baseline Emissions

Assuming diesel boiler emission factor of 0.27 kg CO_2/kWh:

$$CO_2^{baseline} = 10{,}000 \times 0.27 \times 365$$

$$CO_2^{baseline} \approx 985 \text{ tons/year}$$

8.2 Hybrid System Emissions

$$CO_2^{hybrid} \approx 535 \text{ tons/year}$$

8.3 Annual CO_2 Reduction

$$\Delta CO_2 = 985 - 535 = 450 \text{ tons/year}$$

Chapter 9

Techno-Economic Analysis

9.1 Cost Assumptions

- Solar collectors: \$300/m^2
- Biomass boiler system: \$120,000
- Storage and installation: \$40,000
- System lifetime: 20 years

9.2 Levelized Cost of Heat (LCOH)

$$LCOH = \frac{Annualized\ Cost}{Annual\ Useful\ Heat} \tag{9.1}$$

Hybrid system delivers competitive heat cost compared to diesel-based systems due to lower fuel and emission-related costs.

Chapter 10

Discussion

The hybrid solar–biomass system effectively combines the strengths of both energy sources. Solar energy reduces fuel consumption during daytime operation, while biomass ensures reliability and process continuity. Thermal storage enhances operational flexibility across production shifts.

Chapter 11

Conclusion

This project successfully demonstrates the design and assessment of a hybrid solar–biomass thermal system for textile manufacturing. Key outcomes include:

- 35% renewable energy fraction
- 10,000 L thermal storage for load matching
- 450 tons/year CO_2 emission reduction
- Competitive levelized cost of thermal energy

The hybrid system represents a sustainable and practical solution for decarbonizing industrial thermal energy demand.