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Integration of a solar thermal system in canned fish factory

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HIGHLIGHTS

- Integration of solar thermal energy in batch canning process was assessed.
- Optimal energy supply configuration was determined by Pinch analysis.
- Energy efficiency improved by integration of heat pump and solar thermal energy.
- Process fossil fuel consumption was reduced.

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ABSTRACT

Based on mathematical models and pinch analysis, this work evaluates the viability of integrating a solar thermal system, in combination with a heat pump, into the conventional energy structure of a tuna fish canning factory in the Atlantic side of the Basque Country. In order to determine the potential of this technological arrangement, different hypotheses and scenarios were analysed, based on real cases of the productive process. As a result, it could be stated that the energy potential of this combination, for the studied industrial process operating at low and medium temperatures, was considerable, and should be considered for a near future.

1. Introduction

Based on non-renewable energy sources, the current energy status outlines a critical future, which should be faced combining improvements in energy efficiency and the development and implementation of renewable energy types [1]. Whereas solar thermal technology has been well introduced in domestic and building applications, at industrial scale there is yet an important and not enough exploited area of study and implementation. However, there are some examples that illustrate the potential of this emergent technology in industrial activities. In the feed sector, Schnitzer and Gwehenberger [2] presented an interesting example, related to a dairy plant located in Austria. Atkins et al. [3] studied the best integration of thermosolar technology in a dairy milk powder plant of New Zealand using pinch analysis. Quijera et al. [4] analysed the viability of the thermosolar technology in a dairy process located in the north of Spain. Schweiger et al. [5] studied the general viability of this energy technology in Portugal and Spain, presenting some examples in textile and paper industries, brewing, malting, milk sector and some other processes, where solar energy was able to supply different amounts of energy. Nemet et al. presented a study of the integration of solar thermal energy into processes with heat demand [6] and they also presented a methodology for maximising the use of renewables with variable availability [7]. Very recently, Bhutto et al. [8] stated that the use and development of renewable energy technologies, particularly solar energy, could significantly improve environmental protection and guarantee continuing oil supplies in conditions of stability and security in the Persian Gulf region. Additionally, the European Solar Thermal Industry Federation presented some examples of high efficiency industrial applications of solar thermal energy [9]. In the field of solar energy refrigeration, Tora and El-Halwagi [10] analysed the feasibility of absorption refrigeration thermosolar systems by Pinch Analysis in three industrial activities, developing a systematic approach to determine the optimal contribution from an energy mix (solar, fossil and process heat). Nowadays, there is a

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promising investigation line in the field of solar technology implementation in unfavourable climatic zones. Two interesting examples can be found in the work by Tora and El-Halwagi [11] and in the solar heat for industrial processes state of the art description presented by Weiss and Rommel [12]. As many industrial processes operate with a thermal energy with low and moderate temperatures, solar thermal technology would be able to supply a significant amount of the total energy input at an acceptable price. For those processes, advanced flat-plate collectors and evacuated tube collectors would be often enough to produce heat at temperature levels between 60–90 °C and 90–130 °C. Some limitations of the application of thermal solar energy, such as intermittency and low energy density [13], could be solved by the integration of a heat pump. Helen et al. [14] developed a Pinch Analysis based methodology for the heat pump integration in a dairy process. Nuntaphan et al. [15]investigated the combination of thermosolar and heat pump, demonstrating that the temperature of the water from a flat-plate collector with water storage could increase by approximately a 40% by the compression heat pump. Becker et al. [16] presented the results of the integration of a heat pump in a cheese factory.

The north side of Basque Country, is a region where, statistically, beam radiation is lower than diffuses un radiation. In this area, the industrial use of solar thermal energy has not been enough considered because of the specific climatic and meteorological conditions [17]. In order to reduce the fossil fuel dependency, this study analysed the viability of using solar thermal energy in the industrial processing of tuna fish in the mentioned region.

In the energy chain of the global canning process, solar energy is supported by heat pump technology.

2. Conceptual framework of the study

2.1. Pinch analysis

The objective of this study is the integration of thermosolar energy in combination with conventional energy resources in the canning industry.

The energy structure of the plant was considered not only as a hot and cold utility streams production mechanism, but as a complex and dynamic process for energy production. So, the global canning process was considered as a total site where two processes worked together: the productive process and the energy provision process. Based on a systemic understanding of the overall site, it was possible to apply a methodology for the total site integration analysis [18].

The two considered processes operated together at the same time; therefore a single stream data set was defined for the total site with an overall pinch point which articulated the totality of the heat exchange network and a grand composite curve (GCC) representing the overall network [19].

When Pinch Analysis is applied to a batch process, the time average model (TAM) [20] presents an ideal scenario supposing that all the streams are totally coincident in time. Thus, the utility targets set by this methodology would give only an estimation of the energy tendency that needs to be complemented with the time event chart (TEC) [19].

2.2. Heat pump

The performance of three heat pump technologies was evaluated for the canning overall process by the following equations [21]:

Closed compression cycle with electrical engine – HP (Refrigerant R-123):

$$\mathrm{COP_p} = \frac{Q_o}{W} = \eta_{\mathrm{mec}} \cdot \frac{T_{f2}}{T_{f2} - T_{f1}} \tag{1}$$

Closed compression cycle with natural gas engine – GHP (Refrigerant R-123):

$$\mathrm{COP_{pt}} = \frac{Q_{o,t}}{W} = \frac{Q_{o,eng} + Q_{o,rec}}{W} = \eta_{\mathrm{mec}} \cdot \frac{T_{f2}}{T_{f2} - T_{f1}} + \eta_{\mathrm{rec}} \tag{2}$$

Absorption heat transformer, type II – AHT (LiBr/H_2O):

$$\mathrm{COP_p} = \frac{Q_{ab}}{Q_{ev} + Q_{ge}} \tag{3}$$

The payback time of the evaluated heat pumps was determined by Eq. (4) [21] based on the energy prices given by the energy provider in 2011 [22]:

$$\mathrm{PBP} = \frac{I}{\left(\frac{B_{\mathrm{fuel}}}{\eta_b} - \frac{B_{\mathrm{drive}}}{\mathrm{COPpt}}\right) \cdot t_f - m_{\mathrm{IHP}}} \tag{4}$$

2.3. Thermosolar technology

Based on a heat balance of the solar collector, the instantaneous efficiency of 1 m^2absorber area was calculated using Eq. (5), where an incidence angle modifier K_θ was included [23]:

$$\eta_{\mathrm{ins}} = K_\theta \cdot \eta_{\mathrm{op}} - \left[\frac{a_1\left(T_{\mathrm{cif}} - T_a\right) + a_2\left(T_{\mathrm{cif}} - T_a\right)^2}{G_t}\right] \tag{5}$$

To determine the heat flow transferred to the primary fluid through the solar field, Eq. (6) was defined considering the net absorber area of the field:

$$\begin{aligned}\mathrm{HF_{sf}} &= \eta_{\mathrm{ins}} \cdot G_t \cdot A_{sf} \\ &= A_{sf}\left[G_t \cdot K_\theta \cdot \eta_{\mathrm{op}} \cdot - a_1\left(T_{\mathrm{cif}} - T_a\right) - a_2\left(T_{\mathrm{cif}} - T_a\right)^2\right]\end{aligned} \tag{6}$$

The collector internal fluid mean temperature is related to the inlet and outlet temperatures of the primary fluid:

$$T_c = \frac{T_i + T_o}{2} \tag{7}$$

To evaluate the performance of a series connection in the solar field, the influence of primary fluid distribution should be considered. In series arrangement, the increment of the effluent temperature from the solar field is very significant, but the fluid flow rate decreases substantially. The flow rate of the primary fluid can be calculated by Eq. (8), applicable for the series and parallel collectors' arrangements:

$$\dot{m}_{\mathrm{pri}} = \frac{\dot{m}_c \cdot A_{sf}}{N_{\mathrm{series}}} \tag{8}$$

In series arrangement (considering identical all the collector modules in the series), the linear and square coefficients of thermal losses should be adapted. For this propose, a K intermediate parameter was previously determined [23]:

$$K = \frac{A_c \cdot a_1}{\dot{m}_{\mathrm{pri}} \cdot c_p} \tag{9}$$

The characteristic factors for N collectors in series were obtained by Eqs. (10) and (11), [24]: