

Different Integration Alternatives of Thermosolar Energy and Heat Pump Technology in a Fish Canning Process

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The main objective of this work was the evaluation of potential use of a thermosolar-heat pump set in an industrial process, through a systematic methodology which combined the pinch analysis and the exergetic analysis for heat integration and optimization. The methodology was validated in the context of a tuna fish canning industrial plant. The procedure adopted included four steps: analysis of the base case, energy optimization of the base case, integration of solar thermal subsystem in combination with an adequate heat pump and finally the optimization of the resulting system. Using this methodology, the optimum heat integration of the overall system was determined through pinch and exergy analysis, and taking in main environmental and economical parameters.

1. Introduction

Thermosolar technology is a promising option which could supply energy to different processes. There is a significant amount of industrial processes which operate in temperature intervals where thermosolar technology would be able to supply an important amount of the energy at a reasonable economical cost. However, solar thermal technology presents some difficulties for its incorporation in a productive scale: low density of the energy, intermittence of the source and heat integration handicaps (Philibert, 2006).

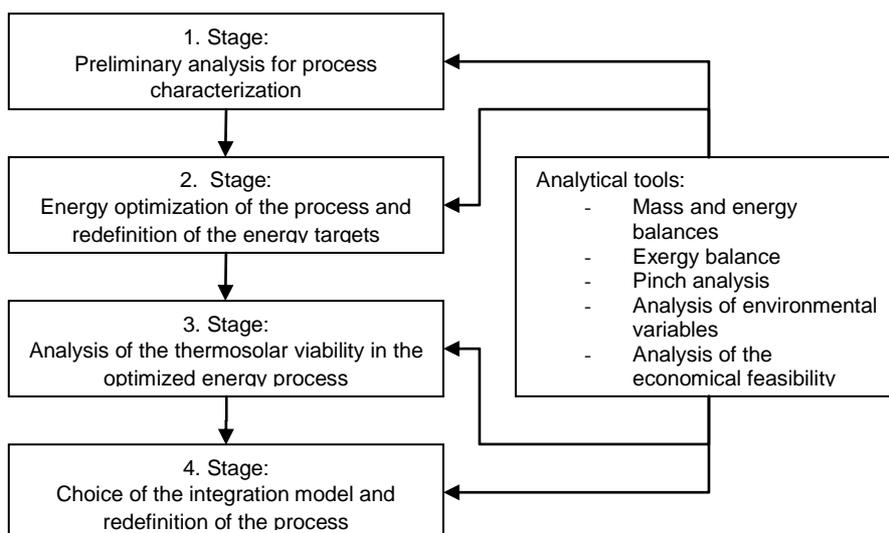


Figure 1: Algorithm of the applied methodology for the analysis of renewable-heat pump integration in the fish canning process.

The principal objective of this study was to evaluate the potentiality of a solar thermal-heat pump-boiler set in an industrial process, through a systematic methodology (Figure 1) developed in four stages, where pinch and exergy analysis are combined for heat integration and optimization, and considering environmental and economical parameters (Quijera, 2012). The study started from establishing mass and energy balances of the process (Stage 1), and continued investigating and proposing viable ways of energy reduction (Stage 2). Reaching this energy optimized configuration of the process, the potential contribution of a solar thermal subsystem in combination with an adequate heat pump to reduce the load of the natural gas boiler was evaluated (Stage 3). At last, the optimum heat integration of the overall system was determined (Stage 4). The methodology was validated in the context of a tuna fish canning industrial plant, located in the seaside of the Basque Country of Spain, a region under non-favourable climatic circumstances for solar thermal implementation in large industrial activities, as diffuse irradiance is mainly relevant than direct irradiance (Basque Government Energy Entity, 2002).

2. Procedure and tools

The analysed process (Quijera, García and Labidi, 2012) is developed by batches; in this context, the Time Average Model, in terms of heat load of the streams, was adopted for the pinch analysis, taken in account time limitations of the streams for their matching-up through the specific Time Event Chart. The basic tool for comparison between evaluated scenarios of heat integration was the Grand Composite Curve GCC. Pinch Analysis was applied to the global processes (Kemp, 2007), where two coincident subprocesses were considered: the fish processing line and the energy supplying system. Heat transfer associated mainly with raw material, product, steam and water flows, and there were not significant chemical reactions to consider and no-change in concentration of taking part substances. Exergy was essentially physical type one, and they must be taken in account its thermal form and the mechanical one linked to the compressor work when a heat pump was adopted for process heat optimization. For exergy analysis, energy η and exergy ψ efficiencies were essential tools for comparing analysed scenarios, as some thermodynamic important parameters like irreversibility of the system I , entropy generation S_{gen} (Dincer and Rosen, 2007) and exergy improvement potential IP (Van Gool, 1997). With the intention of determining the optimum integration opportunity of a heat pump and solar thermal in the process, some design possibilities were analyzed:

- The current process, based only on a natural gas boiler.
- The integration of a heat pump with a natural gas boiler and an economizer, making an allowance for three technologies, that is, compression closed cycle with electric engine, compression closed cycle with explosion engine, and a heat transformer. The selection of the more appropriate technology and the degree of water evaporation in the heat pump was determined considering technical, environmental and economic variables.
- The incorporation to the process of thermosolar energy, linked initially in series arrangement with the mentioned elements of the energy providing system and, next, an arrangement in parallel including two energy chains for the productive line of the canning process; in the both context, different solar field surfaces and subsequent solar fractions were evaluated.

The considered solar thermal system incorporated in the two mentioned thermosolar scenarios, fundamentally, a solar field with evacuated tubes-heat pipe technology in parallel arrangement, a plate heat exchanger and a solar energy storage tank with three stratification nodes (Duffie and Beckman, 2006).

3. Analyzed scenarios for the canning process.

3.1 The current fish canning process. Scenario 1

In the current process, the natural gas boiler supplies steam at 200 °C as hot primary fluid, which is sent to three heat exchangers, and transferred to water to obtain different hot secondary fluids for precooking as steam at 102 °C, can washing as water at 50 °C, and can sterilization as steam at 118 °C. The present boiler provides to the productive line 5,623.0 kWh/d of heat as steam at 200 °C, which supposes a consumption of natural gas of 615.8 Nm³/d. The η and ψ of the current system in Scenario 1 were 0.83 and 0.26 while I , S_{gen} , and IP arrived to 4,536.9 kWh/d, 15.2 kWh/d·K and 3,340.2 kWh/d, all of them considered normal values for natural gas boiler without economizer.

The pinch analysis was performed considering large load heat streams and eliminating contaminated streams. Allowing for the transmission of accessible waste heats (Bending, et al., 2012) to the process, pinch analysis projected a net tendency thermal objective of 3,875.0 kWh/d, all of this heat performed through the current boiler. The GCC of Scenario 1 is presented in Figure 2 for a ΔT_{min} of 10 °C. The only pinch point was set at 105.0 °C. It is remarkable the large quantity of energy as latent heat which was

demanded for water vaporization in the boiler, which was represented in the mentioned GCC by the horizontal superior line, and the cession of this energy through the three heat exchangers when condensing. Thus, it was a good practice to allocate waste heats of the process for this thermal region where the greatest energy utilization was detected.

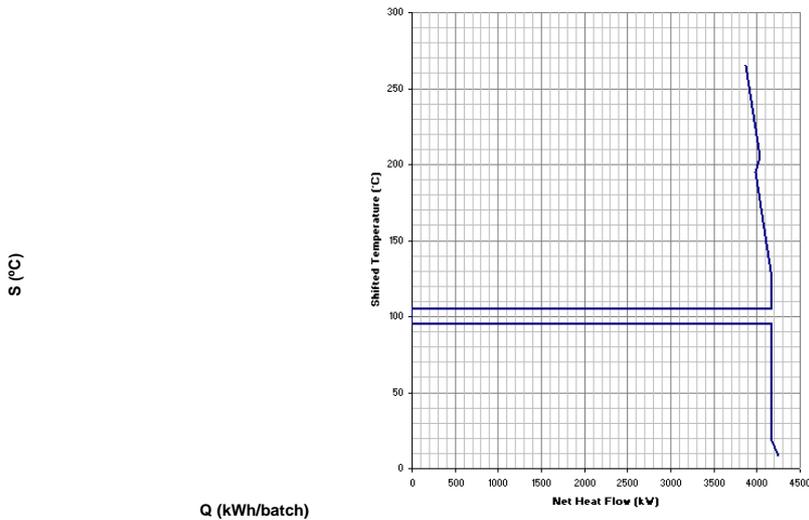


Figure 2: GCC of Scenario 1, based on the streams of the current process before any modification (S, shifted temperature; Q, heat load)

3.2 Integration of thermosolar energy in series with the conventional energy system. Scenario 2

For the solar thermal energy incorporation, it was previously evaluated the potentiality of a solar collector absorber surface of 1,000.0 m² to provide energy directly for the process. As diffuse irradiance on the zone is more important than beam irradiance, it was considered evacuated tube-heat pipe technology for solar incorporation. Figure 3 shows the degree of temporal concurrence between the total energy flow demand of the fish canning productive line and the solar heat (as global irradiance on the mentioned arbitrary surface).

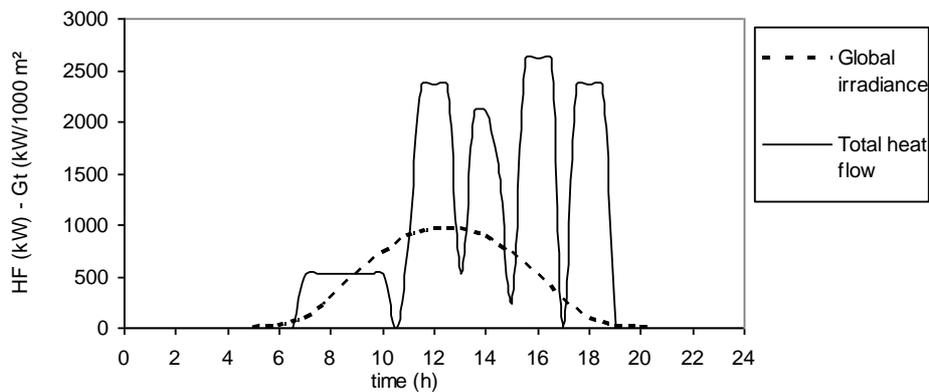


Figure 3: Concurrency between the total energy flow demand of the process and the solar global irradiance

In this Scenario 2, all the elements of the energy supplying process of the plant conformed one heat chain, connected all of them in series arrangement. In short, incoming tap water was preheated by exhausted gasses from the boiler in the economizer until 57.4 °C. Then, this water was heated through thermosolar energy and stored in the solar accumulator at 95 °C. After that, water was sent to the condenser of the heat pump, when it was vaporized until some degree β at 100 °C. At last, the vapour-liquid water mixture was completely vaporized and overheated in the boiler at 200 °C. From the boiler, steam was sent to the three heat exchangers of the fish processing line for precooking, sterilization and can washing. The more suitable heat pump technology resulted a heat compression closed cycle with explosion engine,

and exhausted gas and heat recovery unit GHP. The cold stream for the evaporator of the heat pump was the water condensed inside the current heat exchangers of the production line at 90 °C, after measured temperature losing (limiting factor for heat recovering at the GHP). Figure 4 shows a diagram of this scenario. It was determined a COP_{pt} for the pump of 3.86 and a COP_g of 1.35, with a β of 3.09 %. The maximum solar fraction f that could be achieved for this system without accumulating extremely steam at the upper level of the solar accumulator was 0.12, with an absorber solar field A_{sf} of 358.6 m².

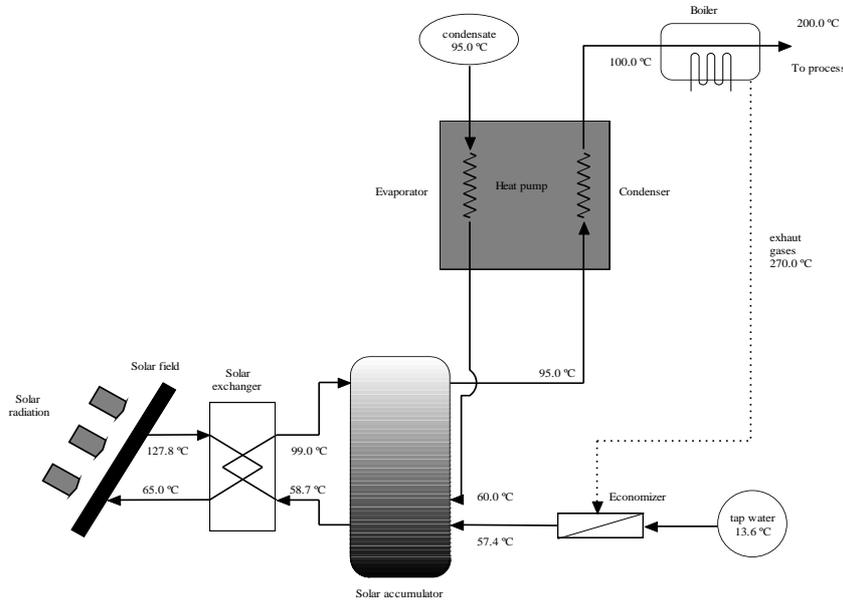


Figure 4: Energy supplying system in series arrangement and one heat chain, integrating conventional and renewable energy

The energy system of the plant presented an overall η of 0.87 and an overall ψ of 0.27, with $I = 4,411.5$ kWh/day, $S_{gen} = 14.8$ kWh/day·K and $IP = 3,223.0$ kWh/d. For the Scenario 2, the total consumption of natural gas (boiler and heat pump) reached to 468.5 Nm³/d, which supposed a reduction of the 23.92 % in fuel dependence respect to Scenario 1. Figure 5.a. presents the GCC for Scenario 2 for ΔT_{min} of 10 °C and pinch at 103.2 °C.

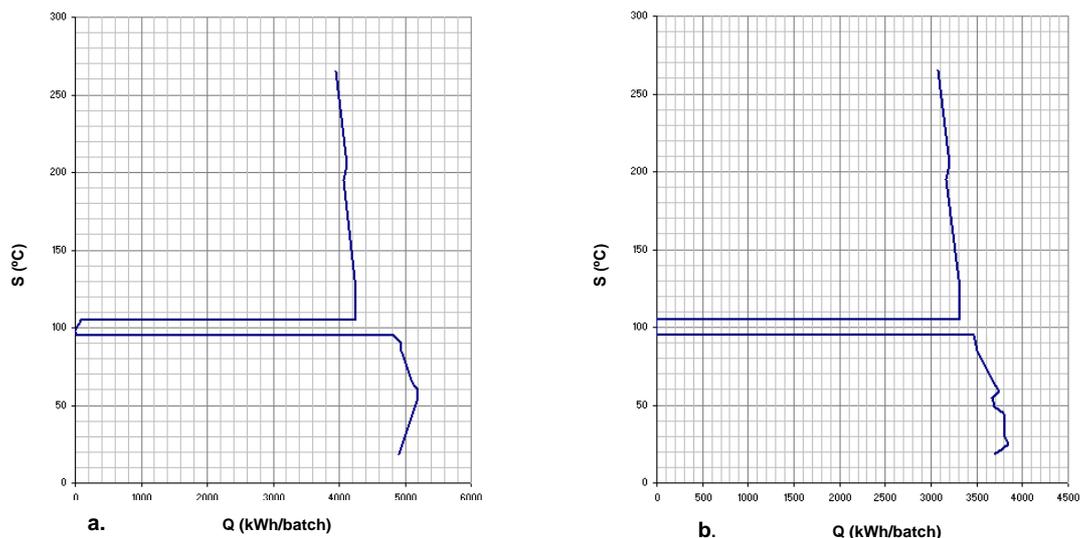


Figure 5: GCC of Scenarios 2 and 3, which incorporate solar energy and the heat pump, a. Scenario 2, one heat chain, and b. Scenario 3, two heat chains

3.3 Integration of thermosolar energy in parallel with the conventional energy system. Scenario 3

Figure 6 shows the diagram of the energy supplying system for Scenario 3.

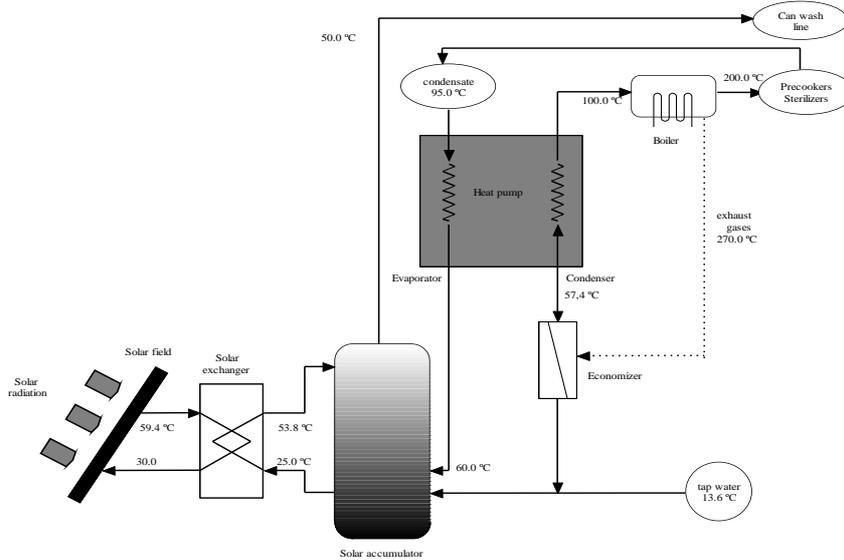


Figure 6: Energy supplying process in parallel arrangement with two heat chains integrating conventional and renewable energy systems

In Scenario 3, the elements of the energy supplying process of the plant were linked in two different heat chains: by one hand, the conventional energy subsystem was formed by the boiler with its economizer and the GHP, and it must send heat as steam at 200 °C to the heat exchangers for pre-cooking and sterilization operations; by the other hand, thermosolar subsystem conformed another heat supplying chain for the can washing line of the plant, sending water at 50 °C. The same GHP technology was adopted for this new scenario, arriving to the same vaporization level and COP than in Scenario 2. In Scenario 3, the heat sent to the production line by steam at 200 °C reached to 5,132.7 kWh/day, f arrived to 0.15 with an A_{sf} of 305.3 m². Exergy indicators were calculated in the next values: $\eta = 0.90$, $\psi = 0.24$, $I = 4,180.9$ kWh/d, $S_{gen} = 14.0$ kWh/d·K and $IP = 3,178.1$ kWh/d. In Scenario 3, it was possible to reduce the total natural gas consumption (boiler and heat pump) until 417.4 Nm³/d, which supposed a reduction of 32.20 % in fuel dependence respect to Scenario 1. Figure 5.b. shows the GCC of Scenario 3 with Pinch Point at 105.5 °C.

4. Conclusions

Table 1 shows some fundamental information for comparison between the three summarized scenarios. When comparing the GCC of Scenario 1 (Figure 2) and 2 (Figure 5), it can be noticed that the contribution of the thermosolar energy and the incorporation of a waste heat through the GHP allowed reducing the heat demand to the boiler at thermal levels upon the pinch point, reflected by a distance difference between the both horizontal lines. The Pinch Analysis determined a tendency heat objective of 3,953.0 kWh/d, while in this case utilized stream data set was more realistic after implementation of solar energy, the GHP, the economizer, and the adjustment of the thermodynamic parameters of the streams to actual limitations of the process. Exergy indicators resulted more convenient in Scenario 2 than in Scenario 1, as both efficiencies increased while entropy generation, irreversibility and exergy improvement potential resulted reduced. When comparing Scenario 3 (Figure 5) to 1 and 2, it can be observe a reduction of the heat load demanded to the boiler, specially notorious at the level of latent heat for water vaporization, because an important amount of water is not vaporized but heated by solar energy to 50 °C for the can washing line. Scenario 3 had a very different stream data set from the predecessors, and its pinch tendency objective was 3,078.5 kWh/d. By the way of Scenario 3, it was possible to incorporate more solar energy replacing more natural gas through a shorter solar field surface, reaching better values of energy efficiency and globally better utilizing the quality of incoming energy as demonstrated the reduction of entropy generation, irreversibility and exergy improvement potential. But it must be refer that the exergy efficiency of Scenario 3 was a little shorter than it's homonymous of Scenario 3. It has to be noticed that thermosolar incorporation could cause the drop of energy and exergy efficiencies, according to the amount of solar fraction. This is because the low intrinsic energy and exergy efficiencies of the current solar

thermal collectors: they receive from the Sun important flows of energy of high quality, but they are not able to take advantage but in a short amount. As a bigger solar fraction was implemented, more dependence on the low efficiencies of solar collector was obtained. By the other hand, when solar fraction decreased, it resulted in a more dependence on the higher energy and exergy efficiencies of the natural gas boiler and the heat pump. In return, more solar fraction allowed decreasing natural gas consumption incorporating more renewable energy to the process and, at last, obtaining a cleaner industrial process.

Table 1: Design main parameter comparative between Scenarios 1, 2 and 3 (in Scenario 1, the present process, there is no solar energy integration and no heat pump incorporation)

Design parameter	Scenario 1 (current process)	Scenario 2 (series)	Scenario 3 (parallel)
Energy contributed from 1m ² of solar collector (W)		131.2	207.2
Solar fraction	0.0	0.12	0.15
Absorber area of the solar field (m ²)		358.6	305.3
Natural gas consumption in the boiler (Nm ³ /d)	615.8	446.9	400.4
Total natural gas consumption, boiler and heat pump (kg/d)	615.8	468.5	417.4
Net solar contribution to the solar accumulator (kWh/d)	0.0	546.6	665.6

As a general conclusion, it can be said that a heat integration in base on the arrangement in parallel of Scenario 3 resulted the more appropriate for residual heat reincorporation to the process by direct and indirect transferences, obtaining the lowest natural gas consumption and incorporating the higher renewable with the lower solar field surface. In this case, there are two different heat integration levels in the process: the heat promoted from the conventional energy subsystem, which is integrated at 200 °C; and the solar heat, integrated at 50 °C.

References

- UK Philibert C., 2006, International Energy Agency, Barriers technology diffusion: the case of solar thermal technologies (Consulted on October, 8th, 2010). <www.iea.org/work/2006/cop12/solar_thermal.pdf>, Accessed 02/07/2013.
- Quijera J.A. Development of a methodology for the integration of renewable energy in chemical processes. PhD Thesis, University of the Basque Country. San Sebastian, Spain; 2012.
- Quijera J.A., García A., Labidi J., 2012, Integration of solar thermal energy and heat pump in a fish canning process combining pinch and exergy analysis, Chemical Engineering Transactions, 29, 1207-1212.,
- Basque Government Energy Entity (EVE- Ente Vasco de la Energía), 2002, Atlas de radiación solar del País Vasco. (Consulted on October, 8th, 2010). <www.eve.es/web/Documentacion/publicaciones/DetallePublicacion.aspx>, Accessed 02/07/2013
- Kemp I.C., 2007, Pinch analysis and process integration. A user guide on process integration for the efficient use of energy, Elsevier, London, UK.
- Dincer I., Rosen M.A., 2007, Exergy. Energy, environment and sustainable development, Elsevier, London, UK.
- Van Gool W., 1997, Energy policy: fairly tales and factualities, Innovation and Technology-Strategies and Policies, 95-105.
- Bending M., Maréchal F., Favrat D., 2012, Defining the potential of usable waste heat in industrial processes with the help of pinch and exergy analysis, Chemical Engineering Transactions, 29, 103-108.
- Duffie J.A., Beckman W.A., 2006, Solar engineering of thermal processes, Wiley, New Jersey, USA.