

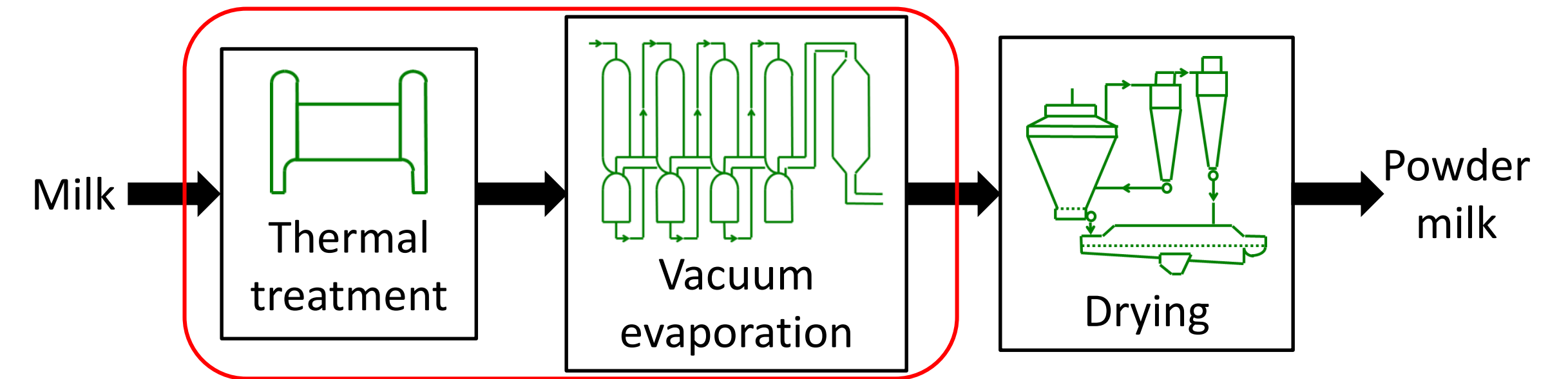
Context

The design and development of sustainable food processes constitute a major challenge in a context of transitions that encompass climate change, energy scarcity and energy price increase. A systemic approach combining process modelling, simulation, and optimization can be a sound way of coping with this issue. While the benefit of using computer-aided process engineering tools has long been recognized in the chemical industry, their use is not yet systematic in the development of food processes.

Objective

Develop a process modelling and simulation tool for embedding in a framework for the systemic eco-design of food processes.

Approach: modelling food products with property models from the literature, directly specified in a chemical process simulator; applying the tool to the modelling and simulation of dairy concentration processes.



Modelling the properties of liquid food products in a chemical process simulator

1 Definition of milk in the simulator

- Water: Component from the simulator database
- Fat, Proteins, Lactose, Minerals: User-defined components

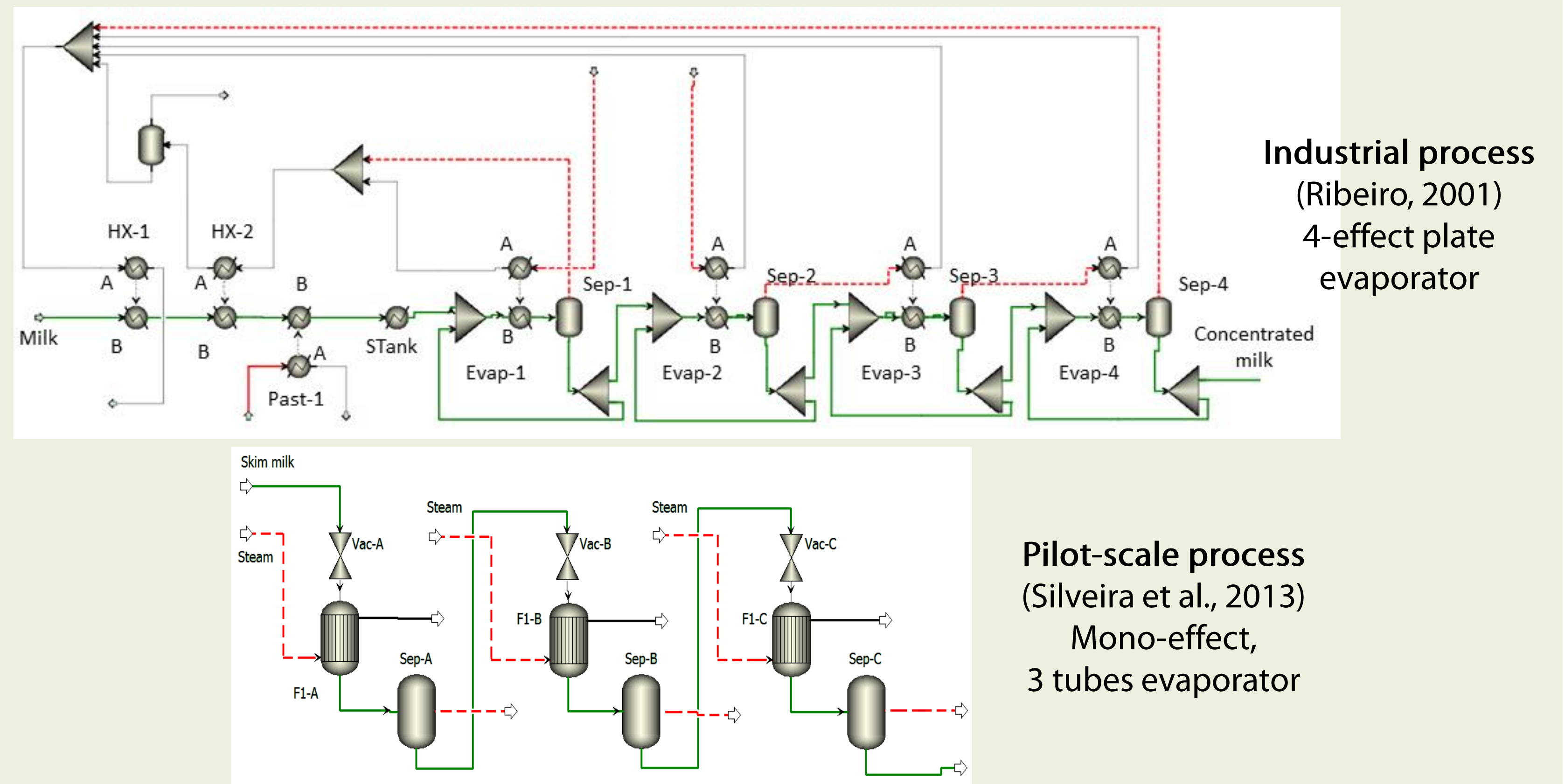
Milk behaviour is defined only by liquid mixture property models.

2 Selection of food property models: comparison of existing models and experimental data over a range of temperature and dry matter content

Example of heat capacity

3 Input macroscopic models in Aspen Plus as Fortran programs compiled and linked to Aspen Plus

Validating the selected milk properties models with an industrial and a pilot-scale processes



1 Choice of the milk properties models

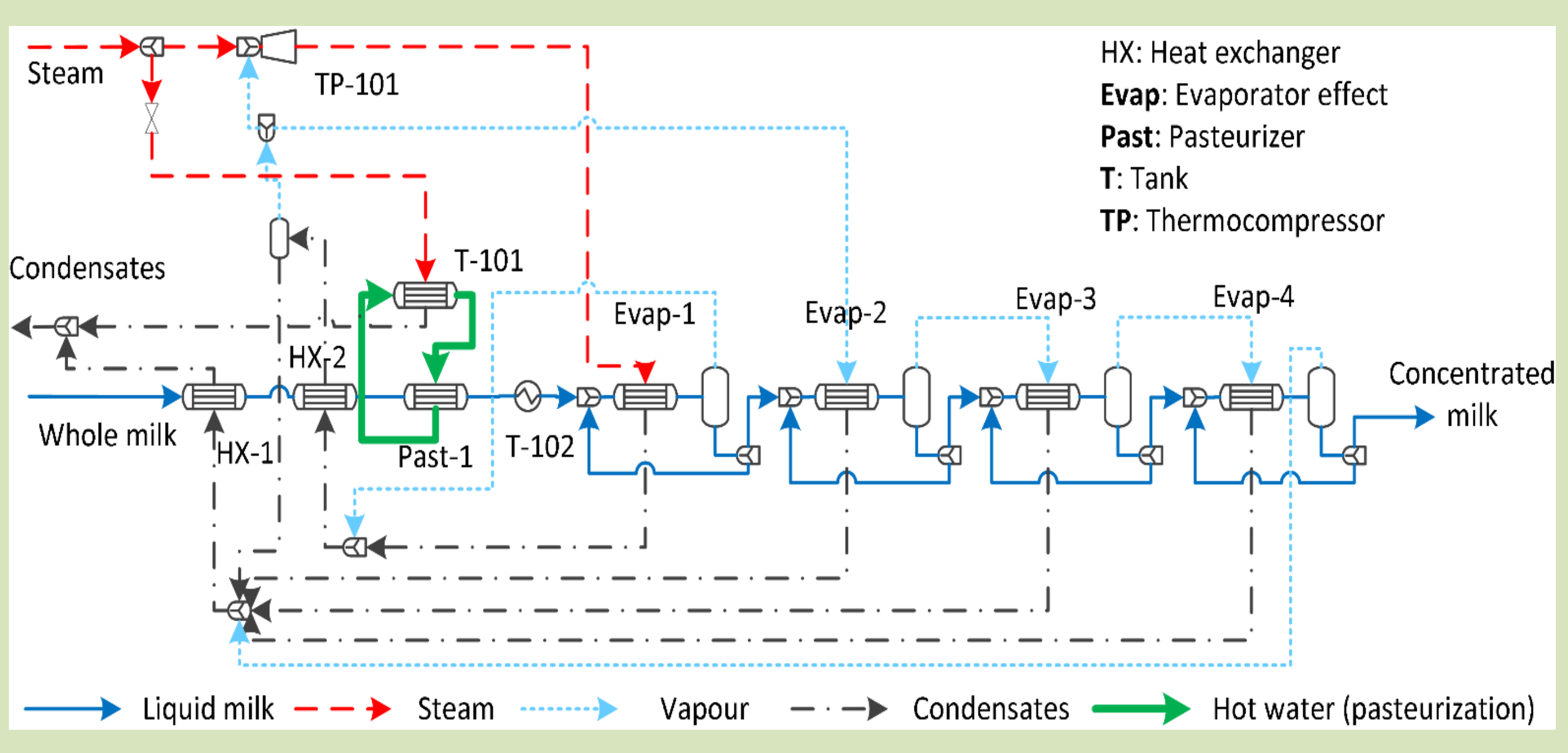
Heat capacity	$C_p = \sum C_{p,i} \times X_i$ With temperature-dependant correlations for fat, protein, carbohydrates and minerals.	Choi and Okos, 1986
Boiling Point Elevation	$\Delta T_{BPE} = \frac{1}{\frac{1}{T_{SAT}} + \frac{R \times \ln(1 - x_{SOL})}{H_{VAP}}} - T_{SAT}$	Winchester, 2000
Density	$\rho = \frac{1}{\sum X_{W,i} / \rho_i}$ With temperature-dependant correlations for fat, protein, carbohydrates and minerals.	Choi and Okos, 1986
Thermal conductivity	$\lambda = (326.58 + 1.0412 \times T - 3.37 \times 10^{-3} \times T^2) \times (0.46 + 0.54 \times X_{Water}) \times 1.73 \times 10^{-3}$	Riedel, 1949
Viscosity	$\mu = 1000 \times \mu_{Water} \times \exp\left(\frac{\sum A_i \times X_{W,i}}{X_{W,Water}}\right)$ With temperature-dependant coefficients A_i for fat, proteins and carbohydrates.	Morison et al., 2013
Surface tension	General model (whole milk & skim milk): $\sigma = 55.6 - 0.163 \times T + 1.8 \times 10^{-4} \times T^2$	Bertsch, 1983

- X_i Component mass fraction
- x_{SOL} Component molar fraction
- T Temperature (°C)
- T_{SAT} Saturation temperature (°C)
- H_{VAP} Water vaporization enthalpy (J.kg⁻¹)

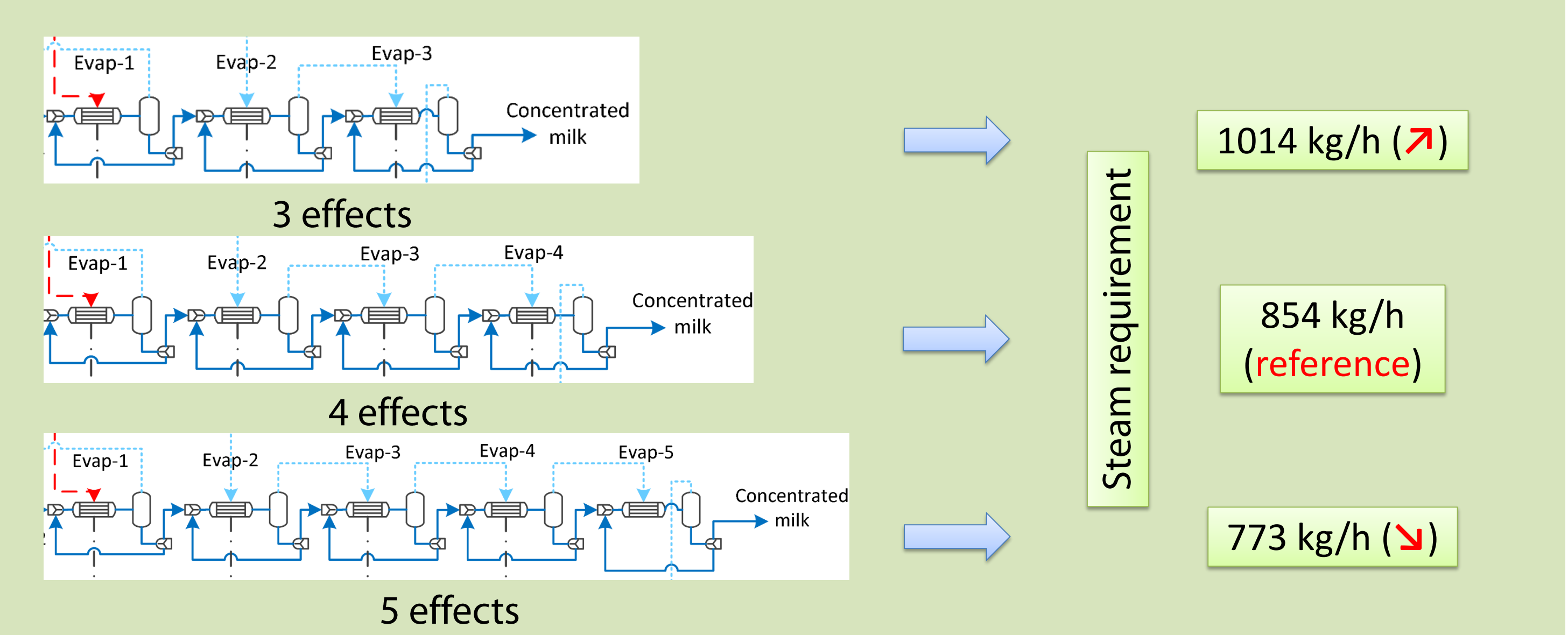
2 Validation of the modelling approach: modelling and simulating milk concentration processes

		Effect 1	Effect 2	Effect 3	Effect 4
Industrial process	Concentrate dry matter	Simulation: 20.4%	25.2%	33.0%	49.2%
	Industrial results	20.5%	25.2%	32.9%	48.0%
Industrial process	Concentrate temperature	Simulation: 66.2°C	61.3°C	55.8°C	45.1°C
	Industrial results	66.0°C	61.0°C	56.0°C	46.0°C
		Run 10% → 24%		Run 24% → 52%	
Pilot-scale process	Concentrate dry matter	Simulation: 21.9%	24.0%	45.5%	52.0%
	Experimental results	24.0%	24.0%	45.5%	52.0%
Pilot-scale process	Concentrate temperature	Simulation: 60.4°C	60.0°C	61.0°C	61.0°C
	Experimental results	60.0°C	60.0°C	61.0°C	61.0°C

3 Computing energy requirements of the industrial process for different evaporator configurations



Evaporator design



Conclusions and perspectives

- A process flowsheeting simulator has been adapted to the simulation of milk concentration processes by incorporating milk physico-chemical property models retrieved from the literature.
- In order to validate the approach, simulations have been performed on thermal treatments and vacuum evaporation steps, classically carried out prior to spray drying.
- The capabilities of the simulator have been used to study energy reduction scenarios.
- The modelling approach may be applied to different food products (fruit juice, whey...).
- This is a first step towards an eco-design approach combining modelling, cost analysis, environmental analysis and multi-objective optimization.

