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Usage of Solar Energy in an Industrial Process

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The current industrial sector is facing a complicated energetic scenario deeply influenced by the petroleum prices and availability. Any improvement of this situation draws on the combination of energy efficiency improvement and the use of renewable-type energies. The industrial use of renewable energies presents some drawbacks that have limited their establishment for the moment. Some of the renewable energy resources work intermittently (like the sun or wind) and the energy they provide is, often, of low intensity. Many industrial processes work in temperature intervals where solar thermal technology could supply a considerable amount of the total energy input at an acceptable price. Based on mathematical modeling, this work evaluates the viability of integrating a solar thermal system to the conventional energy structure of a dairy plant. Pinch methodology was used to develop the integration of the solar subsystem in the energy installation of the plant. As a result, it could be stated that the solar thermal energy potential for the studied industrial process was considerable and should be taken into account for future energy.

1. Introduction

The current energy world scenario instability related to the fluctuation of petroleum prices and availability as well as the environmental concerns related to the use of fossil fuels for energy production is impelling the introduction of renewable-type energies in order to improve its environmental sustainability (Energy Information Administration. U.S. Department of Energy, 2009). The industrial use of renewable energies is not still well established as they present several problems, like intermittency and low intensity, which generate insecurity in the sector (Philibert, 2006). Although the solar thermal technology has been successfully introduced in domestic applications, further work is required to develop and implement this technology at industrial scale. Many industrial processes work in temperature intervals where solar thermal technology would be able to supply an important amount of the total energy input at an acceptable price. Advanced flat-plate collectors and evacuated tube collectors are often enough to produce water, steam and cold, at thermal levels, more or less, between 60 to 90 ºC, or 90 to 160 ºC, respectively. The last mentioned technology can generate energy from sun in climatic conditions where the diffuse component of the total radiation is the main contribution (Weiss and Rommel, 2008). The present work analyzes the case of supplying solar thermal energy to an industrial dairy process located in the Basque

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Country, a region where diffuse radiation is the main component of the sun radiation (Basque Government Energy Entity (Ente Vasco de la Energía), 2002).

2. The process

Figure 1 shows a diagram of the current dairy plant (temperatures are given as annual average values). Table 1 presents the sequence of mass flows.

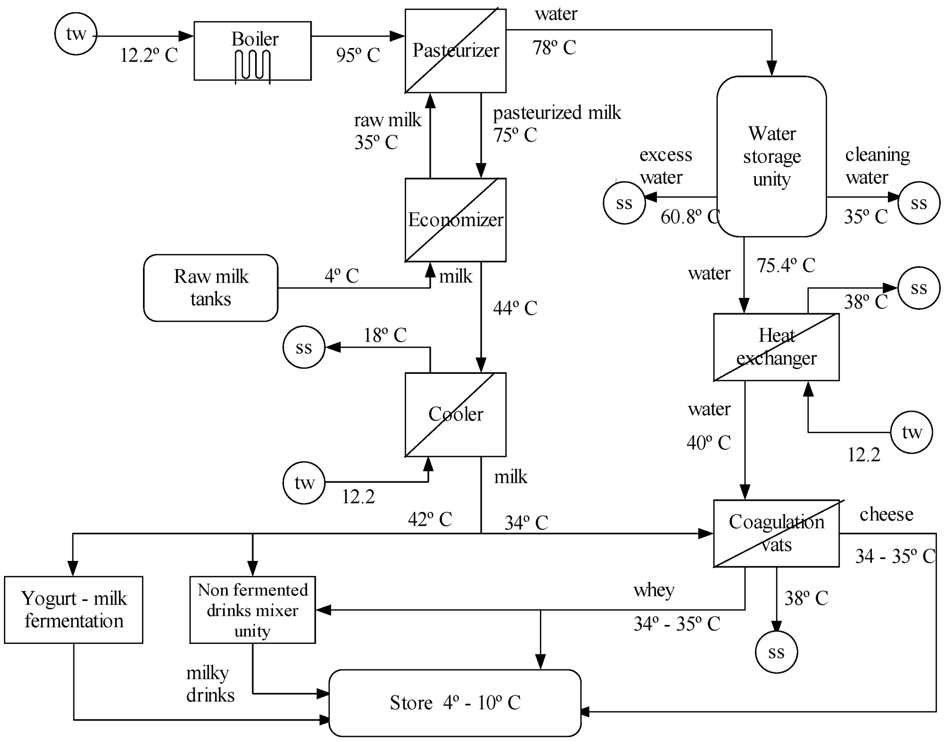

Figure 1: Scheme of the dairy facility (tw: tap water; ss: sewage system)

Pasteurization is the most energy intensive operation of the process. Tap water is heated in a gas boiler up to 95 ºC. Tap water stored in a 50 m^3 capacity tank is used as cooling utility. Water from the pasteurization unit is send to this tank at 78ºC, stored and later distributed to heat exchangers when required. At the end of the day, the tank is emptied and cleaned, as well as the rest of the plant. A big amount of exceeding water is used in the plant cleaning and, also, the stored hot water that has not been used is discharged, losing its heat content. Table 2 presents the plant heat consumption. The current operation requires 1,584 MWh/y and the use of the hot water from pasteurization would reduce the energy consumption in 789 kWh/batch.

Table 1: Data base of mass flows in the dairy process.

Operation	Δt (h)	Flow type	m (kg/batch)
Milk pre-treatment and pasteurization	5.0	Raw milk	20,600
Yogurt elaboration	3.0	Milk to fermentation unity	3,075
Cheese production	4.5	Milk to cheese elaboration unity	16,398
Non fermented milky drinks	1.0	Produced milky drinks	1,751
Cleaning of installation	2.0	Water for cleaning operations	16,000
Extern utilities of heating and cooling	5.0	Water at boiler Water for cooling operations	45,701 37,540
Excess of water	9.5	Water from pasteurization	22,158

Table 2: Energy utilization at the current dairy activity.

Operation	Δt (h)	Hot water demand (kg/batch)	T_1 (ºC)	T_2 (ºC)	Heat flow (kW)	Heat load to process (kWh/batch)
Pasteurization	5.0	45,701	95.0	78.0	-181	-904
Milk coagulation	4.5	7,543	40.0	38.0	-7.8	-35.1
Cleaning	2.0	16,000	65.0	25.0	-377	-754
Boiler	5.0	45,701	12.2	95.0	-880	-4,401

3. Results

3.1 Energy analysis of the process and opportunities for optimization

Pinch analysis was used to evaluate the opportunities for energy optimization. Time phase lags between operations were assumed to be mitigated by the water storage tank. Pinch temperature was found to be 60.5 ºC for ΔT_{min} = 10 ºC. Minimum energy requirements for heating and cooling were 268 kW and 260 kW, respectively. These results were obtained considering a maximum heat transfer between streams (maximum heat recovery, MHR), assuming that all the streams were coincident in time and using the cleaning and excess hot water streams. In fact, the heat from cleaning stream is very difficult to recover so it would be more realistic to exclude this stream from the analysis. Figure 2 shows the shifted grand composite curve - SGCC (Linnhoff et al., 1982) for the process.

The presence of a big pocket of energy (hot water) stands out. The area of this heat pocket quantifies the daily energy loss and the opportunity of assigning this heat to other uses in the plant, under a temperature of 57.4 ºC. In addition to the pinch analysis results, other extern variables which could affect the process energy performance should be considered, like the temperature variability through the year. Required heat from the boiler fluctuates from 914 kW in January, to 840 kW in July (results of the energy balance; annual average of 880 kW, and 4,401 kWh/batch).

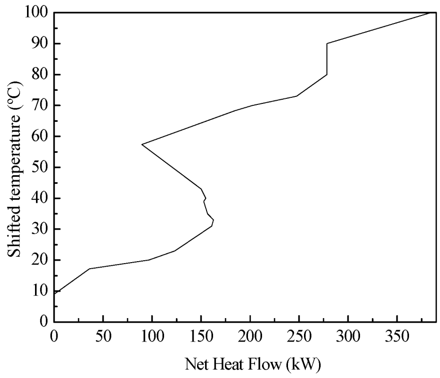

Figure2: Shifted Grand Composite Curve

3.2 Optimization of the process for solar thermal energy implementation

Two options for the improvement of the current process energy efficiency were studied: the first one, considering the possibility of supplying energy to the fermentation unit by the hot water accumulated in the tank and the second option consisted of the reuse of the daily excess of water in the process. The non reutilized water stream volume was 22,158 L/d at 62.4ºC. The fermentation unit consisted of an electric closed incubator with an average electricity consumption of 4 kW (12 kWh/batch). A flow of 115 kg/h (344 kg/batch) of water form the tank would be needed at 76.4 ºC, which means 2.2 kW (6.6 kWh/batch). When water is needed for fermentation, the water reserve was enough to supply the demanded quantity to this unit as well as to the rest of the process operations. In the second option, considering the complete reuse of the pasteurization hot water in the process, at the end of the day, 21,814 L of hot water would be stored in the tank (Walmsley et al., 2009) that, at the beginning of the following day, would be at around 40.6ºC. In order to study the possibility of using this water from day to day, two options were investigated:

- Direct feeding: all the stored water is fed into the boiler. This water can be used from 08:00 h until 10:23 h (from 40.6ºC to 37ºC). After this moment, fresh water is fed to the boiler at 12.2ºC. The energy requirement of the boiler would be 740 kW (3,699 kWh/batch). This configuration would require high operation flexibility.
- Mixed feeding: during the boiler operation time (5 h), it would be possible to mix hot water from the tank with fresh water, giving a mixture at 23.9ºC. For this option, the heat flow required would be 756 kW (3,780 kWh/batch). The energy consumption would be 1.85% lower in the direct feeding option. Nevertheless, the mixed feed would be technically more suitable. On the basis of this choice, the mass and energy balances were established considering the reutilization of all the water of the tank in the same day (this includes the supply to the fermentation unit), and following day to feed the boiler.

The energy balance showed that the annual average heat flow was 756 kW (3,781 kWh/batch), improving the energy efficiency of the plant in a 14% and providing a daily saving of 622 kWh/batch, with high stability of the working process and low investment.

3.3 Viability of a solar thermal system

Once the energy needs of the original and the optimized processes were determined, the viability of incorporating the solar thermal energy in the process was considered. According to the Basque Entity of Energy (EVE), the solar radiation received in the zone is 1,500-1,700 h/y. In terms of a surface of 1 m^2, oriented to the south and tilted 43°, total irradiation varied from the annual minimum of 2,248 $kWh/m^2 \cdot d$, to a maximum of 5,353 $kWh/m^2 \cdot d$. The total radiation accumulation was 1,494 $MWh/m^2 \cdot y$. Considering the heat flow demand in each operation unit throughout a day and examining the total solar radiation (in a daily annual average), received on a horizontal arbitrary surface of 1,000 m^2, it was possible to correlate, at the same time, both solar energy demand and solar contribution. From the study of the overlapping degree as a function of the total sun irradiance, it was observed that the water deposit in the optimized system, which would help to minimize phase lags, would need to be adapted to the solar thermal energy. Furthermore, the study of the overlap between the current energy supplied by the boiler and the total solar radiation received on the exposed area showed that the received radiation was not enough to fit the energy needs at any time. However, it was found to be high enough to ensure the demand of more than half of the days of the year. A high degree of convergence was found between isolation time and the process demand of hot water, as well as a notorious opportunity to provide much of the energy needed to sustain the process through a solar field.

3.4 Outline of the suitable solar system

A key point of the solar radiation in this area is the importance of the diffuse irradiation in comparison with the beam irradiation. Evacuated tube heat pipe collectors were selected as the most appropriate solar technology. The combination of the current energy installation and the solar thermal unit would result in a system with the following components and characteristics:

- A two-tank forced-circulation system with a propylene glycol-water mixture as primary heat transfer fluid (c_p = 3.889 kJ/kg·K) and tap water as the secondary fluid.
- A solar field of high performance vacuum tube heat pipe collectors of low loss ratio.
- A heat exchanger, with an efficiency of 0.95, which would transfer the incoming energy from the primary fluid to the secondary one.
- The auxiliary heat equipment would be the current natural gas boiler.
- Two tanks would be working in the installation; the current deposit would be used for pasteurization, and a second one would supply water to other operations.

This configuration would allow a decrease in the boiler annual average demand down to 2,732 kWh/d, reducing the average fossil fuel consumption in a 27.7%. The annual energy consumption could decrease to 984 MWh/y. Table 3 presents the basic parameters adopted for the thermal feasibility study.

Table 3: Mass flows and temperatures of the dairy process energy system.

Equipment	Parameter	Value	Unit
Gas boiler	Water flow	45,701	kg/d
	Outlet water temperature	95	ºC
	Operation time	5	h
Pasteurizer	Inlet water temperature	95	ºC
	Outlet water temperature	78	ºC
Solar accumulator	Accumulation volume	45,701	kg
	Flow of water from pasteurizer	23,543	kg/d
	Flow of water for the boiler	9,141	kg/h
	Flow of tap water	22,158	kg/d
	Outlet water temperature	95	ºC
Water secondary tank	Accumulation volume	22,158	kg/d
	Inlet water temperature	78	ºC

4. Conclusions

The obtained results have demonstrated the feasibility of using solar fields to provide energy to a dairy process plant located in a zone with a specific climatology. For more than half a year, 50 % of the energy needs of the dairy process could be obtained with relatively small solar fields (less than1000 m^2 of absorber area).

References

Basque Government Energy Entity (EVE- Ente Vasco de la Energía), 2002, Atlas de radiación solar del País Vasco. <www.eve.es/web/Documentacion/publicaciones/ DetallePublicacion.aspx> accessed 08.10.2010.

Energy Information Administration. U.S. Department of Energy, 2009, International energy outlook, <www.eia.doe.gov/oiaf/ieo/pdf/0484(2009).pdf> accessed 08.10.2010.

Linnhoff B., Townsend D.W., Boland D., Hewitt D.F., Thomas B.E.A., Guy A.R. and Marsland R.H., 1982, User Guide on Process Integration for the Efficient Use of Energy, Institution of Chemical Engineers, Rugby, UK

UK Philibert C., 2006, International Energy Agency, Barriers technology diffusion: the case of solar thermal technologies <www.iea.org/work/2006/cop12/solar_ thermal.pdf> accessed 08.10.2010.

Walmsley M.R.W., Atkins M.J., Riley J., 2009, Thermocline Management of Stratified Tanks for Heat Storage. Chemical Engineering Transactions, 18, 231-236.

Weiss W., Rommel M., 2008. IEA-International Energy Agency, Process heat collectors. State of the art within task 33/IV: solar heat for industrial processes. www.ciemat.es/recursos/doc/Centro_Documentacion/323497443_6820091193.pdf accessed 08.10.2010.