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ENERGY OPPORTUNITIES FOR AGRICULTURAL SYSTEMS AND FOOD SECURITY PROJECT

USING SOLAR THERMAL TO LOWER ENERGY COSTS FOR SMALL SCALE DAIRY PROCESSORS

Technical Brief #3

This brief is the third of four practical guides developed by the **Energy Opportunities for Agricultural Systems and Food Security Project** (E4AS). Funded by USAID's Africa Bureau with field work in Senegal and Kenya, E4AS is implemented by Green Powered Technology in partnership with ACDI/VOCA. The objective of E4AS is to expand and focus information related to how clean energy (CE) and energy efficiency (EE) can strengthen post-harvest value chains and reduce loss in sub-Saharan Africa, while also contributing to low emission development strategies (LEDS) and incorporating gender-aware strategies. Visit www.agrilinks.org/post/clean-energy-productive-use-post-harvest-value-chains-integrated-literature-review-field-work to access additional briefs and an integrated literature review with field work findings.

Introduction

Solar energy from the sun can be captured to generate both electricity (solar electric) and heat (solar thermal). Solar electric can be used to provide renewable power to replace traditional fossil fuel based forms of power generation. Solar thermal energy can be used to provide primary and supplemental heat in a wide range of applications from space conditioning in buildings and heating of swimming pools, to specific applications in a variety of industrial processing operations.

This technical brief discusses the use of solar thermal in the dairy processing industry and how solar thermal can reduce milk pasteurizing and processing costs, particularly for small-scale processors in a sub Saharan African context.

Solar thermal explained

Electromagnetic radiation from the sun provides both light and heat on Earth. Much of this radiation is invisible to the human eye, but its impact causes the molecular structure of materials to vibrate which results in heat. This is how the Earth is heated. Capturing that heat provides a renewable and useful source of thermal energy.

A simple example of a garden hosepipe on a sunny day demonstrates this. The water temperature in a hosepipe left out in bright sun, even for a few minutes, can increase to scalding temperatures because the sun's infrared radiation heats the water in the hose. Solar thermal panels operate in the same way, with the sun's infrared radiation heating

Figure 1. Roof Mounted Solar Thermal Panel at Moi's Bridge Muungano Farmer's Cooperative Society Ltd., Moi's Bridge, Kenya

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a fluid (usually water or a water glycol mixture) in a solar collector or panel. These panels are typically flat and mounted in an unshaded area on a roof or the ground. They often have glass covers under which there are multiple interconnected black tubes through which the heat transfer fluid is pumped. Hot fluid is stored in insulated tanks for later use. In some designs thermo-siphoning of the fluid to and from the panel obviates the need for a pump.

Solar thermal in small-scale dairy processing operations

Solar thermal energy can be used in a number of applications in dairy processing operations, including:

- providing hot water for CIP (clean-in-place) and sanitary use
- pre-heating boiler feedwater
- directly heating milk in the pasteurizing process

Each of these are discussed briefly below, and their relative economics examined.

Costs of electricity and equipment used in these economics are based on actual costs found in Kenya, but the applications would be applicable in any country with suitable adjustment for local economics. Because the costs of the alternative fuels used for heating such as oil and biomass can vary considerably between countries and regions within countries, for the summary economic analysis discussed below, it has been assumed that electricity at a cost of 20.0 Kenyan Shillings per kilowatthour (20.0 KSh/kWh or US$0.20/kWh) is used in all heating applications. Local Kenyan equipment supplier costs of 121,000 KSh (US$1,210) for a 3.5 m² solar thermal panel (equipment only) were also used in these calculations.

Clean-in-place (CIP) and sanitary water heating with solar thermal

All equipment used in food processing needs to be cleaned and sanitized on a regular basis. This is especially important in milk processing where bacterial contamination can quickly cause product spoilage and consumer illness. Processing equipment used in milk processing, including the pasteurizing equipment, must be washed and sanitized using warm water, detergents and disinfectants. Typically the water temperature used with the detergents and disinfectants is the same as the temperature used in pasteurizing, but for the initial equipment rinse, milk fat solids that are deposited within the processing equipment will be flushed better using warm water (<55 °C or 131 °F) so proteins in the milk do not coagulate.

- The energy required to raise water temperature from ambient of 16°C (61°F) to 55 °C (131 °F) is 0.045 kWh/litre (= 587 Btu/US Gal or 704 Btu/Imp Gal).
- A **single flat glass panel solar thermal collector** of 3.5 m² in a high solar radiation region (i.e. > 6.3 kWh/m²/day or 2,000 Btu/ft2/day) such as Eldoret, Kenya can heat approximately 200 litres/day (53 US Gal/day or 44 Imp Gal/day) from 16 °C (61 °F) to 55 °C (131 °F).
- If this same heat energy is provided by an **electric heater**, the electric heater would consume approximately 10 kWh/day or 3,650 kWh/year at a cost in Kenya of 20 KSh/kWh (US$0.20/kWh) or 73,000 KSh/year (US$730).

An installed cost of a single 3.5 m² solar thermal panel is estimated at approximately 140,000 – 150,000 KSh (US$1,400 – 1,500). Although this upfront cost is higher than a monthly electric bill (straight-lined monthly average of US$60.80, or $730 a year), **the solar thermal panel pays for itself with a payback period of approximately two years, providing long-term cost savings**.

The number of panels installed would depend on available capital, suitable available space (e.g. available roof space or nearby land), and the total volume of warm water required for CIP and sanitation each day. In a system used to heat CIP and sanitation water in an area where there is no chance of freezing, the actual CIP and sanitation water could flow directly through the solar thermal panel.

Where there is a chance of freezing, a water glycol mixture would be required in the solar thermal panel, so a **heat exchanger** would be required to exchange heat between the water/glycol mix and the CIP and sanitation water. This would add to the installed capital cost and increase the estimated payback by approximately 50%.

Boiler feedwater pre-heating with solar thermal

In a similar way to heating water for CIP, boiler feedwater used for heating milk prior to and during pasteurization can also be heated using solar thermal. A heat exchanger would be used between the fluid flowing in the solar thermal panel and the boiler feedwater to minimize chemical fouling of the solar thermal panel. **Savings, costs and payback are similar to those for the CIP and sanitation water heating.**

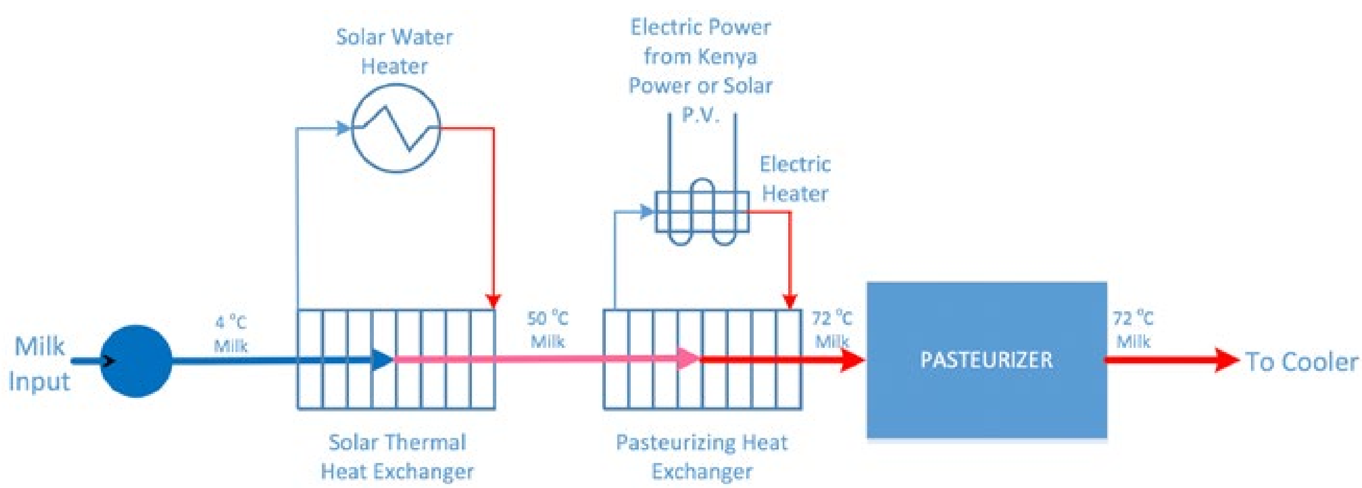
Pre-heating and heating of milk for pasteurizing

Solar thermal can also be used to partially or completely heat the milk input into the pasteurizing equipment.

Depending on the pasteurizing process used and the duration the milk is held at the pasteurizing temperature, the actual input temperature required for the milk may vary. However, the typical flash pasteurizing or High-temperature Short-time (HTST) pasteurizing requires a temperature of 72 °C (161.6 °F) for 15 seconds. Milk stored at 4 °C (40 °F) requires a heat input of 0.0785 kWh/litre (1,015 Btu/US Gal or 1,218 Btu/Imp Gal) to raise it to that pasteurizing temperature.

The figure below illustrates the use of solar thermal to heat the milk completely.

- Because of the higher differential (input to output) temperatures required, a **single flat glass panel solar thermal collector** of 3.5 m² in a high solar radiation region (i.e. > 6.3 kWh/m²/day or 2,000 Btu/ft2/day) can heat approximately 50 litres/day (13 US Gal/day or 11 Imp Gal/day) from 4 °C (40 °F) to 72 °C (161.6 °F).
- If this same heat energy is provided by an electric heater, the **electric heater** would consume approximately 4 kWh/day or 1,460 kWh/year at a cost in Kenya of 20 KSh/kWh (US$0.20/kWh) or 29,200 KSh/year (US$292).



- The installed cost of a single 3.5 m² solar thermal panel with heat exchanger and pumps is estimated at approximately 160,000 – 175,000 KSh (US$1,600 – 1,750). Although this upfront cost is higher than a monthly electric bill (straight-lined monthly average of US$24.33), **the solar thermal panel pays for itself with a payback period of approximately six years—providing long-term cost savings**.
- For a milk processing plant in a high solar radiance region that flash pasteurizes 10,000 litres of raw milk per day with no heat recovery from the hot pasteurizer output milk, the heat required for pasteurizing could be produced by approximately 200 flat glass panel solar thermal collectors at a cost of approximately 30,000,000 - 35,000,000 KSh (US$300,000 - 350,000). This would require 700 m² of flat glass panel solar thermal collectors.

Blended solar/electric model: instead of heating the milk to the full required pasteurizing temperature, solar thermal can be used to partially heat the milk and then the remainder of the heat is provided by the existing electric heaters, as shown in the figure below.

- With this, because the differential temperature between the input and output (ΔT = TOutput – TInput) of the solar thermal panel would be less, and because a solar panel's efficiency is generally greater the lower the differential temperature from input to output, **the number of panels, the capital cost, and the payback would be reduced**.