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Title: Thermoeconomic analysis in solar collector fields: a focus on constant flowrate and variable flowrate models

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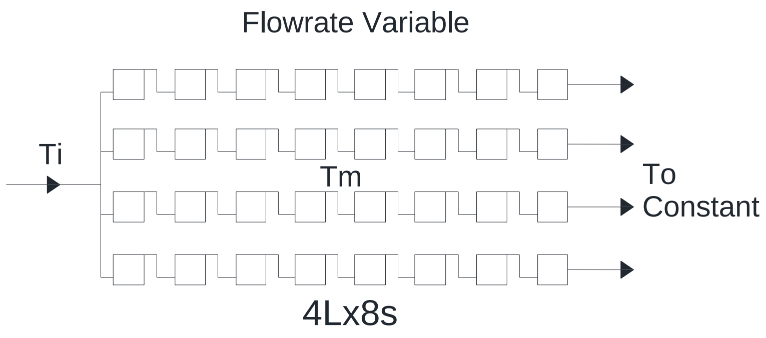
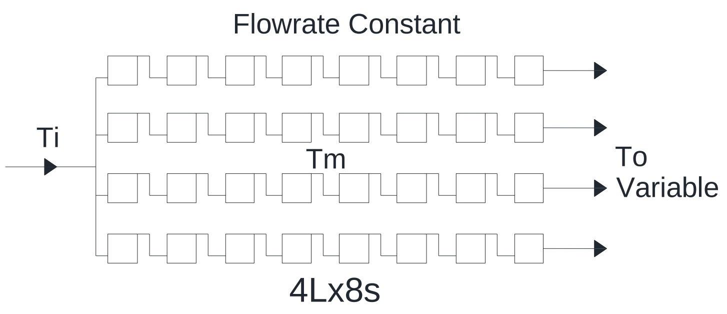
PRESENTATION CONTENT

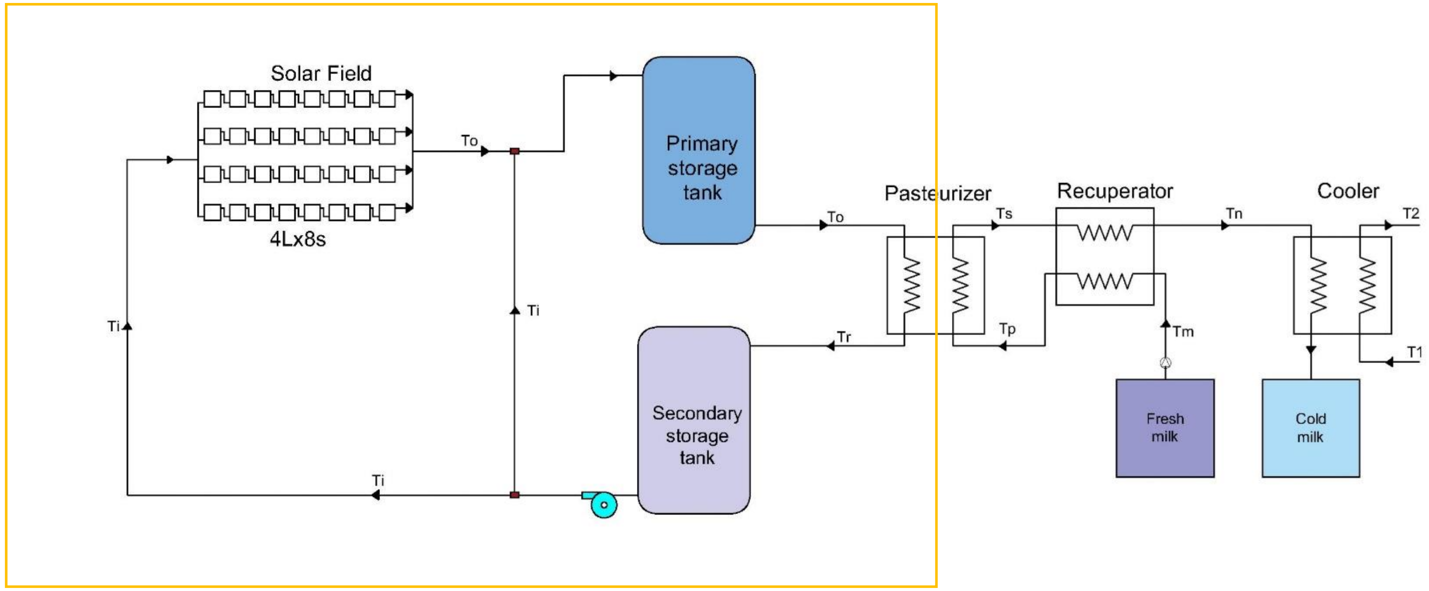
Introduction

In this study, the operation models with **constant flowrate** and **variable flowrate** of a flat-plate solar collector field are analysed.



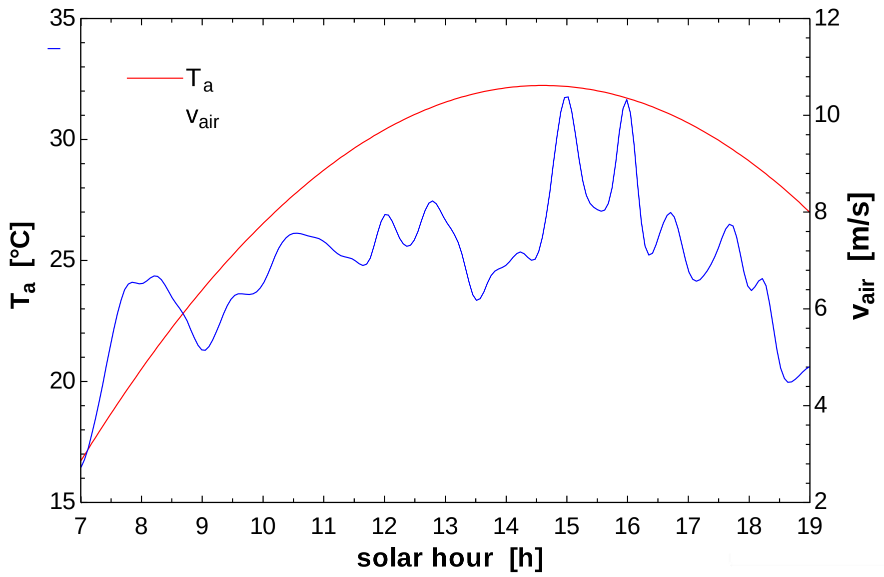


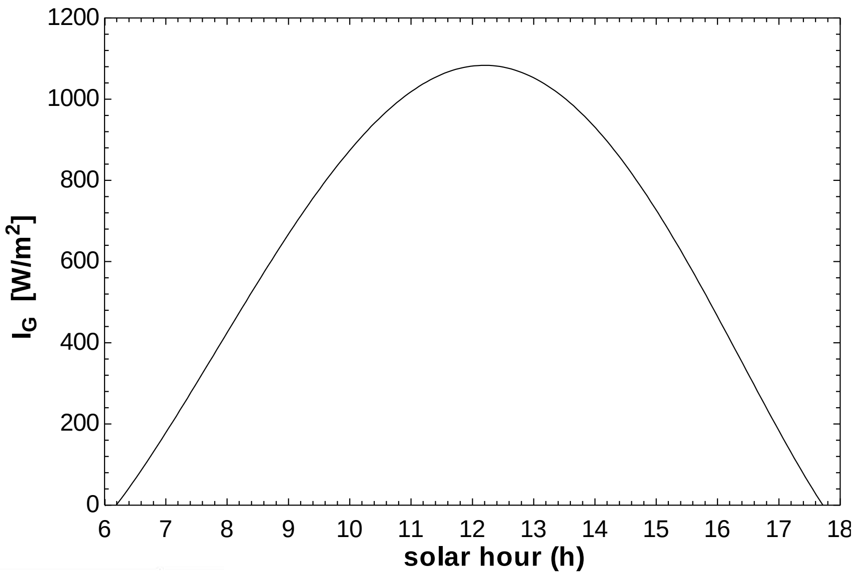
The case study involves a pasteurization plant operating at temperatures above 85°C.



Introduction

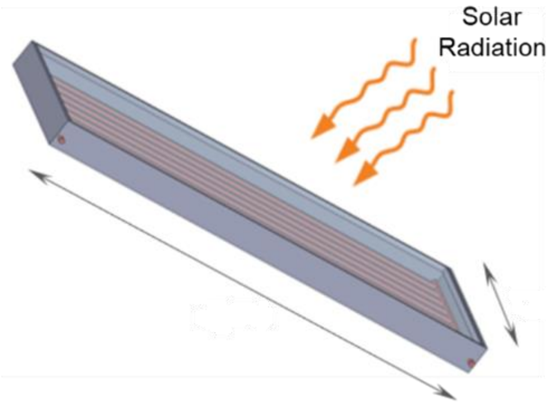
Weather conditions, for example: poor solar radiation, low ambient temperatures, and high air velocities, as well as scaling fouling, are parameters that directly affect the thermal and hydraulic performance of solar collectors. Over time, scaling fouling also causes thermal and hydraulic problems by depositing mineral salts (CaCO3) inside the tubes.





scaling

$CaCO_3$ → 90%



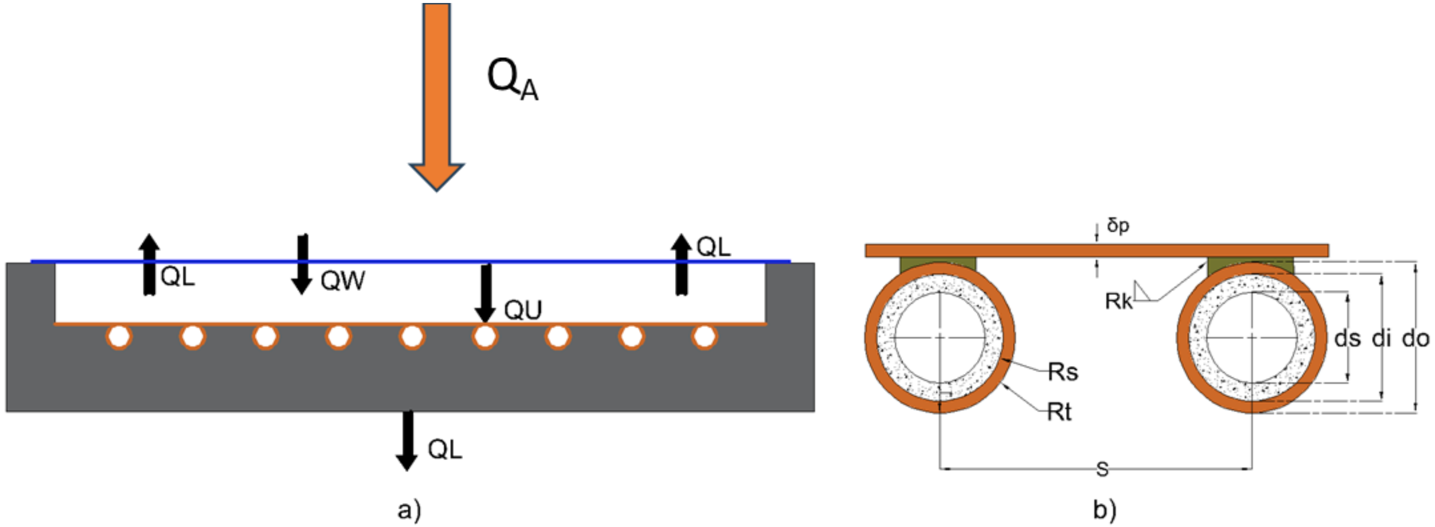
Methodology

Thermal Model

$$Q_A = I_G(\tau\alpha_c) \qquad Q_W = Q_A - Q_L \qquad Q_u = F_R Q_W$$

$$Q_u = F_R A_s[I_G(\tau\alpha_c) - U_c(T_{pm} - T_a)]$$

$$F_R = \frac{\dot{m}_f C_P}{A_s\, U_c}\left[1 - e^{\frac{-A_s\, U_c F\prime}{\dot{m}_f C_P}}\right]$$



$$F' = \frac{1/U_c}{S\left[\frac{1}{U_c[d_0 + F_A(S - d_0)]} + \frac{1}{C_b} + \frac{R_h}{\pi d_s} + \frac{R_t}{\pi d_s} + \frac{R_s}{\pi d_s}\right]}$$

$$F_A = \frac{Tanh[M\,(S - d_0)/2]}{M\,(S - d_0)/2}$$

Model to predict fouling deposition due to scaling

$$\dot{m}_d = \frac{\beta}{2}\left(\frac{\beta}{\alpha\, k_r} + (C_1 + C_2) - \sqrt{\frac{[\beta + (C_1 + C_2)\,\alpha\, k_r]^2 + 4\,\alpha^2\, {k_r}^2 (K_{sp} - [C_1][C_2])}{\alpha^2\, {k_r}^2}}\right)$$

From the mass flux deposited with time $\dot{m}_d \left(\frac{kg}{m^2 s}\right)$ the fouling resistance can be calculated:

$$\frac{dR_s}{dt} = \frac{\dot{m}_d - \dot{m}_r}{\rho_f \lambda_f}$$

Methodology

Hydraulic Model

$$\Delta P_T = \dot{V}^2 \sum_{i=1}^{n} K_i$$

The main hydraulic resistances are due to friction (K_1, kPa s^2/m^6) along the length of the pipes and due to the loss generated in the fittings (K_2 (kPa s^2/m^6) such as elbows, valves, joints, among others.

$$K_1 = \frac{8L}{\pi^2 d^5} f \qquad K_2 = \frac{8\rho}{\pi^2 d^5} k_f$$

Cost Estimation

The total annualized cost:

$$Cos\_T = Cost\_A + Cost\_b$$

Pumping power:

$$\dot{w} = \frac{\dot{V}\Delta P}{\eta_b}$$

Operating Cost:

$$Cos_b = cost_u \dot{w}\, t$$

Average electricity rate 0.3 ($USD/kWh).

Annualized cost of a solar collector network:

$$Cost\_A = C\_u \cdot Fac\_A \cdot Nt\_col$$

The commercial cost of a solar collector is estimated at $811.76 USD.

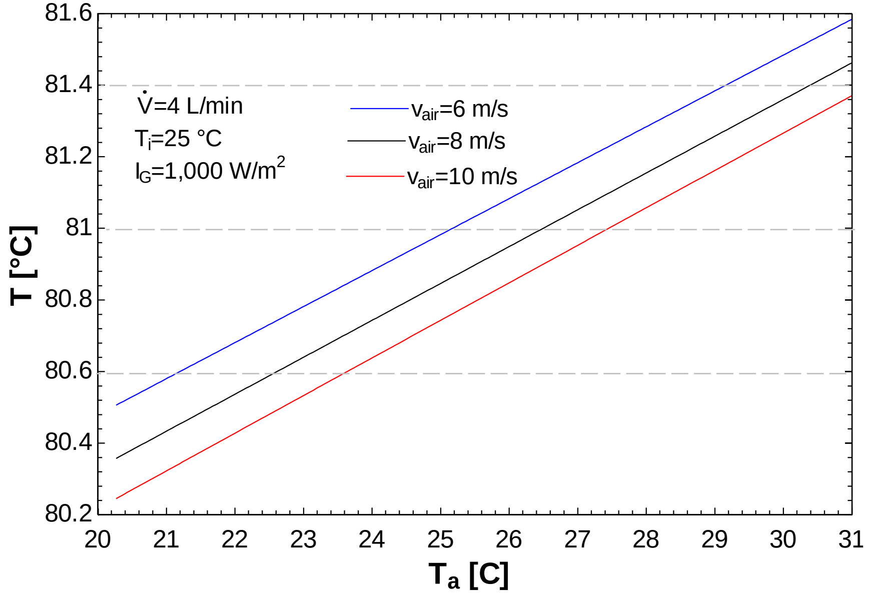
Annualization Factor:

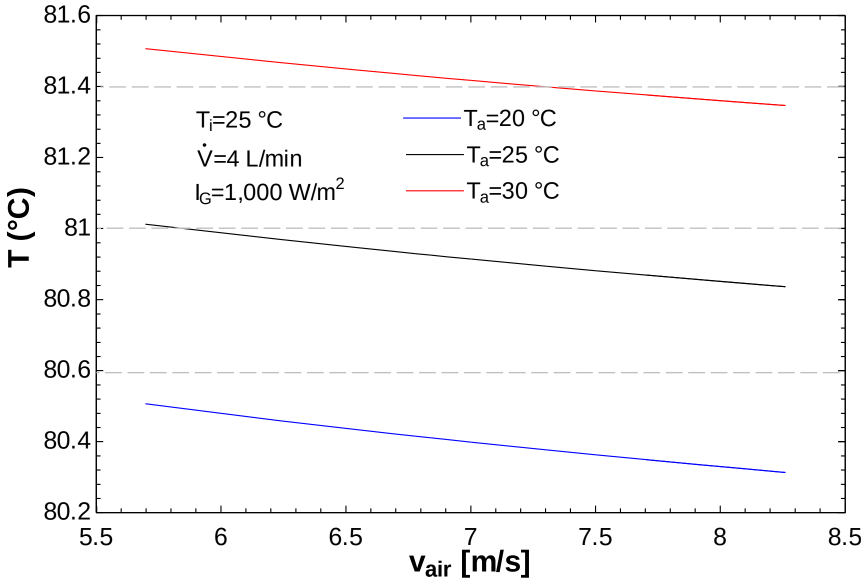
$$Fac\_A = \left[\frac{i(1+i)^n}{(1+i)^n - 1}\right]$$

A useful life of the equipment is considered to be 20 years and the annual interest of 10%.

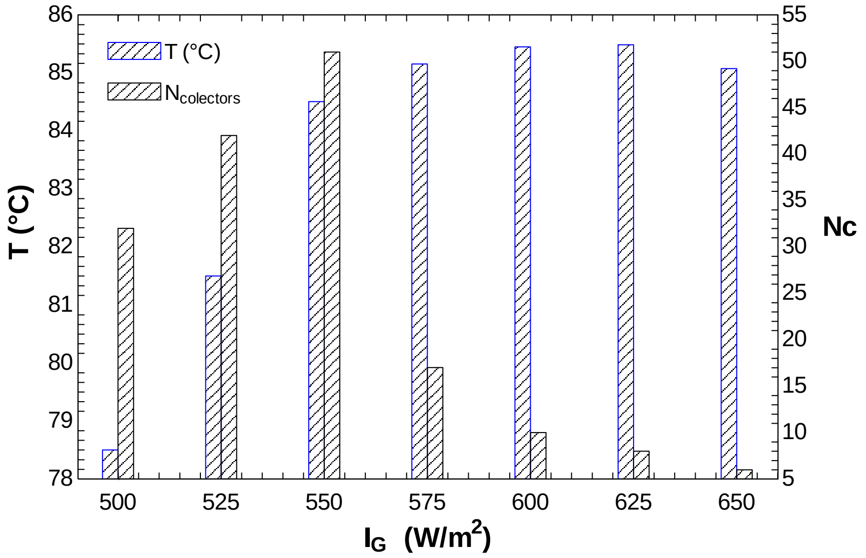
Results

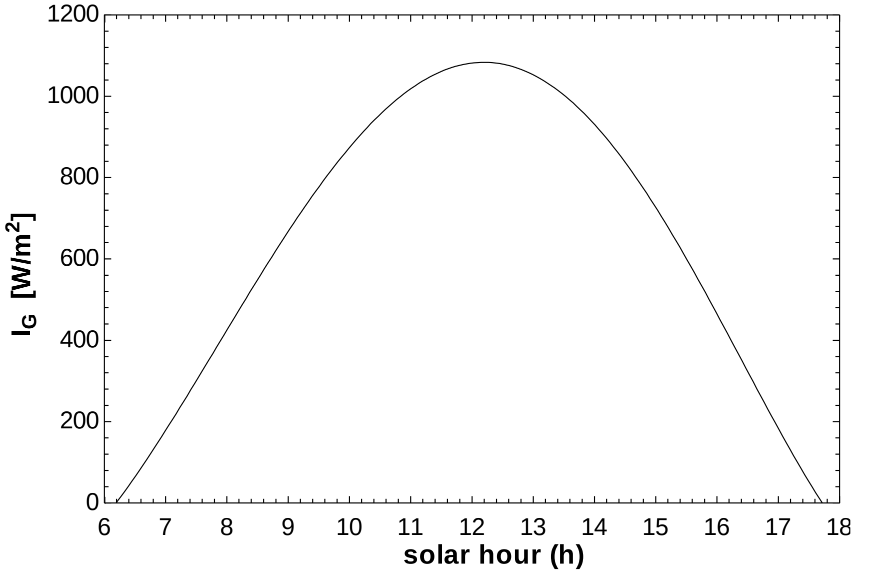
Climate Conditions





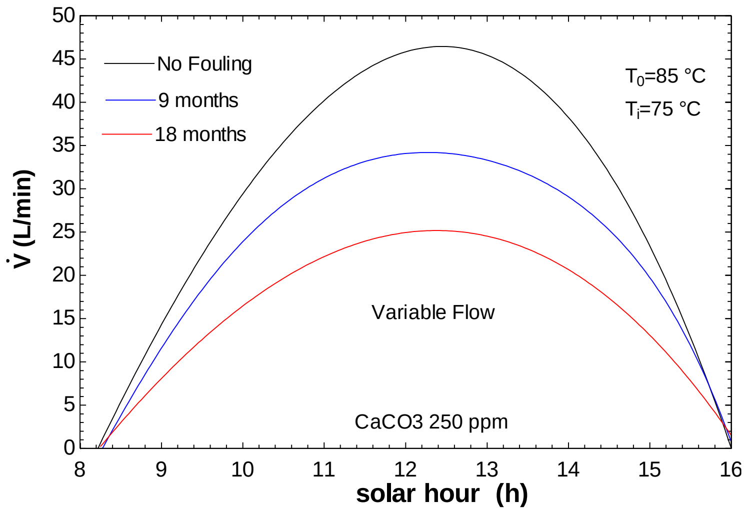
Network design

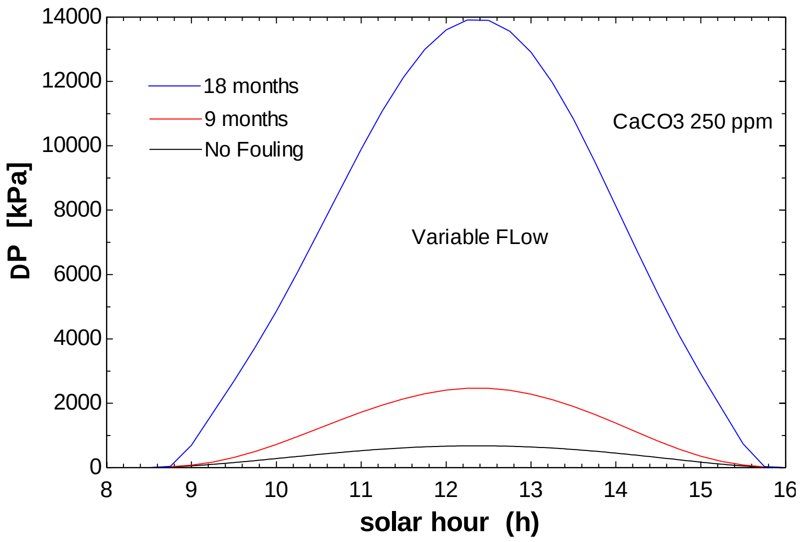


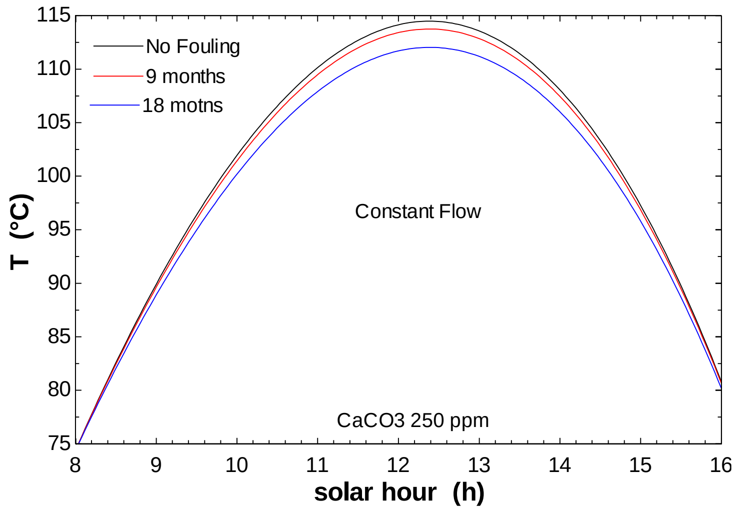


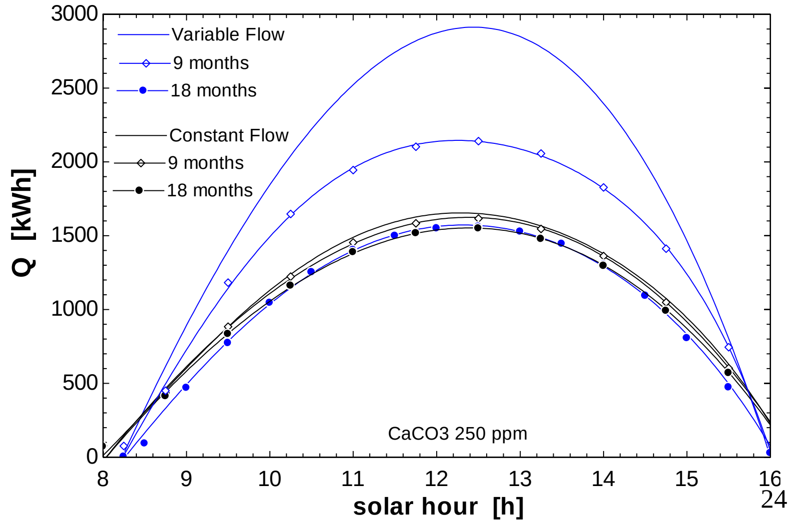
Results

Effect of scaling fouling in the operation models: constant flowrate and variable flowrate









Results

Cost Analysis

without fouling

Flowrate (l/min)	ΔP (kPa)	Cost_pump ($)	Cost Total ($)	Q (kWh)	Cost_Q ($/kWh)	T_o (°C)	T_tank (°C)
Reference case							
6.685	14.66	16.08	2,613.72	13,831.93	0.189	85	85
Constant flowrate							
6.685	14.66	16.08	2,613.72	36,239.59	0.072	Variable	101.20
Variable flowrate							
Variable	Variable	297.33	2,894.98	59,613.12	0.048	85	85

With fouling (18 months operation)

Flowrate (l/min)	ΔP (kPa)	Cost_pump ($)	Cost Total ($)	Q (kWh)	Cost_Q ($/kWh)	T_o (°C)	T_tank (°C)
Reference case							
6.685	36.88	$18.67	$2,616.32	13,662.000	$0.191	85	85
Constant flow rate							
6.685	Variable	18.56	2,616.21	33,904.90	0.077	Variable	99.5
Variable flowrate							
Variable	Variable	2,503.64	5,101.29	32,979.48	0.154	85	85

Conclusions

1. The solar collector's inlet temperature is relatively high at 75°C, requiring elevated radiation (<550 W/m²) to reach the target temperature.
2. With radiation below 600 W/m², 17 collectors are needed to achieve the target temperature (85°C). Operating above this radiation level reduces the required area by 53%. Therefore, it is recommended to operate during hours when radiation exceeds 600 W/m² rather than attempting to increase the collection area.
3. According to the network design, a configuration of 4 lines with 8 series-connected heat exchangers per line is sufficient to provide the thermal load to the process. With this network configuration, operating with constant flowrate can increase the required thermal load (13,831.93 kWh) by 162% (36,239.59 kWh), while variable flowrate increases it by **331%** (59,613.12 kWh).
4. Under clean conditions, operating with variable flowrate presents better thermoeconomic performance compared to constant flowrate. Achieves a 64% higher thermal load and 33% lower unit operating costs than the constant flowrate model.
5. Using solar collectors with a variable flowrate model for pasteurization reduces costs by more than half (**0.048 $/kWh**) compared to natural gas usage (assuming a unit cost of 0.1/kWh). However, the effects of scaling fouling on solar collectors must be considered. If operated without maintenance for 18 months, the cost increases to **0.154 $/kWh.**
6. In the presence of scaling, it is better to operate with constant flowrate since fouling has a lesser impact on the thermoeconomic performance of the collectors. If maximising solar field benefits, operating with constant flowrate and performing cleaning at least once a year is ideal for economic viability.

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