ProSim PHE Application Example

Simulation of a Plate Heat Exchanger used to Cool a Sucrose Solution with ProSim PHE CAPE-OPEN Unit Operation

Interest of this example
This example shows a two-fluid plate heat exchanger used to cool a solution of sucrose (60° Brix) with water. This counter-current heat exchanger has two passes on both sides. Each pass is counter-current. Pure sucrose component is modified to represent the thermal and transport properties of the sucrose solution (60° Brix). This heat exchanger is modeled using ProSim PHE, ProSim's CAPE-OPEN unit operation dedicated to the simulation of plate heat exchangers. ProSim PHE can take into account the effect of the stacking and of the pressure drop on the enthalpy curves. In this example, the ProSim PHE unit operation runs inside the ProSimPlus environment, i.e., within the ProSimPlus simulation software where the thermodynamic and physico-chemical data needed are automatically calculated using Simulis Thermodynamics, the thermodynamic calculation server of ProSimPlus.

Access	☑ **Free-Internet**	☐ **Restricted to ProSim clients**	☐ **Restricted**	☐ **Confidential**

Corresponding ProSimPlus file	*COPROPHE_EX_EN-Sucrose-cooling.pmp3*

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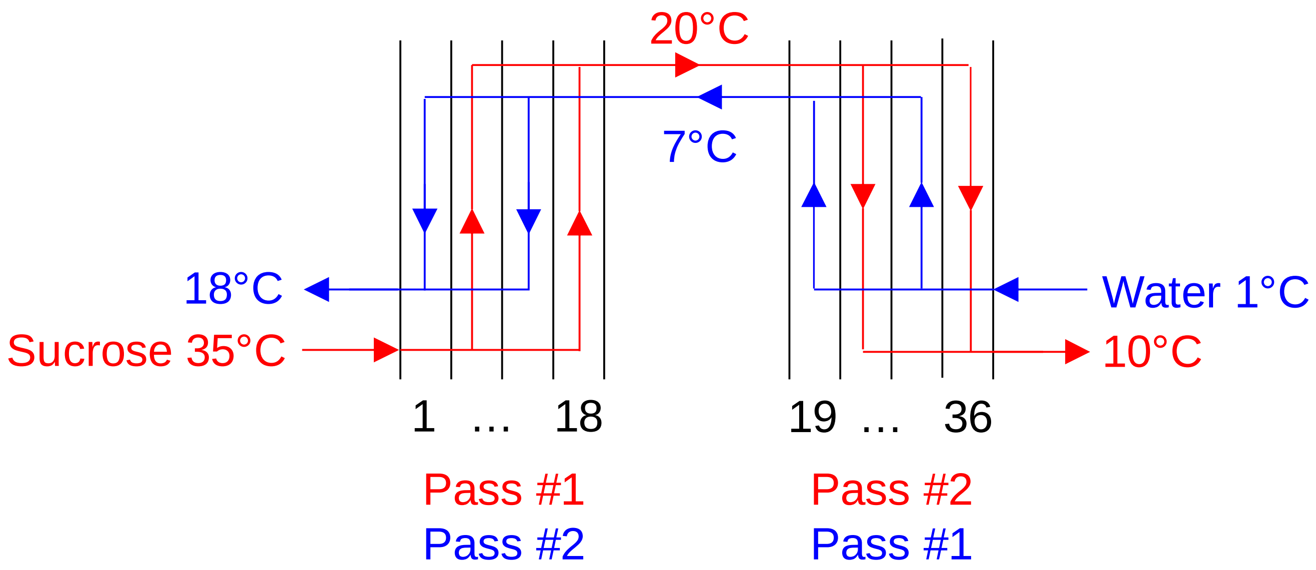
1. PROCESS MODELING

1.1. Process description

In this example a plate heat exchanger is used to cool a solution of sucrose (60° Brix) with water. The hot stream is the sucrose solution and the cold stream is the water stream. This is a counter-current heat exchanger with two passes on both sides. Each pass is counter-current and has 18 passages (9 for each fluid). Its scheme is shown in the figure below. This example is built form [GUT03].



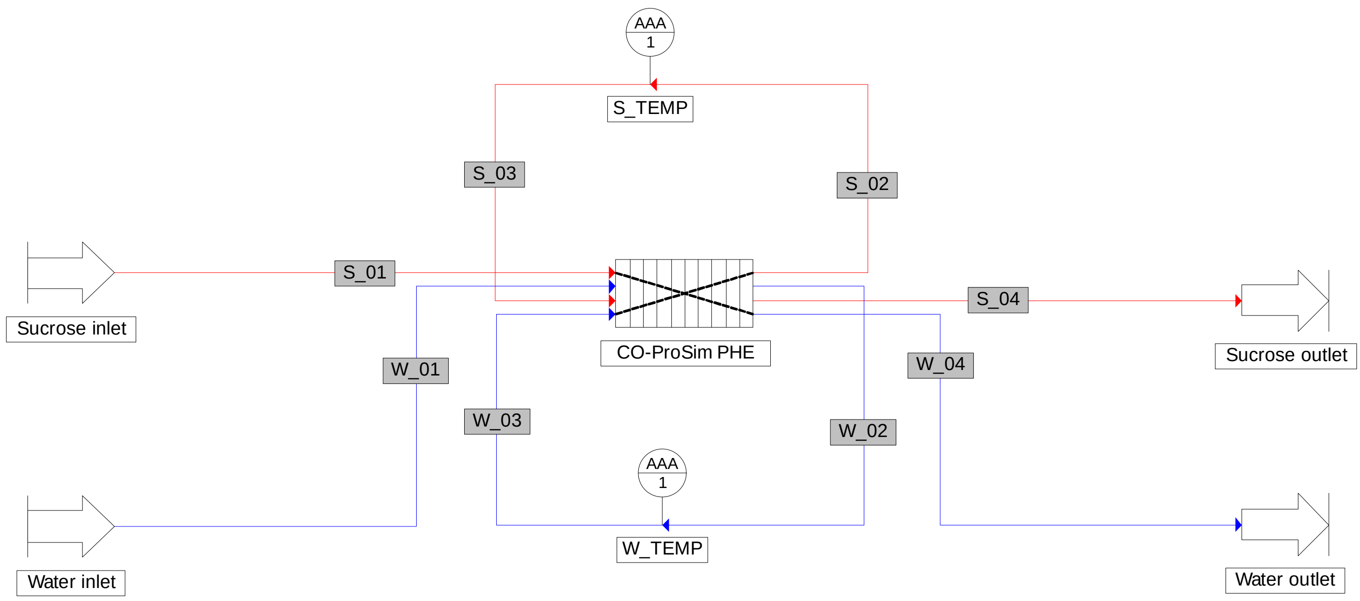
In this example, the ProSim PHE CAPE-OPEN unit operation is used within the ProSimPlus simulation environment and the Simulis Thermodynamics calculation server for thermophysical properties and phase equilibria calculations is used.

1.2. Process flowsheet

The process flowsheet is represented below. One ProSim PHE CAPE-OPEN unit operation is used to model in the same module the two passes of the heat exchanger.

The hot sucrose solution enters in the heat exchanger by the stream “S_01”. The stream “S_02” leaving the unit operation is the sucrose solution outlet of the pass #1. As in ProSimPlus simulation environment it’s not allowed to connect directly an outlet of a unit operation to an inlet of the same unit operation, a measurement unit operation, “S_TEMP”, is used to allow this connection as two streams are then used. Thus, the streams “S_02” and “S_03” are the connection from the pass #1 and the pass #2 on the sucrose side, “S_03” being the entering stream of the pass #2. Finally, the cooled sucrose solution leaves the heat exchanger by the stream “S_04”.

The water follows an analogous path.



1.3. Compounds

The compounds in the simulation, their chemical formula and CAS numbers are shown in the following table. Water pure component properties are extracted from the standard data base provided with ProSimPlus [ROW17].

Compound	Chemical formula	CAS number
Water	H_2O	7732-18-5
Sucrose 60° Brix	-	55000-01-6

The sucrose solution (60° Brix) was created from the sucrose compound (CAS number: 57-50-1) available in the standard data base provided with ProSimPlus [ROW17]. The properties modified to model the thermal and transport properties of a sucrose solution (60° Brix) are:

- ✓ IUPAC name: Sucrose 60° Brix
- ✓ CAS number: 55000-01-6
- ✓ Liquid specific heat [GUT03]:

$$Cp_L = 4.803T + 2696 \quad (J.kg^{-1}.K^{-1})$$

$$0 \leq T \leq 100°C$$

- ✓ Ideal gas specific heat:

$$Cp_G = Cp_L$$

- ✓ Vaporization enthalpy:

$$\Delta H_{vap} = 0$$

- ✓ Liquid density [GUT03]:

$$\rho_L = -1.451 \times 10^{-3}T^2 - 0.4281T + 1296 \quad (kg.m^{-3})$$

$$0 \leq T \leq 60°C$$

- ✓ Liquid dynamic viscosity [GUT03]:

$$log\mu_L = -4.513 + \frac{421.8}{T + 108.5} \quad (Pa.s)$$

$$0 \leq T \leq 80°C$$

- ✓ Liquid thermal conductivity [GUT03]:

$$\lambda_L = -3.696 \times 10^{-6}T^2 + 1.201 \times 10^{-3}T + 0.3825 \quad (W.m^{-1}.K^{-1})$$

$$0 \leq T \leq 80°C$$

1.4. Thermodynamic model

As both sides of the heat exchanger are liquid streams modeled with pure component (water on cold side) and pseudo-component (sucrose on hot side), the “Ideal” thermodynamic profile is selected.

1.5. Operating parameters

1.5.1. Process feeds

	Hot stream	Cold stream
Temperature (°C)	35	1
Pressure (bar)	2	1.2
Total flow rate (kg/s)	1.3	1.3
Mole fractions		
Sucrose 60° Brix	1	0
Water	0	1

1.5.2. Plate heat exchanger

✓ General parameters

Parameters	Value
Type of exchanger	CO-ProSim PHE
Number of bodies	1
Orientation	Vertical
Used width (cm)	23.6
Thickness of the plates (mm)	0.7
Material Type Name Thermal conductivity (W/m/K)	 Other Stainless steel 17

- ✓ Streams parameters

	Stream			
	Sucrose solution Inlet pass #1	Water Inlet pass #1	Sucrose solution Inlet pass #2	Water Inlet pass #2
Name	Hot	Cold	Hot2	Cold2
Color				
Flow direction	From bottom to top		From top to bottom	
Fouling factor ($W/m^2/K$)	11 627.90698	58 823.52941	11 627.90698	58 823.52941
Heat exchange correlation	GREThplates and frames			
Generation of physico-chemical properties	Not tabulated (i.e. automatically calculated by the thermodynamics calculation server of the simulation environment, Simulis Thermodynamics in this example)			
Pressure effect on enthalpy curves	Not taken into account			

The name and the color will be used to well recognize each stream in the later part (reference layer and stacking description).

✓ Plates characteristics

The correlations proposed by [WAN95] is available in ProSim PHE to compute the Colburn and Fanning coefficients. In this example, to compare ProSim PHE results with the ones of [GUT03], the correlations of [GUT03] will be used instead of the one of [WAN95] in the form of tabulated values. Due to the differences in the Reynolds number between the two sides, two plates are specified (one for each side).

Name	Hot plate	Cold plate
Reference	1001	1002
Calculation mode	Performance data provided	
Type	Corrugated plate	
Corrugation height (mm)	2.7	
Corrugation angle (°)	45	
Plate area enlargement factor **Type** **Value**	 Supplied 1.17	

The performance data of the two plates are listed in the following table.

Hot plate			**Cold plate**		
Reynolds number	**Fanning coefficient**	**Colburn coefficient**	**Reynolds number**	**Fanning coefficient**	**Colburn coefficient**
1	18.290000	0.400000	100	0.558038	0.063551
4	7.407482	0.229104	200	0.483784	0.050312
7	5.142920	0.182949	300	0.445017	0.043887
10	4.075808	0.158511	400	0.419411	0.039832
13	3.434968	0.142644	500	0.400568	0.036946
16	3.000043	0.131221	600	0.385802	0.034744
19	2.682047	0.122462	700	0.373744	0.032986
22	2.437553	0.115453	800	0.363603	0.031534
25	2.242626	0.109670	900	0.354887	0.030307
28	2.082892	0.104786	1000	0.347267	0.029250
31	1.949153	0.100585	1100	0.340516	0.028325
34	1.835226	0.096918	1200	0.334467	0.027507
37	1.736785	0.093679	1300	0.328997	0.026775
40	1.650709	0.090789	1400	0.324012	0.026114
43	1.574680	0.088187	1500	0.319440	0.025514
46	1.506939	0.085828	1600	0.315221	0.024965
49	1.446125	0.083676	1700	0.311309	0.024460
52	1.391168	0.081701	1800	0.307665	0.023994
55	1.341211	0.079879	1900	0.304257	0.023560

✓ Reference passages

The characteristics of the distributors are displayed in the following table.

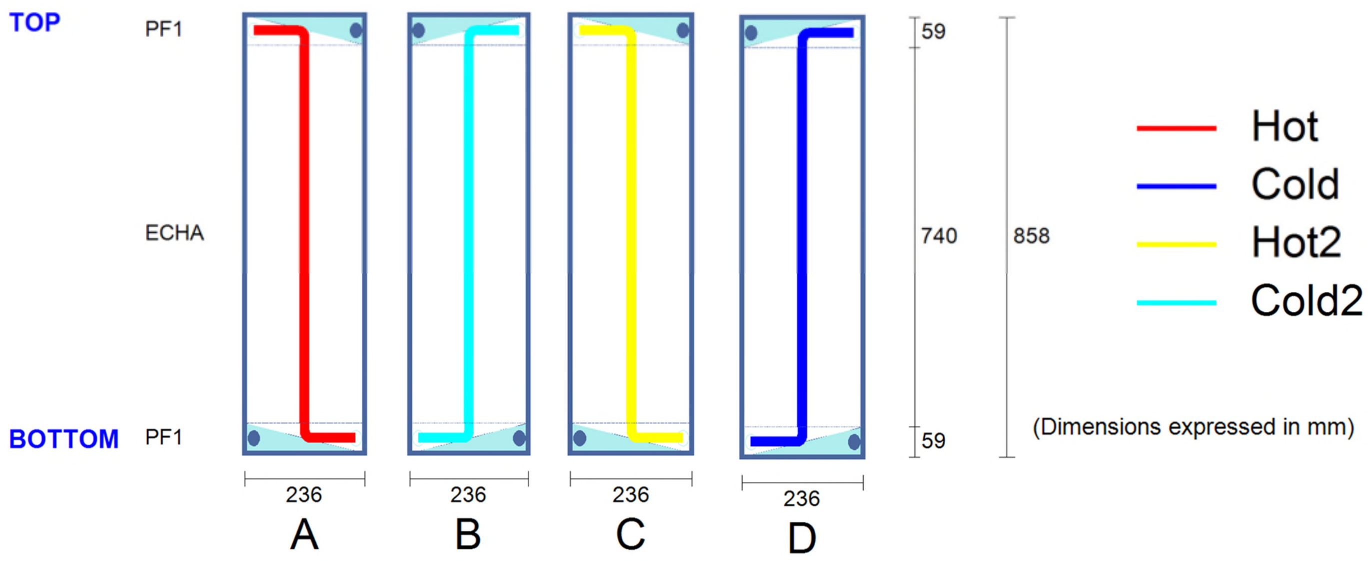
	Distributor characteristics			
Reference layer	A	B	C	D
Distributor type	PF1			
Block height (mm)	59			
Main plate	Hot plate	Cold plate	Hot plate	Cold plate
Roughness **Type** **Value (mm)**	 Absolute 0			
Port geometry	Circular			
Port diameter (mm)	59			
Stream	Hot	Cold2	Hot2	Cold

To compare with [GUT03] results, it's assumed that the distributor block height is equal to their port diameter.

The plates used for the heat exchange zone are shown in the table below:

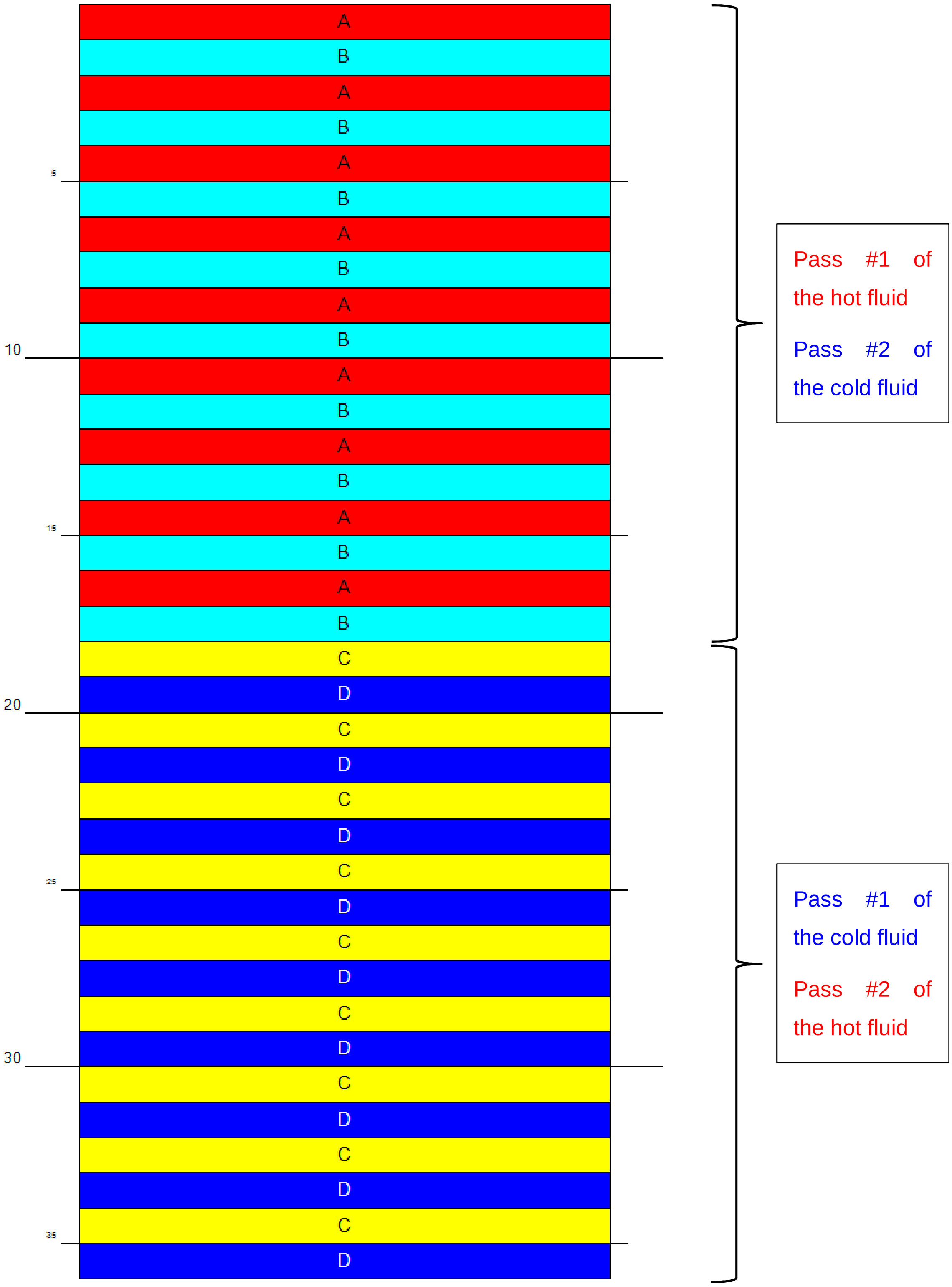
	Heat exchange zone characteristics			
Reference layer	A	B	C	D
Block height (mm)	740			
Main plate	Hot plate	Cold plate	Hot plate	Cold plate
Stream	Hot	Cold2	Hot2	Cold

The following figure shows the four reference passages of the heat exchanger.

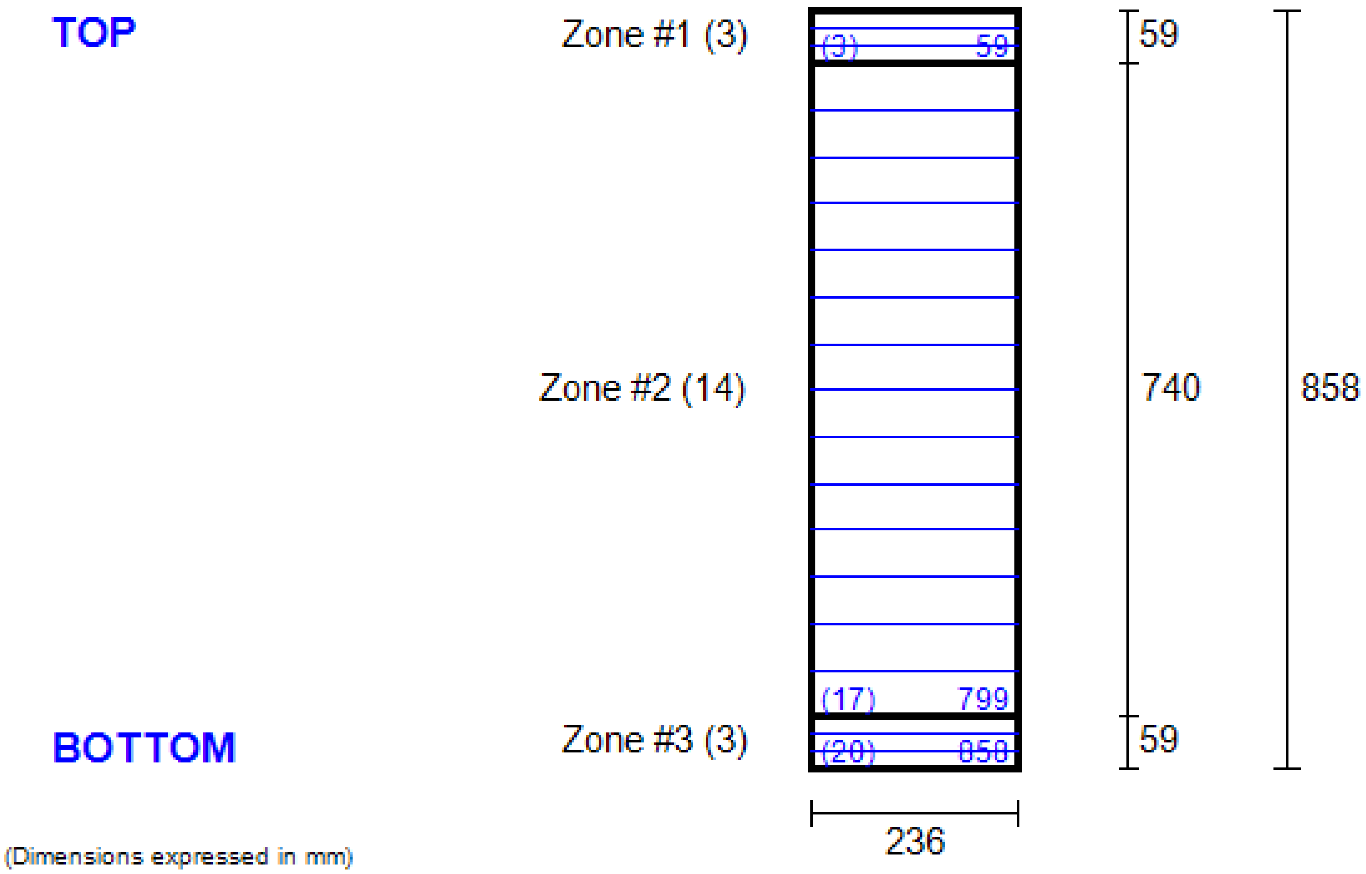


✓ Stacking

Parameters	Value
Sequence 1	
Number of repetitions of the sequence	9
Sequence	A B
Sequence 2	
Number of repetitions of the sequence	9
Sequence	C D



✓ Number of meshes for each elementary zone



✓ Numerical parameters

In ProSimPlus PHE, the heat transfer coefficients for the distributors are set by default at 20% of the ones corresponding to the heat exchange plate of the same characteristics. In this example, to make a comparison with the results of [GUT03], this parameter is set to zero: i.e. the thermal performances of the distributors are not taken into account in the example.

1.5.3. Measurement unit operations

As in ProSimPlus simulation environment it's not allowed to connect directly an outlet of a unit operation to an inlet of the same unit operation, measurement unit operations are used to allow this connection as two streams are then used. They are configured here to give the deviation with the temperature between the two passes reported by [GUT03].

	Parameter	
Stream	Sucrose solution	Water
Measurement	Temperature	
Set point (°C)	20	7

1.6. Initializations

The calculation sequence is automatically determined by ProSimPlus. Two tear streams are detected: "S_03" and "W_03", i.e. the streams linking the two passes of the heat exchanger. The following initializations are used in the simulation.

	S_03	**W_03**
Temperature (°C)	20	7
Pressure (bar)	2	1.2
Total flow rate (kg/s)	1.3	1.3
Mole fractions		
Sucrose 60° Brix	1	0
Water	0	1

2. RESULTS

2.1. Mass and energy balances

This document presents only the most relevant stream results. In ProSimPlus, mass and energy balances and transport properties are provided for all streams. Stream results are also available at the unit operation level ("Stream" tab in the configuration window).

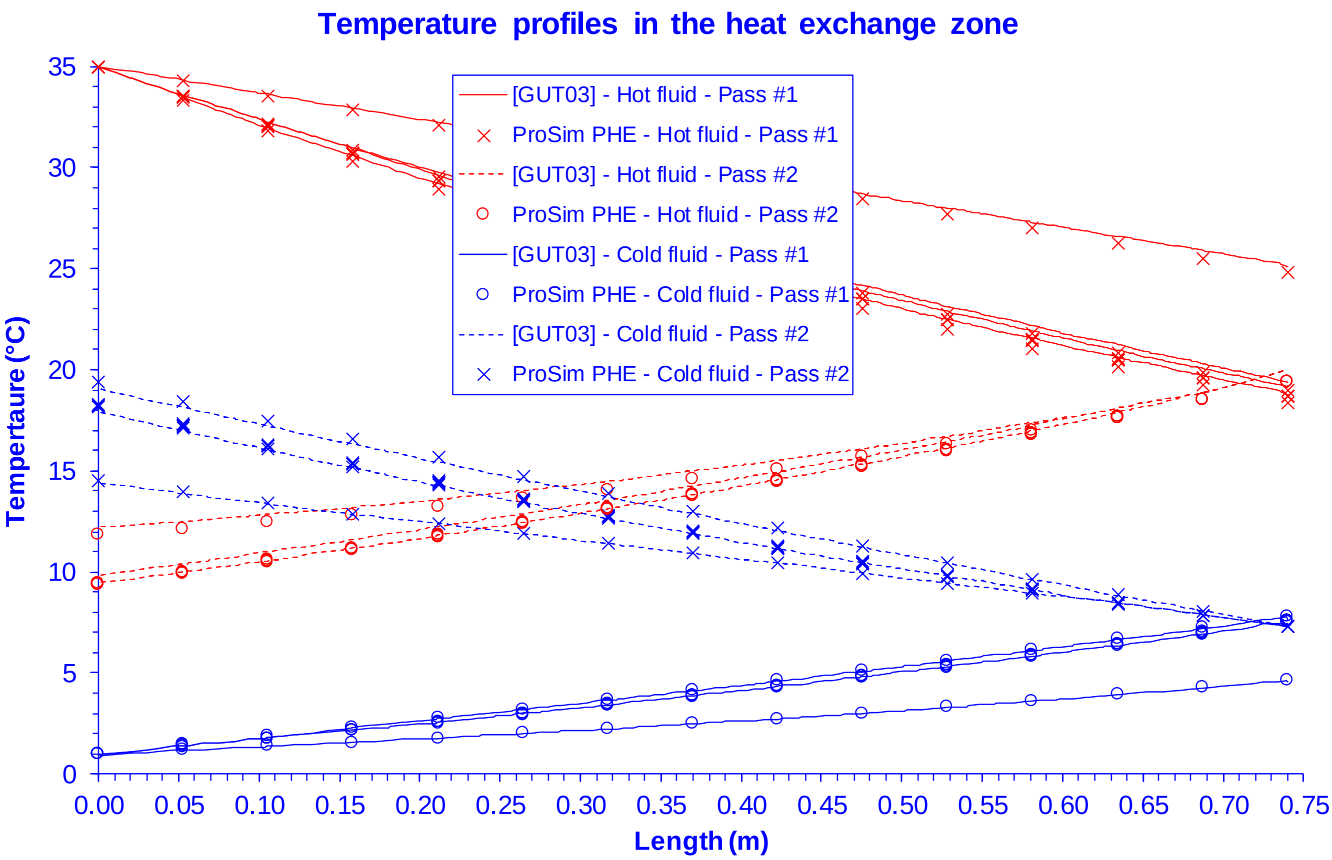
Streams		S_01	S_03	S_04	W_01	W_03	W_04
Total flow	kg/h	4680	4680	4680	4680	4680	4680
Mass fractions							
WATER		0	0	0	1	1	1
Sucrose 60° Brix		1	1	1	0	0	0
Physical state		Liquid	Liquid	Liquid	Liquid	Liquid	Liquid
Temperature	°C	35	19.379	9.5827	1	7.279	17.954
Pressure	bar	2	1.5509	1.117	1.2	1.0431	1.0578
Enthalpic flow	kW	36.921	-20.481	-55.699	-3293.1	-3258.7	-3200.4
Vapor molar fraction		0	0	0	0	0	0

The following table shows that ProSim PHE gives similar results as the ones of [GUT03].

	[GUT03]	ProSim PHE
Outlet temperature (°C)		
Hot fluid (sucrose 60° Brix)	10.0	9.6
Cold fluid (water)	17.7	18.0
Temperature between passes (°C)		
Hot fluid (sucrose 60° Brix)	20.0	19.4
Cold fluid (water)	7.6	7.3
Pressure drop (bar)		
Hot fluid (sucrose 60° Brix)	0.814	0.883
Cold fluid (water)	0.211	0.142

2.2. Plate heat exchanger profiles

Several profiles (wall temperature, fluid temperature, pressure, heat transfer coefficient, vaporization ratio…) in the heat exchanger are available after the simulation, from the ProSim PHE edition window ("Results" tab). The following figure shows that ProSim PHE gives similar temperature profiles in the heat exchange zone (distributor not represented in this figure) as the ones of [GUT03] for each passage of each passes for both sides.



3. REFERENCES

[GUT03] GUT J.A.W., PINTO J.M., "Modeling of Plate Heat Exchangers with Generalized Configurations", Int. J. Heat Mass Trans., 46, 2571-2585 (2003)

[ROW17] ROWLEY R.L., WILDING W.V., OSCARSON J.L., GILES N.F., "DIPPR® Data Compilation of Pure Chemical Properties", Design Institute for Physical Properties, AIChE, New York, NY (2017)

[WAN95] WANNIARACHCHI A.S., RATNAM U., TILTON B.E., DUTTA-ROY K., "Approximate Correlations for Chevron-Type Plate Heat Exchangers", 30th National Heat Transfer Conference, Vol. 12, HTD Vol. 314, ASME, 145-151 (1995)