# TRNSYS Type 1924

# Stratified Plug Flow Solar Combi-Store Model

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**Abstract**

Description of inputs and outputs of Type 1924 of the release $v_3$ as Trnsys Type. The model allow direct ports and immersed heat exchangers solved by means of a physical model or with the expressions used in the MultiPort model.

# Contents

# 1. Introduction

This TRNSYS Type simulates a stratified plug flow solar combi-store.

# 2. Warnings

- The outputs regarding entropy are not validated and therefore should not be used. We are not paying attention of what comes out from it.
- Only ONE unit of Type 1924 is allowed per simulation deck. Using several units of this type will definitely mix up the values of both units and lead to incorrect results.

# 3. Revision history

- Version: 3.1- 140616 - DC - Units of mass flows changed and calculated fixed temperatures positions (20CV) for interpolations of temperature sensors and heat source devices.
- Version: 3.0- 131203 - DC - Reverted flow included in hx.
  Added a heat source device with 20 cv for each that need power as input in order to couple with heat pump with a condenser inside the storage tank. Each Cv needs also as parameter the relative position to the storage
  Number of maximum hx changed from 10 to 6
- Version: 2.3- 130211 - DC - Read input file for plugs initialization
- Version: 2.2- 130207 - DC - Error in insulation plate
- Version: 2.1- 130107 - DC - Using standard Type Form from SPF 2013. Change of UNITS
- Version: 2.0- 121215 - DC - added immersed heat exchangers with two models : i) physical and ii) MultiPort UA model
- Version: 1.2 - 120827 - MH - added simulation of movable insulation plate
- Version: 1.1 - 120827 - MH - added average temperature sensors
- Version: 1.0 - 120229 - MH - remove plugs first, then input new plugs - this procedure seems to be unusual, but it gets effectively rid of convergence problems.

# 4. Model

The plug flow model solved the TES in two parts. First the direct ports are solved in the so-called plug flow model and afterwards the unsteady heat conduction equation inside the TES considering the source terms of the heat exchangers is solved.

The plug flow model part is direct and very fast but it has some limitations. The main sequence of this section reads:

- Shift the outlet positions of TES by a tiny bit if they are identical with an inlet position.
- Split plugs if fluid needs to be removed from or added to a plug
- Determine mass flow direction and quantity inside TES for each CV-plug
- Remove CV-plugs (whenever there is mass flow coming in / moving out of the TES)
- Find inlet positions and add new CV-plugs in (mass flow into the TES)
- Sort the CV-plugs and adjust heights of upper and lower edges of each plug (stored in plug array)
- Clean the CV-plugs : remove plugs of too low capacitance or too low Temp. difference, split plugs that are too big

The second part of the model solves the heat conduction process and here it needs to iterate. The model solves all the heat exchangers using an step-by-step model considering the transient term and afterwards it calculates how much energy is introduced in each CV-plug of the TES. This energy is considered as a heat source term and the one-dimensional unsteady heat conduction equation of the TES is solved. This process is repeated until convergence. The step-by-step model is explained in detail in the Appendix A

# 5. List of parameters

| Nr. | Name | Description | Units | Type/Range |
|---|---|---|---|---|
| 1 | $V_s$ | Effective volume of combi-store | $m^3$ | $\mathbb{R}\,(0:\infty)$ |
| 2 | $\rho_s$ | Density of storage material | $kg/m^3$ | $\mathbb{R}\,(0:\infty)$ |
| 3 | $c_{p,s}$ | Specific heat capacity of storage material | $kJ/kgK$ | $\mathbb{R}\,(0:\infty)$ |
| 4 | $\lambda_{eff,s}$ | Effective thermal conduction / diffusion in vertical direction | $W/mK$ | $\mathbb{R}\,(0:\infty)$ |
| 5 | $h_s$ | Height of store (used to calculate cross-section area that has an influence on the thermal diffusion) | m | $\mathbb{R}\,(0:\infty)$ |
| 6 | $T_{ini}$ | Initial temperature of store | $^oC$ | $\mathbb{R}\,(0:90)$ |
| 7 | $nCv_{max}$ | Maximum number of allowed plugs | - | $\mathbb{Z}\,(10:400)$ |
| 8 | $nCv_{min}$ | Minimum number of allowed plugs | - | $\mathbb{Z}\,(10:400)$ |

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| Nr. | Name | Description | Units | Type/Range |
|---|---|---|---|---|
| 9 | $\Delta T_{p,max}$ | Minimum temperature difference between two plugs, plugs of smaller difference will be merged if the merger will not be larger than | $^oC$ | $\mathbb{R}\,(0:\infty)$ |
| 10 | $Bo_{prof}^{start}$ | 1: start temperature profile read in from data-file, 2: start profile based on $T_{ini}$ and $\Delta z_{p,max}$ | | $\mathbb{Z}\,(1,2)$ |
| 11 | $T_{ref}$ | Reference temperature for energy and exergy calculation | $^oC$ | $\mathbb{R}\,(0:\infty)$ |
| 12 | $UA_{bot}$ | Bottom heat loss coefficient of the TES | $W/K$ | $\mathbb{R}\,(0:\infty)$ |
| 13 | $UA_{zo1}$ | Side heat loss coefficient in lower third of TES | $W/K$ | $\mathbb{R}\,(0:\infty)$ |
| 14 | $UA_{zo2}$ | Side heat loss coefficient in mid third of TES | $W/K$ | $\mathbb{R}\,(0:\infty)$ |
| 15 | $UA_{zo3}$ | Side heat loss coefficient in upper third of TES | $W/K$ | $\mathbb{R}\,(0:\infty)$ |
| 16 | $UA_{top}$ | Top heat loss coefficient of the TES | $W/K$ | $\mathbb{R}\,(0:\infty)$ |
| 17-20 | | Unused. Specify as 0 | | |
| 20+4(i-1) | $z_{i,in}$ | Port inlet height $i$ from $i=1,4$ of TES relative to TES height, specify as -1 if not in use | $m$ | $\mathbb{R}\,(0:1)$ |
| 21+4(i-1) | $z_{i,out}$ | Port outlet height $i$ of TES relative to TES height, specify as -1 if not in use | $m$ | $\mathbb{R}\,(0:1)$ |
| 22+4(i-1) | | **Presently not used** with $i$ | | |
| 23+4(i-1) | $Bo_{1,strat}$ | Port inlet Bool $i$ . $Bool = 1$for stratifying and $Bool = 0$ for non-stratifying | | $\mathbb{Z}\,(0-1)$ |
| $\vdots$ | $\vdots$ | for i=1 i $\leq$ 10 i=i+1 | $\vdots$ | $\vdots$ |
| 60+i | $z_{Tss,i}$ | Rel. height of the free positioned storage temperature sensor $i$ relative to store height | $m$ | $\mathbb{R}\,(0:1)$ |
| $\vdots$ | $\vdots$ | for i=1 i $\leq$ 10 i=i+1 | $\vdots$ | $\vdots$ |
| 70+2(i-1) | $z_{Tss_{i,av,l}}$ | Rel. height of lower limit of average temperature sensor $i$ from $i=1,5$, relative to store height | $m$ | $\mathbb{R}\,(0:1)$ |

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| Nr. | Name | Description | Units | Type/Range |
|---|---|---|---|---|
| 71+2(i-1) | $z_{Tss_{i,av,u}}$ | Rel. height of upper limit of average temperature sensor $i$ from $i = 1, 5$, relative to store height | $m$ | $\mathbb{R}\,(0:1)$ |
| ⋮ | ⋮ | for i=1 i $\leq$ 5 i=i+1 | ⋮ | ⋮ |
| 81 | $Ins_{p,m}$ | Mode for calculation of internal insulation plate: 0 = no internal insulation plate, 1 = internal insulation plate at fixed height 2 = internal insulation plate at fixed temperature level / density (moving) | | $\mathbb{Z}\,(0-2)$ |
| 83 | $z_{Ins_p}$ | Relative height of immobile internal insulation plate (only for$Ins_{p,m} = 1$) | | $\mathbb{R}\,(0:1)$ |
| 84 | $T_{Ins_p}$ | Temperature level at which mobile internal insulation plate floats (only for$Ins_{p,m} = 2$) | $^oC$ | $\mathbb{R}\,(0:90)$ |
| 85 | $UA_{Ins,p}$ | UA-value of internal insulation plate, surrounding water gab and tank material at the height / thickness of the internal insulation plate | $W/K$ | $\mathbb{R}\,(0:\infty$ |
| 85 | $n_{hx}$ | Number of used heat exchangers | | $\mathbb{Z}\,(0-8)$ |
| 86+19[a](i-1) | $z_{in,hx,i}$ | Rel. inlet position of heat exchanger $i$ | | $\mathbb{R}\,(0:1)$ |
| 87+19(i-1) | $z_{out,hx,i}$ | Rel. outlet position of heat exchanger $i$ | | $\mathbb{R}\,(0:1)$ |
| 88+19(i-1) | $d_{in,hx,i}$ | Inside diameter of heat exchanger $i$ pipe (used if $mod_{hx1} = 0$) | $m$ | $\mathbb{R}\,(0:\infty)$ |
| 89+19(i-1) | $d_{out,hx,i}$ | Outside diameter of heat exchanger $i$ pipe (used if $mod_{hx,i} = 0$) | $m$ | $\mathbb{R}\,(0:\infty)$ |
| 90+19(i-1) | $L_{out,hx,i}$ | Length of the heat exchanger $i$ pipe (used if $mod_{hx,i} = 0$) | $m$ | $\mathbb{R}\,(0:\infty)$ |
| 91+19(i-1) | $\lambda_{hx,i}$ | Thermal conductivity of heat exchanger $i$ pipe wall (used if $mod_{hx,i} = 0$) | $W/mK$ | $\mathbb{R}\,(0:\infty)$ |
| 92+19(i-1) | $pAf_{hx,i}$ | Percentage of antifreeze of heat exchanger $i$ (used if $mod_{hx,i} = 0$) | % | $\mathbb{R}\,(0:100)$ |
| 93+19(i-1) | $V_{hx,i}$ | Volume of heat exchanger $i$ (used if $mod_{hx,i} = 1$) | $m^3$ | $\mathbb{R}\,(0:\infty)$ |
| 94+19(i-1) | $c_{p,hx,i}$ | Fluid specific thermal capacity of heat exchanger $i$ | $kJ/kgK$ | $\mathbb{R}\,(0:\infty)$ |
| 95+19(i-1) | $\rho_{p,hx,i}$ | Fluid density of the heat exchanger $i$ | $kg/m^3$ | $\mathbb{R}\,(0:\infty)$ |
| 96+19(i-1) | $n_{cv,hx,i}$ | Number of control volumes used for the heat exchanger $i$ | | $\mathbb{Z}\,(0:\infty)$ |
| 97+19(i-1) | $mod_{hx,i}$ | Model used for the heat exchanger $i$. $mod_{hx1} = 0$ uses a physical model for the UA and $mod_{hx,i} = 1$ uses MultiPort model. | | $\mathbb{Z}\,(0,1)$ |

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[a] i=1 to 6 which is the maximum number of heat exchangers allowed

| Nr. | Name | Description | Units | Type/Range |
|---|---|---|---|---|
| | | – continuation from previous page – | | |
| 98+19(i-1) | $C_{hx,i}$ | C Factor used for the Nusselt correlation $Nu = CRa^n$ of heat exchanger $i$. Used if $mod_{hx,i} = 0$ (typical values range from 0.5-0.55) | | $\mathbb{R}\,(0,1)$ |
| 99+19(i-1) | $n_{hx,i}$ | n Factor used for the Nusselt correlation $Nu = CRa^n$ of heat exchanger $i$. Used if $mod_{hx,i} = 0$ (typical values range from 0.25-0.33) | | $\mathbb{R}\,(0,1)$ |
| 100+19(i-1) | $UA_{\dot{m},hx,i}$ | Mass flow dependency factor of MultiPort's model of heat exchange $i$r. Used if $mod_{hx,i} = 1$ | | $\mathbb{R}\,(0,\infty)$ |
| 101+19(i-1) | $UA_{\Delta T,hx1}$ | Temperature difference dependency factor of MultiPort's model of heat exchanger $i$. Used if $mod_{hx,i} = 1$ | | $\mathbb{R}\,(0,\infty)$ |
| 102+19(i-1) | $UA_{T,hx,i}$ | Temperature dependency factor of MultiPort's model of heat exchanger $i$. Used if $mod_{hx,i} = 1$ | | $\mathbb{R}\,(0,\infty)$ |
| 103+19(i-1) | $UA_{hx,i}$ | global heat transfer coefficient used in MultiPort's model of heat exchanger $i$. Used if $mod_{hx,i} = 1$ | $[kJ/hK]$[a] | $\mathbb{R}\,(0,\infty)$ |
| 104+19(i-1) | $F_{start,hx,i}$ | Start up factor used in MultiPort's model of heat exchanger $i$. Used if $mod_{hx,i} = 1$. **Presently not used** | | $\mathbb{R}\,(0,\infty)$ |
| ⋮ | ⋮ | for i=1 i $\leq$ 6 i=i+1 | ⋮ | ⋮ |
| 200+(j[b]-1) | $z_{hs,j}$ | Position $i$ of the heat source device | | $\mathbb{Z}\,(0-1)$ |
| ⋮ | ⋮ | for j=1 j $\leq$ 20 j=j+1 | ⋮ | ⋮ |

[a] Be careful this parameter input unit change from the others because it usually comes from Multiport's model

[b] j=1 to 20 which is the maximum number of control volumes per heat source device

## 6. List of inputs

| Nr. | Name | Description | Units | Type/Range |
|---|---|---|---|---|
| 1+3(i-1)[a] | $T_{in,p,i}$ | Inlet fluid temperature of the direct port $i$ | $^oC$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 2+3(i-1) | $\dot{m}_{in,p,i}$ | Inlet mass flow rate of the direct port $i$ | $kg/h$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 3+3(i-1) | $T^{rev}_{in,p,i}$ | Inlet temperature of the direct port $i$ for negative flows | $^oC$ | $\mathbb{R}\,(-\infty,\infty)$ |
| ⋮ | ⋮ | for i=1 i ≤10 i=i+1 | ⋮ | ⋮ |
| 31 | $T_{amb}$ | Surrounding temperature around the TES (for heat loss calculation) | $^oC$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 32+3(i-1)[b] | $T_{in,hx1}$ | Inlet fluid temperature of the heat exchanger $i$ | $^oC$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 33+3(i-1) | $\dot{m}_{in,hx1}$ | Inlet mass flow rate of the heat exchanger $i$ | $kg/h$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 34+3(i-1) | $T^{rev}_{in,hx1}$ | Inlet temperature of the heat exchanger $i$ for negative flows | $^oC$ | $\mathbb{R}\,(-\infty,\infty)$ |
| ⋮ | ⋮ | for i=1 i ≤6 i=i+1 | ⋮ | ⋮ |
| 50+(j-1) | $\dot{Q}_{hs,j}$ | Power for the control volume j of the heat source device | kW | $\mathbb{R}\,(0,\infty)$ |
| ⋮ | ⋮ | for j=1 j ≤ 20 j=j+1 | ⋮ | ⋮ |

[a] i=1 to 10 which is the maximum number of direct ports
[b] i=1 to 6 which is the maximum number of heat exchangers

# 7. List of outputs

| Nr. | Name | Description | Units | Type/Range |
|---|---|---|---|---|
| 1+2(i-1)[a] | $Tp_{i,out}$ | Fluid temperature of the direct port $i$ | $^oC$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 2+2(i-1) | $\dot{m}_{i,out}$ | Mass flow rate of the of the direct port $i$ | $kg/h$ | $\mathbb{R}\,(0,\infty)$ |
| ⋮ | ⋮ | for i=1 i $\leq$ 10 i=i+1 | ⋮ | ⋮ |
| 20+i[a] | | Temperatures at relative heights $z_i = 0.05+0.1(i-1)$ from $i=1,10$ of the TES height | $^oC$ | $\mathbb{R}\,(-\infty,\infty)$ |
| ⋮ | ⋮ | for i=1 i $\leq$ 10 i=i+1 | ⋮ | ⋮ |
| 30+i[a] | $\dot{Q}p_i$ | Heat transfer rate of direct port $i$ | $kW$ | $\mathbb{R}\,(-\infty,\infty)$ |
| ⋮ | ⋮ | for i=1 i $\leq$ 10 i=i+1 | ⋮ | ⋮ |
| 40+i[a] | $\dot{S}p_i$ | Entropy transfer rate of of direct port $i$ | $kW/K$ | $\mathbb{R}\,(-\infty,\infty)$ |
| ⋮ | ⋮ | for i=1 i $\leq$ 10 i=i+1 | ⋮ | ⋮ |
| 50+i[a] | $\dot{\xi}p_i$ | Exergy transfer rate of first input | $kW$ | $\mathbb{R}\,(-\infty,\infty)$ |
| ⋮ | ⋮ | for i=1 i $\leq$ 10 i=i+1 | ⋮ | ⋮ |
| 61 | $Q_s$ | Total energy content of store (ref. temp. $= T_{ref}$ ) | $MJ$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 62 | $S_s$ | Total entropy content of store (ref. temp. $= T_{ref}$ ) | $MJ/K$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 63 | $\xi_s$ | Total exergy content of store (ref. temp. $= T_{ref}$ ) | $MJ$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 64 | $\dot{Q}_{imb}$ | Energy balance error of store for this time step ($Q_{imb} =$) | $kW$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 65 | $T_{s,av}$ | Average temperature of store | $^oC$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 66 | $N_{plug}$ | Number of temperature plugs in use at current time step | | $\mathbb{R}\,(-\infty,\infty)$ |
| 67 | $\Delta t_{diff}$ | Internal time step used for calculation of diffusion. **Not used** | $h$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 68 | $\dot{Q}_{loss}$ | Total heat gain/loss rate of store to ambient (positive values = losses) | $kW$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 69 | $\dot{S}_{loss}$ | Total entropy gain/loss rate of store to ambient (negative values = losses) | $kW/K$ | $\mathbb{R}\,(-\infty,\infty)$ |

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[a] i=1 to 10 which is the maximum number of direct ports

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| Nr. | Name | Description | Units | Type/Range |
|---|---|---|---|---|
| 70 | $\dot{\xi}_{loss}$ | Total exergy gain/loss rate of store to ambient (negative values = losses) | $kW$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 71+(k-1) [a] | $T_{sen,i}$ | Temperature of the freely positioned temperature sensors $i$ from $i = 1, 10$ (temp. at the end of the time step) | $^oC$ | $\mathbb{R}\,(-\infty,\infty)$ |
| ⋮ | ⋮ | for k=1 k $\leq$ 10 k=k+1 | ⋮ | ⋮ |
| 81 | $\dot{S}_{int}$ | Internal entropy generation rate of TES | $kW/K$ | $\mathbb{R}\,(0,\infty)$ |
| 82 | $\dot{S}_{mix,int}$ | Internal entropy generation rate of fully mixed reference TES | $kW/K$ | $\mathbb{R}\,(0,\infty)$ |
| 83 | $\dot{S}_{s}$ | Entropy change rate of TES | $kW/K$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 84 | $\dot{S}_{mix,s}$ | Entropy change rate of fully mixed reference TES | $kW/K$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 85 | $\dot{S}_{inp}$ | Entropy flow balance of TES inputs and outputs | $kW/K$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 86 | $\dot{S}_{inp,mix}$ | Entropy flow balance of fully mixed reference TES inputs and outputs | $kW/K$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 87 | $\dot{S}_{loss}$ | Entropy gain/loss rate of TES to ambient (negative values = losses) | $kW/K$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 88 | $\dot{S}_{mix,loss}$ | Entropy gain/loss rate of fully mixed reference TES to ambient (negative values = losses) | $kW/K$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 89 | $\dot{\xi}_{int}$ | Internal exergy loss rate of TES (negative values = losses) | $kW$ | $\mathbb{R}\,(-\infty,0)$ |
| 90 | $\dot{\xi}_{int,mix}$ | Internal exergy loss rate of fully mixed reference TES (negative values = losses) | $kW$ | $\mathbb{R}\,(-\infty,0)$ |
| 91+(j-1) [b] | $T_{Sav,i}$ | Temperature reading of the average temperature sensor $i$ | $^oC$ | $\mathbb{R}\,(-\infty,\infty)$ |
| ⋮ | ⋮ | for j=1 i $\leq$5 j=j+1 | ⋮ | ⋮ |
| 96+10(i-1)[c] | $lmtd$ | Logarithmic mean temperature difference of the HX $i$ | $^oC$ | $\mathbb{R}\,(0,\infty)$ |
| 97+10(i-1) | $U_A$ | Global heat transfer coefficient of the HX $i_{Hx}$ from | $kW/K$ | $\mathbb{R}\,(0,\infty)$ |
| 98+10(i-1) | $\epsilon$ | Efficiency ($\epsilon = T_{in} - T_{out}/(T_{in} - T_s)$)of the HX $i$ | % | $\mathbb{R}\,(0,\infty)$ |
| 99+10(i-1) | $\alpha_{in}$ | Inside heat transfer coefficient of the HX $i$ . Only valid if $mod_{hx,i} = 0$ | $kW/m^2K$ | $\mathbb{R}\,(0,\infty)$ |
| 100+10(i-1) | $\alpha_{wall}$ | Wall heat transfer coefficient of the HX $i$ . Only valid if $mod_{hx,i} = 0$ | $kW/m^2K$ | $\mathbb{R}\,(0,\infty)$ |
| 101+10(i-1) | $\alpha_{out}$ | Outside heat transfer coefficient of the HX $i$. Only valid if $mod_{hx,i} = 0$ | $kW/m^2K$ | $\mathbb{R}\,(0,\infty)$ |
| 102+10(i-1) | $T_{i,out}$ | Fluid Outlet temperature of the HX $i$ . | $^oC$ | $\mathbb{R}\,(0,\infty)$ |
| 103+10(i-1) | $T_{i,in}$ | Fluid inlet temperature of the HX $i$ . | $^oC$ | $\mathbb{R}\,(0,\infty)$ |

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[a] i=1 to 10 which is the maximum number of sensors
[b] j=1 to 5 which is the maximum number of reading sensors
[c] i=1 to 6 which is the maximum number of heat exchangers

| Nr. | Name | Description | Units | Type/Range |
|---|---|---|---|---|
| | | – continuation from previous page – | | |
| 104+10(i-1) | $\dot{Q}_{Hx,tnk}$ | Power provided to the store from the HX $i$ . | $kW$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 105+10(i-1) | $\dot{Q}_{Hx}$ | Fluid outlet power from the HX $i$ ($\dot{Q}_{Hx} = \dot{m}c_p(T_o - T_i)$). | $kW$ | $\mathbb{R}\,(-\infty,\infty)$ |
| ⋮ | ⋮ | for i=1 i ≤6 i=i+1 | ⋮ | ⋮ |
| 176 | $\dot{Q}_{hx}$ | Total heat provided by the Hx to the storage tank | $kW$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 177 | $\dot{Q}_{loss}$ | Total heat losses of the storage tank | $kW$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 178 | $\dot{Q}_{acum}$ | Total heat accumulated of the storage tank | $kW$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 179 | $\dot{Q}_{port}$ | Total power introduced in the storage from direct ports | $kW$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 180 | $\dot{Q}_{imb}$ | Energy balance error of store for this time step ($Q_{imb} = \dot{Q}_{hx} + \dot{Q}_{port} - \dot{Q}_{acum} - \dot{Q}_{loss}$) | $kW$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 181 | $\dot{Q}_{hsd}$ | Total power introduced in the storage from the heat source device | $kW$ | $\mathbb{R}\,(-\infty,\infty)$ |
| 182+(j-1) | $T_{hs,j}$ | Temperature of the storage at the heat source device j position | $^oC$ | $\mathbb{R}\,(-\infty,\infty)$ |
| ⋮ | ⋮ | for j=1 j ≤ 20 j=j+1 | ⋮ | ⋮ |

# Appendix A. Step by step model

The step-by-step model consists on a one-dimensional analysis in the fluid direction applying a finite control volume discretization technique. Energy balance takes into an account the thermal losses through the external surface and convective heat transfer with the neighboring steps. The heat axial conduction is neglected.

The discretized mesh is displaced for variables like $\dot{m}$, $T$ and $P$, but is centered for wall or external values.

Applying the mass conservation law in the whole domain, the mass flow rate at the outlet is directly obtained from the given mass flow rate at the inlet:

$$\dot{m}_{out} = \dot{m}_{in} \tag{A.1}$$

Under the above mentioned hypothesis, the energy conservation expression is discretized resulting in an algebraic equation in terms of temperature for a CV $i$ of the form:

$$\rho c_p V \frac{\overline{T} - \overline{T}^0}{\Delta t} + \dot{m} c_p (T_{i+1} - T_i) = -\dot{q}_e \tag{A.2}$$

where $\overline{T}$ represents the arithmetic average of the temperature and the superscript 0 refers to the value at previous time step. The subscripts $i$ and $i+1$ represents the value at the inlet and outlet of the CV $i$ respectively. In the present implementation, the net heat exchanged $q_e$ is calculated as:

$$\dot{q}_e = -\gamma \cdot h(\overline{T} - T_e) \tag{A.3}$$

where $h$ the heat transfer coefficient from the fluid to the exterior and $T_e$ is the exterior temperature.

The coefficients from the discretized algebraic equation in the form $a_p T_i = a_e T_{i+1} + a_w T_{i-1} + b$ are:

$$\begin{aligned} a_p &= \dot{m} c_p + \frac{\rho c_p V}{2\Delta T} \\ a_e &= 0 \\ a_w &= \dot{m} c_p - \frac{\rho c_p V}{2\Delta T} \\ b &= \frac{\rho c_p V}{2\Delta T} \overline{T_i^0} - \dot{q}_{loss,i} \end{aligned} \tag{A.4}$$

If we assume that $q_{loss} = U_A(0.5(T_i + Ti + 1) - T_{amb,i})$ then:

$$
\begin{aligned}
a_p &= \dot{m}c_p + \frac{0.5\rho c_p V}{\Delta T} + 0.5U_A \\
a_e &= 0 \\
a_w &= \dot{m}c_p - \frac{0.5\rho c_p V}{\Delta T} - 0.5U_A \\
b &= \frac{\rho c_p V}{\Delta T}\overline{T_i^0} + U_A T_{amb,i}
\end{aligned}
\tag{A.5}
$$

Algebraic equations resulting from the discretized energy and mass conservation laws shown above are solved following a step by step procedure (from the inlet to the outlet). The model needs no iterations if $\dot{q}_w$ or $h$ are known and the thermo-physical properties are calculated from conditions at the inlet of the CV. From the mass flow rate and temperature of the fluid at the inlet, and a proper boundary condition, the distribution of temperatures, mass flow rate (constant), and heat losses-gains throughout the physical domain are evaluated.