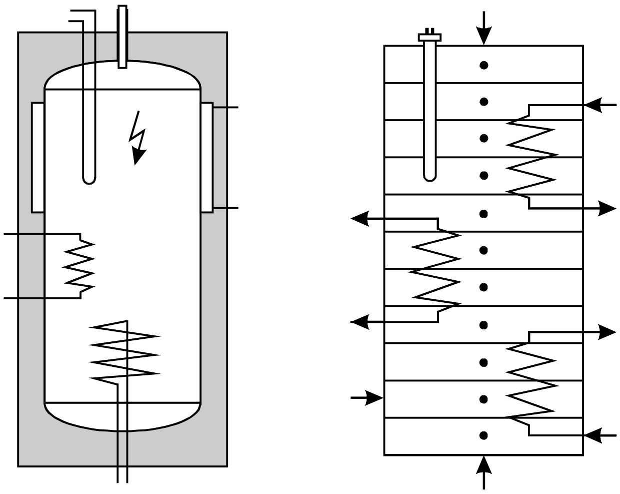
MULTIPORT Store - Model



for TRNSYS

Stratified fluid storage tank with
four internal heat exchangers,
ten connections for direct charge and discharge
and an internal electrical heater

Type 140

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1 Introduction

A short term thermal store is one of the key components of solar domestic hot water systems and systems for domestic hot water preparation and space heating, so-called combisystems.
Stores for this kind of application are often equipped with heat exchangers which are located inside the storage tank. Depending on the store concept, these heat exchangers can be used for both charging and discharging.
Charging the store with solar energy is typically performed by using a heat exchanger, since the working fluid of the collector loop is mostly not water but a mixture of water and anti-freeze.
Domestic hot water stores are mostly discharged in a direct way. Stores for combined domestic hot water preparation and space heating, so-called combistores, are often directly connected to the space heating circuit of the building. Hence, in this case the water of the space heating loop is used as storage medium. As a consequence, the domestic hot water has to be prepared via a heat exchanger.

As the hot water consumption cannot fully be covered by solar energy, an auxiliary heater is necessary. Auxiliary heating of the store can either be performed by an internal electrical heater or with hot water from the boiler of the space heating system. The energy of the boiler can be transferred to the store in a direct way or via a further heat exchanger.

Up to now many thermal solar systems of this type could not be implemented in TRNSYS, since no corresponding store model was available. We hope that the Type 140 will be useful for this purpose.

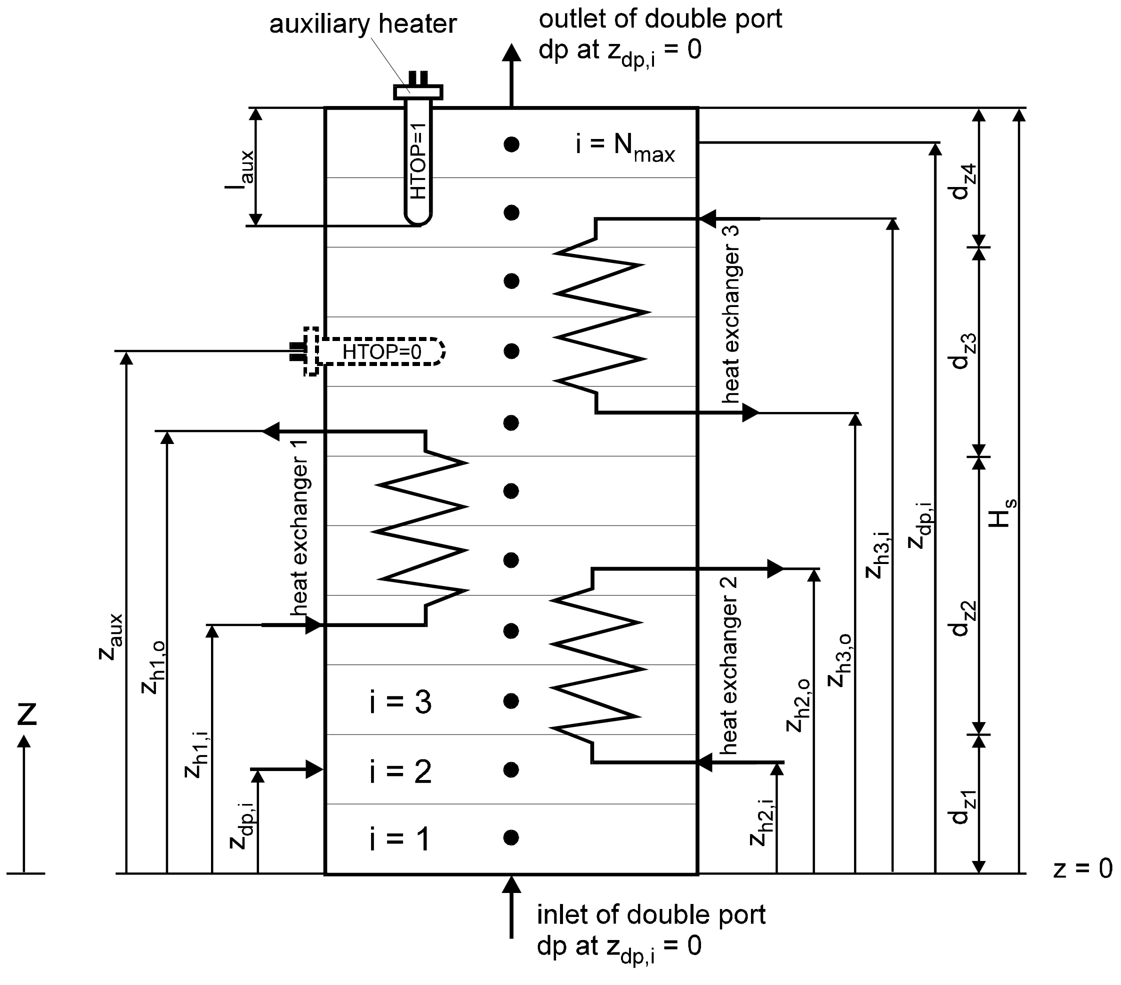
The present version of Type 140 models a stratified fluid storage tank with at most four heat exchangers, an internal electrical auxiliary heater and a maximum of ten times twice connections for direct charge and discharge.

The MULTIPORT store model is quite universal, so it should be possible to simulate nearly all kinds of stores used for solar thermal systems. For example small stores with a volume of about 0.1 m^3 and three or four heat exchangers, or large stores as directly charged and discharged buffer stores with a volume of about 10 m^3 and up to ten connections for direct charging and discharging.

This version of Type 140 is a further development of Type 74 (see /1/). The theory of this type is based on the 'MULTIPORT' store model, which is further developed from a '4PORT' store model, initially introduced by the European Solar Store Testing Group (SSTG see /2/).

2 General Description

As in the TRNSYS Type 4 thermal store model, the fluid in the store is assumed to consist of N_{max} completely mixed equal volume segments (nodes). The store can be charged and discharged directly by ten double ports. A double port is a pair of two pipes that belong to the same circuit (e.g. mains connection and hot water outlet or inlet and outlet of a direct charge loop). The four heat exchangers can be internal or mantle heat exchangers and they can be used to charge or discharge the store. The schematic of the Type 140 store model is shown in Fig.1.



p = number of a double port [1...10]

x = number of a heat exchanger [1...4]

d_{zk} = relative height of a zone with $(UA)_{s,ak}$ = const. [k=1...4]

Fig. 1: Schematic of the MULTIPORT store model

2.1 Basic Concepts

The vertical position (height) of each component of the store is indicated by numbers which are related to the absolute height of the store. How to work with relative store heights is shown by an **example:**

It is assumed that the height (H_s) of the store is 1.75 m and the auxiliary heater is installed 1.05 m above ground.

Hence the relative position (z_{aux}) where the auxiliary heater is installed (Parameter 40) gives:

$$z_{aux} = \frac{1.05\text{m}}{1.75\text{m}} = 0.6 \tag{2.1}$$

2.2 Heat loss to ambient

The heat loss capacity rate from the store to the ambient can be specified individual for the bottom and top of the store, and four zones of the store-mantle. The relative length of each zone is variable between 0 and 1, but the amount of the first three zones may not be bigger than 1. If it is less than 1, the difference between 1.0 and the amount equals the relative length of the fourth zone. The number of nodes must be equal or greater than the number of specified zones with different values of $(UA)_{s,ak}$.

The heat loss capacity rate of the first zone $(UA)_{s,a1}$ includes the entire surface area of the store, if only $(UA)_{s,a1}$ is specified and dz_1 = -1.

2.3 Charging and discharging with double ports

As already explained, a double port is a corresponding pair of an inlet and outlet connection for the direct charge and discharge of the store. It is assumed, that the mass of water in the store is constant, so that the mass flow rates in both connections (in and out of the store) are equal.

The inlet and outlet positions of each double port can be placed at any arbitrary height of the store. If the inlet is placed below the outlet, then the flow direction is upwards (positive). If the inlet is above the outlet, the flow direction is downwards (negative). Using a double port, stratified charging and discharging can be selected.

If a store is charged or discharged **stratified** by a double port, it is assumed that the water enters the store in that node, were the store temperature is equal to the temperature of the incoming water. This effect can be physically explained by the fact, that cold water has a higher density than hot water. So, if the store temperature at the inlet position is higher than the temperature of the water used for charging, in reality it is possible that the incoming water will sink down till it reaches a zone with the same temperature. This effect is called stratified charging or discharging respectively.

Note: For **stratified charging** as described here, it is necessary that the inlet position is above the outlet position! For **stratified discharging,** it is vice versa (outlet above inlet).

The counterpart of stratified charging is charging with fixed inlet positions. In that case the incoming water mixes directly with the water at the inlet position. If a store is not charged stratified by a double port, and if the inlet temperature of the fluid is less than the store temperature at the inlet position, the store will be cooled down in the area of the inlet position. As a consequence inversion layers are formed, which are later resolved by the natural mixing of the hot water layers.

If the store is charged or discharged directly, stratified charging can be selected for this double port in the TRNSYS deck of the Type 140.

2.4 Charging and discharging with heat exchangers

For charging and discharging a maximum of four heat exchangers can be implemented. In case that hx1 and hx4 are used, they can not be located in the same node (height); the same is relevant for hx2 and hx3.
This is not valid for the usage of hx1 and hx2, respectively hx1 and hx3.
The positions and flow directions of the heat exchangers are specified analogues to those of the double ports.

The heat capacity of the fluid in the heat exchangers is taken into account. If the volume of the heat exchanger is specified by a positive number, the heat capacity of the heat exchanger is added to the one of the store. Using this approach (positive volume) is recommended for ’typical’ immersed heat exchangers.
If the value of the hx volume is negative, the heat capacity of the heat exchanger is subtracted from the heat capacity of the tank. It is recommended to use this option for the modelling of ’Tank-in-Tank" stores.

The power through the heat exchangers ($\dot{Q}_{hx}$) and the power transferred between the heat exchangers and the store ($\dot{Q}_{hx,s}$) are available as outputs. For ordinary simulations $\dot{Q}_{hx}$ should be used.

2.4.1 Heat transfer capacity rate $(UA)^*_{hx}$

The heat transfer capacity rate $(UA)^*_{hx,s}$ between the heat exchangers and the store can be specified individually for each heat exchanger. The dependency of $(UA)^*_{hx,s}$ on the time, the temperature difference and mean temperature (between hx-inlet and store) as well as the mass flow through the heat exchanger can be taken into account. In this case $(UA)^*_{hx,s}$ is calculated individual for e*ach node (i) of the heat exchang*ers (x=1,2,3,4) by equation 2.2

$$\frac{(UA)^*_{hx,s}}{n_{hx}} = \frac{(UA)_{hx,s}}{n_{hx}} \cdot F_{hx} \cdot \dot{m}_{hx}^{b_{hx,1}} \cdot \left[\vartheta_{hx,in} - \vartheta_{s,i}\right]^{b_{hx,2}} \cdot \left[\frac{\vartheta_{hx,in} + \vartheta_{s,i}}{2}\right]^{b_{hx,3}} \qquad (2.2)$$

with: $(UA)_{hx,s}$ = capacity rate from the TRNSYS - Deck [kJ/(hK)]
n_{hx} = number of nodes occupied by heat exchanger x [-]
F_{hx} = factor for time dependency (calculated acc. to eqn. 2.3) [-]
$\dot{m}_{hx}$ = mass flow rate through the heat exchanger [kg/s]
$\vartheta_{hx,in}$ is the inlet temperature of the heat exchanger x [^{o}C]
$\vartheta_{s,i}$ is the temperature of the corresponding store tank node i [^{o}C]
$b_{hx,1}$, $b_{hx,2}$, $b_{hx,3}$ are the parameters specified in the TRNSYS-Deck

The accuracy of the temperature dependency of $(UA)^*_{hx,s}$ can be specified in the TRNSYS-Deck with Parameter 122. It is recommended to use 10 %.

Eqn. 2.2 is calculated in the subroutine UAHXS. If the use of a different equation is necessary, the source code of the subroutine UAHXS has to be changed.

If $b_{hx,1}$ and $b_{hx,2}$ and $b_{hx,3}$ are zero, then instead of $(UA)^*_{hx,s}$ the constant value $(UA)_{hx,s}$ is used over the entire heat exchanger.

2.4.1.1 Time dependency of $(UA)^*_{hx}$

The time dependency of the $(UA)^*_{hx}$ - value for immersed heat exchangers is caused by the inertia of the fluid inside the tank. Due to this, no natural convection appears shortly after starting the operation of the heat exchanger. The increase of natural convection with time results in an increasing $(UA)^*_{hx}$ - value. In order to take the time dependency of $(UA)^*_{hx}$ during the start-up period of the heat exchanger into account, the factor F_{hx} is used in eqn. (2.2).

The value of F_{hx} is calculated by equation 2.3:

$$F_{hx,t} = \frac{1}{S_{hx}} \cdot \int_{t=0}^{t=t-1} \dot{m}_{hx} \cdot (1 - F_{hx}) \cdot dt_{\mathrm{hx}} \qquad (2.3)$$

with: $\dot{m}_{hx}$ = mass flow rate through the heat exchanger [kg/h]
S_{hx} = factor characterising the start-up behaviour of the heat exchanger
t = 0 is the start time of heat exchanger operation [h]
t = -1 is the time step before t [h] and t is the current time [h]

After the operation of the heat exchanger has stopped, the time depending decrease of the $(UA)^*_{hx}$ is calculated respectively.

How to handle the time dependency of $(UA)^*_{hx}$?
Regarding to the solar loop heat exchanger, the transferred power is relatively low. Hence inertia will only have a minor influence and the time dependence of $(UA)^*_{hx}$ during the start-up of the heat exchanger can be neglected.
Contrary to the solar loop heat exchanger, immersed heat exchangers for discharge used in tap water systems to warm up the water during it passes the heat exchanger, usually transfer a high thermal power. In this case the impact of the start-up behaviour is important. In order to describe the time dependency of $(UA)^*_{hx}$ the factor S_{hx} characterising the start-up behaviour of the heat exchanger can be specified as an individual parameter for each heat exchanger. Typical values for S_{hx} are in the range of $0.01 < S_{hx} < 0.05$.

2.4.2 Mantle heat exchangers

If the heat loss capacity rate form the heat exchanger to the ambient $(UA)_{hx,a}$ is not equal zero, the heat exchanger is assumed to be a mantle heat exchanger. With this type of heat exchangers stratified charging is possible.
If the store is charged stratified by a heat exchanger, the fluid entering the hx with a temperature lower than the fluid in the store, it will sink down until it reaches an area with the same temperature or the outlet.
The advantage of stratified charging is, that the store is not cooled down if the inlet temperature in the hx is lower than the corresponding store temperature. Usually mantle heat exchangers are used for stratified charging.

2.4.3 Stratified charging/discharging via heat exchangers

Stratified charging/discharging via heat exchangers can be treated by the model in two ways:

1. Stratified charging where the heat transfer capacity rate of the heat exchanger directly depends on the part of the store that is charged in a stratified way. This behaviour is typically for mantle heat exchangers. This mode is selected if $sc_{hx} = 1$, represented by parameter 79 (or 92, 105 or 118 respectively). Parameter 80 (or 93, 106 or 119 respectively) is not used in this case.
   Mantle heat exchangers without stratified charging are modelled with sc_{hx}, = 0 (for mantle heat exchangers see also chapter 2.4.2)

2. Stratified charging/discharging via an immersed heat exchanger that is equipped with a certain kind of stratification device (e. g. a vertical pipe which can additionally have horizontal wholes equipped with flaps). In that case the flow through this pipe is strongly driven by natural convection due to density differences (caused by temperature differences) between the heat exchanger (outlet) and the store.

In order to model the thermal behaviour of such stores, a special mode for stratified charging/discharging can be activated if sc_{hx} = 2 or -2; sc_{hx} is represented by parameter 79 (or 92, 105 or 118 respectively) .

There are two modes how (stratified) charging is treated in this case:

sc_{hx}, = 2: Stratified charging is support. This is e. g. the case if there are horizontal outlets (wholes) in the vertical pipe.

sc_{hx}, = -2: Stratified charging is **not** actively support. This is e. g. the case if there are no horizontal outlets (wholes) in pipe. In this case the fluid is leaving the pipe only at the end.

The flow rate through the vertical convection pipe can be adjusted with the value used for sm_{hx} (heat exchanger x=1 ..3) represented by Parameter 80 (or 93, 106 or 119 respectively).

There are two modes to control this natural convection flow:

$sm_{hx} > 0$: The driving force for the natural convection flow is the difference between the density at the heat exchanger outlet and the **mean density of the water inside the store** (in the range of the heat exchanger).

$sm_{hx} < 0$: The driving force for the natural convection flow is the difference between the density at the heat exchanger outlet and the **density of the water inside the store at the height of the heat exchanger inlet.**

Note: In combination with each heat exchanger that is operated in the natural convection charging/discharging mode (sc_{hx} = 2 or sc_{hx} = -2), a double port is occupied virtually.

In the parameter list this virtual double port has to be indicated as not used (relative position of the inlet and outlet = -1) and no temperatures or mass flow rates shall be given as inputs to that double port. In the output list the temperature and the mass flow rate of this virtual double port are used. The **outlet temperature of the double port** represents the temperature of the fluid leaving the convection pipe and entering the storage tank. The **mass flow rate** is the one through the convection pipe (connective or secondary mass flow rate).

The interconnection between heat exchangers (hx) and double ports (dp) is a follows.

hx 1 ---> dp 7 hx 2 ---> dp 8 hx 3 ---> dp 9 hx 4 ---> dp 10

Note: If the heat exchangers are operated in the standard mode sc_{hx} = 0 or sc_{hx} = 1 (heat exchanger x = 1...4) represented by Parameter 79 (or 92, 105 or 118 respectively) it is not possible that heat exchanger 1 and heat exchanger 4 are located (partly) in the same horizontal positions. The same is relevant for heat exchanger 2 and heat exchanger 3.

2.5 Internal electrical auxiliary heater

There are two possible modes for the operation of the internal auxiliary heater. For HMOD=1 the heating power is variable and can be assigned by using Input No. 30. This is particularly useful for the simulation of store tests, since measured data for P_{aux} are available.

Selecting HMOD=2 means that the electrical heating is controlled by an internal thermostat. The heater is switched on if the temperature of the thermostat at its relative position (z_{taux}) is equal (or smaller) than the selected temperature T_{set} (Parameter 67).
Counterwise it is switched off if the temperature at the thermostat is equal (or greater) than ($T_{set} + \Delta T_{db}$), where ΔT_{db} represents the deadband temperature of the thermostat. Type 140 aims to control exactly at its threshold value. If this is not possible, the following warning will be displayed:

Warning in Type 140 at Time:#####.## Heat controller temperature out of limit: xx.xx!

If *xx.xx* amounts only a few degrees Kelvin, no serious mistake is made. To avoid the warning the difference between z_{aux} (Parameter 65) and z_{taux} (Parameter 66) must be enlarged.

2.6 Temperature sensors

Generally fluid temperatures at a specific height of the store are desired for means of control. Therefore up to five temperature sensors can be implemented and accessed at output channels 46 to 50. The relative position of these temperature sensors can be specified with parameter 57...61. Though the temperatures of all nodes (in the store) are available through the outputs 86...86+N_{max}, the usage of temperature sensors is recommended since no change of the configuration is necessary if N_{max} is altered.

Note: The values of the temperature sensors at the end of a TRNSYS time step are calculated as mean values of the temperatures (after mixing) at the end of each internal time step.

2.7 General remarks

After each time step the energy balance of the entire store is calculated. The difference in this balance is summed up (Qerrsum) and printed to the TRNSYS.LOG-file at the end of the simulation. A relative high value of Qerrsum indicates inaccurate results of the simulation.

The accuracy of the temperatures obtained by the iteration process can be specified at the TRNSYS-Deck by varying Parameter 121. The smallest value which yields convergence is depending, among other things, on the compiler used. For the Lahey Compiler the minimum of epstmp is 0.00001 K. Using higher values of epstmp reduces calculation time, on the other hand the relative error of the energy balance (Qerrsum) increases. Fixing the value of epstmp to 0.001 K might be a reasonable compromise when using TDTSC=0.

It is possible to use a temperature dependent timestep control (TDTSC) (Parameter 124). In this case all temperatures are first calculated with one large time step and then with two smaller time steps. The value of the time step is obtained by checking that the difference in temperatures (between the calculation using one large and two small time steps) is smaller than 10·esptmp for the store, and smaller than 100·esptmp for the heat exchangers. This is a very exact method of calculating temperatures, but if small TRNSYS time steps (e.g. 0.05 h) are used, computation time increases to about three times. The reason is, that all temperatures have to be calculated twice. First with a large time step, and than with two smaller ones.
The difference of the results either calculated with TDTSC=1 or TDTSC=0 is often not significant, so that it is usually sufficient to use TDTSC=0.

Since no inversion layers in the store are physically existent, a mixing routine is required. This results in so-called mixing errors, which mainly influence the energy transfer of the heat exchangers. The precision for the mixing process can be specified by parameter 123. A value in the range of 10 to 100 is suggested.
The theoretical background concerning the mixing process in the store and its mathematical description are large-scale and can be found in /1/ in further detail.

The MULTIPORT store model Type 140 chooses its own internal time step(s), depending on the operation conditions. The internal time steps are less or equal than the TRNSYS time step, so that the results delivered by this model are nearly independent to the size of the TRNSYS time step.

The differential equation system of the whole store model is solved within Type 140, without using the TRNSYS module DIFFEQ. Therefore the specification of derivatives is not necessary.

Evaluating N_{max}:

The degree of stratification in the store is defined by the number of nodes N_{max}.

Three methods are given to find N_{max} (Parameter 125):

- Comparison of the measured outlet temperature of a full store which is directly discharged to several transient values of the outlet temperature using simulations with different numbers of N_{max}.
- Comparison of the measured and with different N_{max} obtained simulated values of power ($\dot{Q}_{dp}$, $\dot{Q}_{hx}$) or daily energy throughputs (parameter identification). This is the most accurate method, however the thermal behaviour of the store must be measured and recorded for several days.
- The third method to obtain N_{max} is an estimation. For a fully mixed store N_{max} = 1 must be selected. For fairly good stratified stores, which are commonly used for solar hot water systems, a value of N_{max} = 30 to 1000 is realistic.

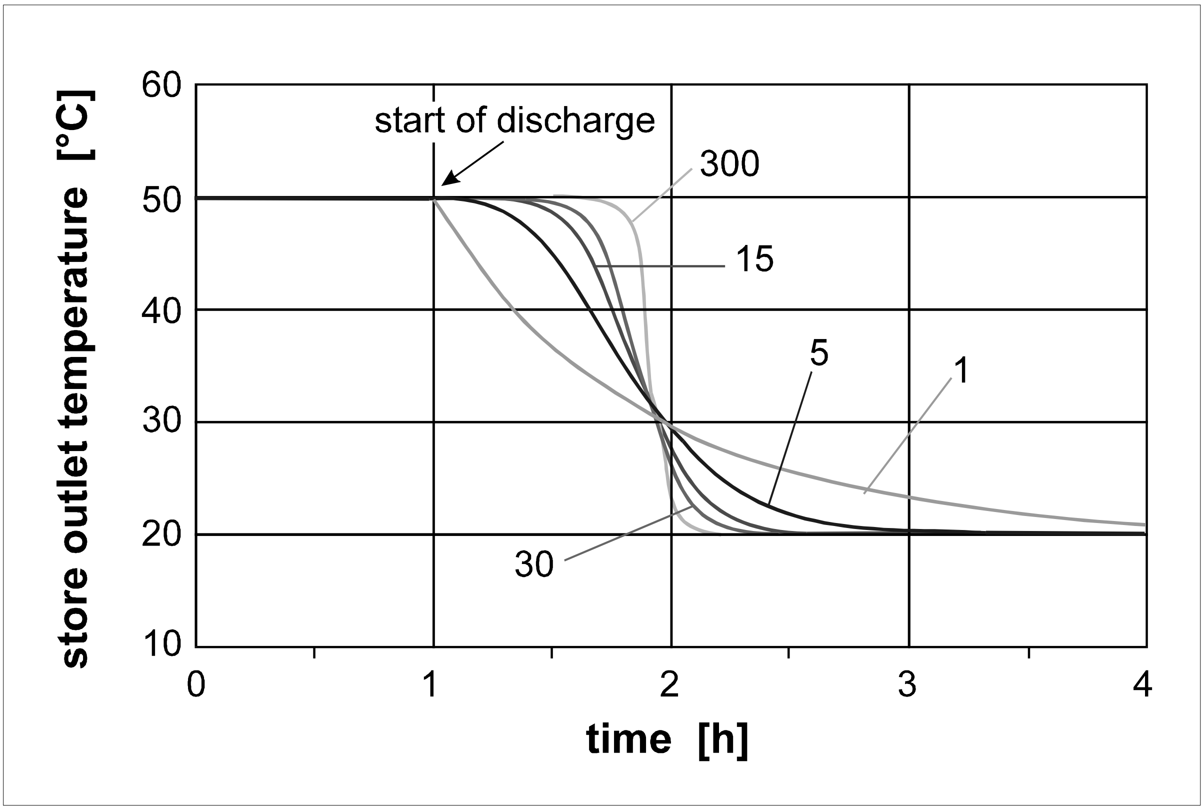


Fig. 2: Outlet temperature at the top of the store calculated with different values of N_{max}

2.8 Parameter identification using MULTIPORT

The results calculated by a numerical model during a dynamic simulation depend on the model itself, the input quantities fed into the model and the parameters used for the calculation. One way of determining certain parameters for the model is the numerical method of parameter identification. However, this requires appropriate measured data of the component. A test procedures for stores of solar domestic hot water systems, which is based on parameter identification, is described in /3/ and in /4/.

In order to describe a typical solar domestic hot water store as used in a single family house, the range of the parameter values of Type 140 varies e.g. from 0.3 (store volume in litres) to 1500 (heat transfer rate of the solar loop heat exchanger in kJ/(hK)). For some parameter identification programs, as e.g. DF /6/, this may cause problems because the different values of the parameters being identified, should be in the same range. Hence Type 140 provides an option to solve this problem:

If parameter 126 is set to ’-7’ Type 140 operates in the ’fitting mode’.

In the fitting mode the values, respectively units, of the following parameters are changed:

Par. 74: The heat transfer capacity rate of the first heat exchanger is changed to [MJ/(h K)]

Par. 87: The heat transfer capacity rate of second heat exchanger is changed to [MJ/(h K)]

Par. 100: The heat transfer capacity rate of third heat exchanger is changed to [MJ/(h K)]

Par. 113: The heat transfer capacity rate of fourth heat exchanger is changed to [MJ/(h K)]

Par. 125: The number of nodes in the store is multiplied by 10000.
E. g.: If 100 nodes are usually used, Parameter 125 has to be 0.003 if Type 140 is operating in fitting mode.

3 Nomenclature

Symbol	Quantity	Unit
A_q	horizontal cross-section of the store (tank)	[m²]
$\dot{m}_{dp}$	mass flow rate through the double port p (p=1...10)	[kg/h]
nhx	number of nodes occupied by heat exchanger x (x=1...4)	[-]
ndzk	number of nodes in zone k with $(UA)_{s,ak}$ = const. (k=1...4)	[-]
$(UA)_{hx,s}$	constant heat transfer capacity rate between heat exchanger x and the store	[kJ/(hK)]
$(UA)^{*}_{hx,s}$	temperature-difference and mass flow dependent heat transfer capacity rate between heat exchanger x and the store	[kJ/(hK)]
ξ	logical switch	[-]

General

k	number of a zone with $(UA)_{s,ak}$ = const.	[1...4]
p	number of a double port	[1...10]
x	number of a heat exchanger	[1...4]

Note: *Power into the store counts positive, out of the store negative!*

All other nomenclature is explained in the Component Configuration of Type 140!!

4 Mathematical description

All temperatures are calculated by solving a set of differential equations. All necessary data are therefore stored in an array of N_{max} x 3 as shown in the theoretical store model in Fig. 3. The first column (j=1) includes the data of the first and fourth heat exchanger, the second (j=2) the data of the store (tank) and the last one (j=3) the data of the second and third heat exchanger.
Up to ten different mass flow rates ($\dot{m}_{dp}$) through the ten double ports can occur in one segment of the store (node). Therefore eqn. (4.1) includes the sum over all ($\dot{m}_{dp} \cdot c_{p,s} \cdot \Delta\vartheta$). A mass- flow from the bottom to the top counts positive, and vice versa negative.

The energy balance for each node (i) of the **store** (j=2) is represented by equation 4.1 using the logical switches ξ_i:

$$
\begin{aligned}
\frac{V_s \cdot \rho_s \cdot c_{p,s}}{N_{\max}} \cdot \frac{\partial \vartheta_{i,2}}{\partial t} = & \sum_{p=1}^{10} \dot{m}_{dp} \cdot c_{p,s} \cdot \left[\xi_1 \cdot \left(\vartheta_{i-1,2} - \vartheta_{i,2} \right) + \xi_2 \cdot \left(\vartheta_{i,2} - \vartheta_{i+1,2} \right) \right] \\
& + \xi_3 \cdot \frac{(UA)^*_{h1/4,s}}{n_{h1/4}} \cdot \left(\vartheta_{i,1} - \vartheta_{i,2} \right) + \xi_4 \cdot \frac{(UA)^*_{h2/3,s}}{n_{h2/3}} \cdot \left(\vartheta_{i,3} - \vartheta_{i,2} \right) \\
& + \lambda_{con} \cdot \frac{A_q}{H_s} \cdot N_{\max} \cdot \left[\left(\vartheta_{i+1,2} - \vartheta_{i,2} \right) + \left(\vartheta_{i-1,2} - \vartheta_{i,2} \right) \right] \\
& - \frac{(UA)_{s,ak}}{ndzk} \cdot \left(\vartheta_{i,2} - \vartheta_{amb} \right)
\end{aligned}
\qquad (4.1)
$$

with: $(UA)^*_{h1/4,s}$ = heat transfer capacity rate between the heat exchanger 1 and heat exchanger 4 and the store [kJ/(h K)]

nh1/4 = number of nodes occupied by heat exchanger 1 and 4 [-]

$(UA)^*_{h2/3,s}$ = heat transfer capacity rate between the hx 2/3 and the store [kJ/(h K)]

nh2/4 = number of nodes occupied by heat exchanger 2 and 3 [-]

$\xi_1 = 1$ if $\dot{m}_{dp} > 0$, else $\xi_1 = 0$

$\xi_2 = 1$ if $\dot{m}_{dp} < 0$, else $\xi_2 = 0$

$\xi_3 = 1$ if the store node i is in contact with the node i of heat exchanger 1 or 4, else $\xi_3 = 0$

$\xi_4 = 1$ if the store node i is in contact with the node i of heat exchanger 2 or 3, else $\xi_4 = 0$

λ_{con} effective thermal conductivity in the store [kJ/(m h K)]

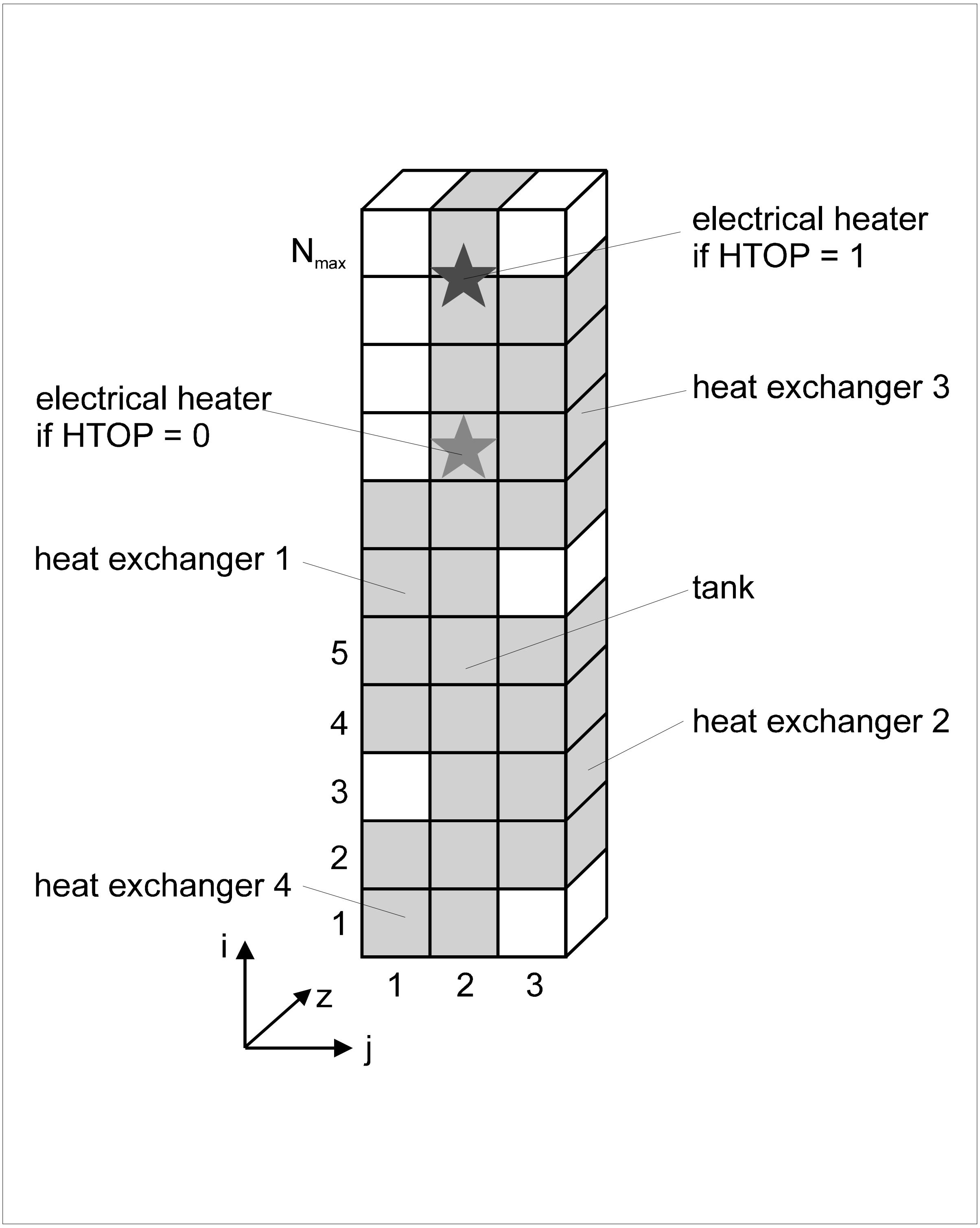


Fig. 3: Theoretical MULTIPORT store model

The left hand side of eqn. 4.1 describes the change of internal energy in a node with the time. The heat transfer caused by mass flows is represented by the first sum on the right hand side. The heat transfer between the heat exchanger nodes and a store node is described with the second and third term. The fourth term describes the conductivity between the layers in the store (tank) and the last one the heat loss to the surroundings.

The energy balance for a **heat exchanger** node is given by eqn. (4.2). For the first heat exchanger (x=1) or fourth (x=4) and j=1. For the second (x=2) or third (x=3) heat exchanger j = 3.

with: $\xi_5 = 1$ if $\dot{m}_{hx} > 0$, else $\xi_5 = 0$

$$\frac{V_{hx} \cdot \rho_{hx} \cdot c_{p,hx}}{n_{hx}} \cdot \frac{\partial \vartheta_{i,j}}{\partial t} = \xi_5 \cdot \dot{m}_{hx} \cdot c_{p,hx} \cdot \left(\vartheta_{i-1,j} - \vartheta_{i,j}\right) + \xi_6 \cdot \dot{m}_{hx} \cdot c_{p,hx} \cdot \left(\vartheta_{i,j} - \vartheta_{i+1,j}\right)$$
$$\frac{(UA)^{*}_{hx,s}}{n_{hx}} \cdot \left(\vartheta_{i,2} - \vartheta_{i,j}\right) - \frac{(UA)_{hx,a}}{n_{hx}} \cdot \left(\vartheta_{i,j} - \vartheta_{amb}\right) \tag{4.2}$$

$\xi_6 = 1$ if ${}_{hx} < 0$, else $\xi_6 = 0$

For j=1 or j=3 and node i+1 or i-1 contains no heat exchanger node, the temperatures $\vartheta_{i+1,j}$ or $\vartheta_{i-1,j}$ represent the inlet and outlet temperature of the heat exchanger.
Note that $(UA)_{hx,a} = 0$ is only valid for mantle heat exchangers, since in that case the heat loss from the tank to the surroundings passes the heat exchanger. For $(UA)_{hx,a} \neq 0$ the user should concern about $(UA)_{s,ak}$ in the area of the mantle heat exchanger. General $(UA)_{hx,a}= 0$, but if a mantle heat exchanger is in the area of the bottom or top, values of $(UA)_{hx,a} \neq 0$ are reasonable.

The stratified charging or discharging as described in 2.2 and 2.3 is modelled in Type 140 by connecting the real physical inlet positions to the nodes with the corresponding temperatures.

5 Component Configuration TYPE 140

Parameters

No.	**Parameters**	Description	Unit
1	H_s	store height	[m]
2	V_s	store volume	[m^3]
3	$c_{p,s}$	specific heat capacity of the fluid in the store	[kJ/kgK]
4	ρ_s	density of the fluid in the store	[kg/m^3]
5	λ_{con}	effective vertical thermal conductivity in the store	[kJ/mhK]
6	-	not used	[-]
7	T_{ini}	initial temperature of the whole store	[^{o}C]
	heat loss capacity rate from store to ambient		
8	$(UA)_{s,bot}$	heat loss capacity rate through bottom of the store	[kJ/hK]
9	$(UA)_{s,top}$	heat loss capacity rate through the top of the store	[kJ/hK]
10	dz_1	dz1>0: relative length of first zone with $(UA)_{s,a1}$ dz1<0 and (P8,9,12..16)=0: $(UA)_{s,a1}$ is used for the whole store	[-]
11	$(UA)_{s,a1}$	heat loss capacity rate of the store through the first zone (dz_1) of the store mantle	[kJ/hK]
12	dz_2	relative length of the second zone with $(UA)_{s,a2}$	[-]
13	$(UA)_{s,a2}$	heat loss capacity rate of the store through the second zone (dz_2) of the store mantle	[kJ/hK]
14	dz_3	relative length of the third zone with $(UA)_{s,a3}$	[-]
15	$(UA)_{s,a3}$	heat loss capacity rate of the store through the third zone (dz_3) of the store mantle	[kJ/hK]
16	$(UA)_{s,a4}$	heat loss capacity rate from the store to ambient through the zone of the store-mantle with the relative length $dz_4 = 1-dz_1-dz-_2-dz_3$	[kJ/hK]
	double ports		
17	$z_{d1,i}$	rel. height of inlet position from double port 1	[-]
18	$z_{d1,o}$	rel. height of outlet position from double port 1 (no double port if $z_{dx,i}$ or $z_{dx,o}$ are negative)	[-]
19	d_{d1}	additional parameter for double port 1 (not used)	[-]
20	sc_{d1}	sc_{d1} = 1 for stratified charging with double port 1	[-]
21	$z_{d2,i}$	rel. height of inlet position from double port 2	[-]
22	$z_{d2,o}$	rel. height of outlet position from double port 2	[-]
23	d_{d2}	additional parameter for double port 2 (not used)	[-]

24	sc_{d2}	sc_{d2} = 1 for stratified charging with double port 2	[-]
25	$z_{d3,i}$	rel. height of inlet position from double port 3	[-]
26	$z_{d3,o}$	rel. height of outlet position from double port 3	[-]
27	d_{d3}	additional parameter for double port 3 (not used)	[-]
28	sc_{d3}	sc_{d3} = 1 for stratified charging with double port 3	[-]
29	$z_{d4,i}$	rel. height of inlet position from double port 4	[-]
30	$z_{d4,o}$	rel. height of outlet position from double port 4	[-]
31	d_{d4}	additional parameter for double port 4 (not used)	[-]
32	sc_{d4}	sc_{d4} = 1 for stratified charging with double port 4	[-]
33	$z_{d5,i}$	rel. height of inlet position from double port 5	[-]
34	$z_{d5,o}$	rel. height of outlet position from double port	[-]
35	d_{d5}	additional parameter for double port 5 (not used)	[-]
36	sc_{d5}	sc_{d5} = 1 for stratified charging with double port 5	[-]
37	$z_{d6,i}$	relative height of inlet position from double port 6	[-]
38	$z_{d6,o}$	relative height of outlet position from double port 6	[-]
39	d_{d6}	additional parameter for double port 6 (not used)	[-]
40	sc_{d6}	sc_{d6} = 1 for stratified charging with double port 6	[-]
41	$z_{d7,i}$	relative height of inlet position from double port 7	[-]
42	$z_{d7,o}$	relative height of outlet position from double port 7	[-]
43	d_{d7}	additional parameter for double port 7 (not used)	[-]
44	sc_{d7}	sc_{d7} = 1 for stratified charging with double port 7	[-]
45	$z_{d8,i}$	relative height of inlet position from double port 8	[-]
46	$z_{d8,o}$	relative height of outlet position from double port 8	[-]
47	d_{d8}	additional parameter for double port 8 (not used)	[-]
48	sc_{d8}	sc_{d8} = 1 for stratified charging with double port 8	[-]
49	$z_{d9,i}$	relative height of inlet position from double port 9	[-]
50	$z_{d9,o}$	relative height of outlet position from double port 9	[-]
51	d_{d9}	additional parameter for double port 9 (not used)	[-]
52	sc_{d9}	sc_{d9} = 1 for stratified charging with double port 9	[-]
53	$z_{d10,i}$	relative height of inlet position from double port 10	[-]
54	$z_{d10,o}$	relative height of outlet position from double port 10	[-]
55	d_{d10}	additional parameter for double port 10 (not used)	[-]
56	sc_{d10}	sc_{d10} = 1 for stratified charging with double port 10	[-]

temperature sensors

57	z_{s1}	relative position of temperature sensor 1 {0,1}	[-]
58	z_{s2}	relative position of temperature sensor 2 {0,1}	[-]
59	z_{s3}	relative position of temperature sensor 3 {0,1}	[-]
60	z_{s4}	relative position of temperature sensor 4 {0,1}	[-]
61	z_{s5}	relative position of temperature sensor 5 {0,1}	[-]

	auxiliary heater		
62	HMOD	Auxiliary heater mode: 0...none (then P38-P43 not used) 1...P_{aux} variable 2...P_{aux} constant	[-]
63	HTOP	HTOP=1 if the auxiliary heater is installed from the top, (else installed from the side)	[-]
64	l_{aux}	absolute length of auxiliary heater (only if HTOP=1)	[m]
65	z_{aux}	relative position where the auxiliary heater is installed (only if HTOP $\neq$ 1)	[-]
66	z_{taux}	relative position of the temperature controller for the auxiliary heater (only if HMOD = 2)	[-]
67	T_{set}	set temperature of the controller for the aux. Heater (only if HMOD = 2)	[^oC]
68	ΔT_{db}	dead band temperature difference of the controller (only if HMOD = 2)	[K]
	first heat exchanger		
69	$z_{h1,i}$	rel. inlet position of the first heat exchanger {0,1}	[-]
70	$z_{h1,o}$	rel. outlet position of the first heat exchanger {0,1} (no heat exchanger if $z_{hx,i}$ or $z_{hx,o}$ are negative)	[-]
71	V_{h1}	volume of the first heat exchanger	[m³]
72	$c_{p,h1}$	specific heat capacity of the fluid in the first heat ex.	[kJ/kgK]
73	ρ_{h1}	density of the fluid in the first heat exchanger	[kg/m³]
74	$(UA)_{h1,s}$	heat transfer capacity rate from the first heat exchanger to the store	[kJ/hK]
75,76,77	$b_{h1,i}$	parameters for the calculation of $(UA)^*_{h1,s}$ = function($(UA)_{h1,s}$, $\dot{m}_{h1}$, $\vartheta_{s,i}$, $\vartheta_{h1,i}$)	[-]
78	$(UA)_{h1,a}$	heat loss capacity rate from the first heat exchanger to ambient	[kJ/hK]
79	sc_{h1}	stratified charging with first hx if sc_{h1}= 1 or sc_{h1}= 2	[-]
80	sm_{h1}	factor for secondary mass flow rate (only if sc_{h1}=2)	[-]
81	S_{h1}	factor for time dependency of $(UA)_{h1,s}$	[-]
	second heat exchanger		
82	$z_{h2,i}$	rel. inlet position of the second heat exchanger {0,1}	[-]
83	$z_{h2,o}$	rel. outlet position of the second heat exchanger {0,1}	[-]
84	V_{h2}	volume of the second heat exchanger	[m³]
85	$c_{p,h2}$	specific heat capacity of the fluid in the second heat exchanger	[kJ/kgK]
86	ρ_{h2}	density of the fluid in the second heat exchanger	[kg/m³]

87	$(UA)_{h2,s}$	heat transfer capacity rate from the second heat exchanger to the store	[kJ/hK]
88,89,90	$b_{h2,i}$	parameters for the calculation of $(UA)^*_{h2,s} = \text{function}((UA)_{h2,s}, \dot{m}_{h2}, \vartheta_{s,i}, \vartheta_{h2,i})$	[-]
91	$(UA)_{h2,a}$	heat loss capacity rate from the second heat exchanger to ambient	[kJ/hK]
92	sc_{h2}	stratified charging with second hx if sc_{h2}= 1 or sc_{h2}= 2	[-]
93	sm_{h2}	factor for secondary mass flow rate (only if sc_{h2}=2)	[-]
94	S_{h2}	factor for time dependency of $(UA)_{h2,s}$	[-]
	third heat exchanger		
95	$z_{h3,i}$	rel. inlet position of the third heat exchanger {0,1}	[-]
96	$z_{h3,o}$	rel. outlet position of the third heat exchanger {0,1}	[-]
97	V_{h3}	volume of the third heat exchanger	[m^3]
98	$c_{p,h3}$	specific heat capacity of the fluid in the third heat ex.	[kJ/kgK]
99	ρ_{h3}	density of the fluid in the third heat exchanger	[kg/m^3]
100	$(UA)_{h3,s}$	heat transfer capacity rate from the third heat exchanger to the store	[kJ/hK]
101,102, 103	$b_{h3,i}$	parameters for the calculation of $(UA)^*_{h3,s} = \text{function}((UA)_{h3,s}, \dot{m}_{h3}, \vartheta_{s,i}, \vartheta_{h3,i})$	[-]
104	$(UA)_{h3,a}$	heat loss capacity rate from the third heat exchanger to ambient	[kJ/hK]
105	sc_{h3}	stratified charging with third hx if sc_{h3}= 1 or sc_{h3}= 2	[-]
106	sm_{h3}	factor for secondary mass flow rate (only if sc_{h3}=2)	[-]
107	S_{h3}	factor for time dependency of $(UA)_{h3,s}$	[-]
	fourth heat exchanger		
108	$z_{h4,i}$	rel. inlet position of the fourth heat exchanger {0,1}	[-]
109	$z_{h4,o}$	rel. outlet position of the fourth heat exchanger {0,1}	[-]
110	V_{h4}	volume of the fourth heat exchanger	[m^3]
111	$c_{p,h4}$	specific heat capacity of the fluid in the fourth heat ex.	[kJ/kgK]
112	ρ_{h4}	density of the fluid in the fourth heat exchanger	[kg/m^3]
113	$(UA)_{h4,s}$	heat transfer capacity rate from the fourth heat exchanger to the store	[kJ/hK]
114,115, 116	$b_{h4,i}$	parameters for the calculation of $(UA)^*_{h4,s} = \text{function}((UA)_{h4,s}, \dot{m}_{h4}, \vartheta_{s,i}, \vartheta_{h4,i})$	[-]
117	$(UA)_{h4,a}$	heat loss capacity rate from the fourth heat exchanger to ambient	[kJ/hK]
118	sc_{h4}	stratified charging with fourth hx if sc_{h4}= 1 or sc_{h4}= 2	[-]
119	sm_{h4}	factor for secondary mass flow rate (only if sc_{h4}=2)	[-]
120	S_{h4}	factor for time dependency of $(UA)_{h4,s}$	[-]

	general		
121	epstmp	accuracy for calculating the temperatures	[K]
122	epsua	accuracy for temperature-dependence of $(UA)^*_{hx,s}$	[%]
123	epsmix	precision of the mixing process in the store	[-]
124	TDTSC	flag if temperature-dependence time step control is used (1...yes)	[-]
125	N_{max}	number of nodes for the store ($N_{max} < 200$)	[-]
126	ver	emulation of former versions (number of version) latest: ’ver’ = 0 or ’ver’ = -7; fitting mode if ’ver’ is negative	[-]

Inputs

No.	Inputs	Description	Unit
1	$T_{d1,i}$	inlet temperature of double port 1	[^{o}C]
2	$\dot{m}_{d1}$	mass flow rate of double port 1	[kg/h]
3	$T_{d2,i}$	inlet temperature of double port 2	[^{o}C]
4	$\dot{m}_{d2}$	mass flow rate of double port 2	[kg/h]
5	$T_{d3,i}$	inlet temperature of double port 3	[^{o}C]
6	$\dot{m}_{d3}$	mass flow rate of double port 3	[kg/h]
7	$T_{d4,i}$	inlet temperature of double port 4	[^{o}C]
8	$\dot{m}_{d4}$	mass flow rate of double port 4	[kg/h]
9	$T_{d5,i}$	inlet temperature of double port 5	[^{o}C]
10	$\dot{m}_{d5}$	mass flow rate of double port 5	[kg/h]
11	$T_{d6,i}$	inlet temperature of double port 6	[^{o}C]
12	$\dot{m}_{d6}$	mass flow rate of double port 6	[kg/h]
13	$T_{d7,i}$	inlet temperature of double port 7	[^{o}C]
14	$\dot{m}_{d7}$	mass flow rate of double port 7	[kg/h]
15	$T_{d8,i}$	inlet temperature of double port 8	[^{o}C]
16	$\dot{m}_{d8}$	mass flow rate of double port 8	[kg/h]
17	$T_{d9,i}$	inlet temperature of double port 9	[^{o}C]
18	$\dot{m}_{d9}$	mass flow rate of double port 9	[kg/h]
19	$T_{d10,i}$	inlet temperature of double port 10	[^{o}C]
20	$\dot{m}_{d10}$	mass flow rate of double port 10	[kg/h]
21	$T_{h1,i}$	inlet temperature of the first heat exchanger	[^{o}C]
22	$\dot{m}_{h1}$	mass flow rate of the first heat exchanger	[kg/h]
23	$T_{h2,i}$	inlet temperature of the second heat exchanger	[^{o}C]
24	$\dot{m}_{h2}$	mass flow rate of the second heat exchanger	[kg/h]
25	$T_{h3,i}$	inlet temperature of the third heat exchanger	[^{o}C]
26	$\dot{m}_{h3}$	mass flow rate of the third heat exchanger	[kg/h]
27	$T_{h4,i}$	inlet temperature of the fourth heat exchanger	[^{o}C]
28	$\dot{m}_{h4}$	mass flow rate of the fourth heat exchanger	[kg/h]
29	T_{amb}	ambient temperature	[^{o}C]
30	P_{aux}	auxiliary heater input	[kJ/h]

Outputs

No.	Outputs	Description	Unit
1	$T_{d1,o}$	outlet temperature of double port 1	[^{o}C]
2	$\dot{m}_{d1}$	mass flow rate of double port 1	[kg/h]
3	$T_{d2,o}$	outlet temperature of double port 2	[^{o}C]
4	$\dot{m}_{d2}$	mass flow rate of double port 2	[kg/h]
5	$T_{d3,o}$	outlet temperature of double port 3	[^{o}C]
6	$\dot{m}_{d3}$	mass flow rate of double port 3	[kg/h]
7	$T_{d4,o}$	outlet temperature of double port 4	[^{o}C]
8	$\dot{m}_{d4}$	mass flow rate of double port 4	[kg/h]
9	$T_{d5,o}$	outlet temperature of double port 5	[^{o}C]
10	$\dot{m}_{d5}$	mass flow rate of double port 5	[kg/h]
11	$T_{d6,o}$	outlet temperature of double port 6	[^{o}C]
12	$\dot{m}_{d6}$	mass flow rate of double port 6	[kg/h]
13	$T_{d7,o}$	outlet temperature of double port 7	[^{o}C]
14	$\dot{m}_{d7}$	mass flow rate of double port 7	[kg/h]
15	$T_{d8,o}$	outlet temperature of double port 8	[^{o}C]
16	$\dot{m}_{d8}$	mass flow rate of double port 8	[kg/h]
17	$T_{d9,o}$	outlet temperature of double port 9	[^{o}C]
18	$\dot{m}_{d9}$	mass flow rate of double port 9	[kg/h]
19	$T_{d10,o}$	outlet temperature of double port 10	[^{o}C]
20	$\dot{m}_{d10}$	mass flow rate of double port 10	[kg/h]
21	$T_{h1,o}$	outlet temperature of the first heat exchanger	[^{o}C]
22	$\dot{m}_{h1}$	mass flow rate of the first heat exchanger	[kg/h]
23	$T_{h2,o}$	outlet temperature of the second heat exchanger	[^{o}C]
24	$\dot{m}_{h2}$	mass flow rate of the second heat exchanger	[kg/h]
25	$T_{h3,o}$	outlet temperature of the third heat exchanger	[^{o}C]
26	$\dot{m}_{h3}$	mass flow rate of the third heat exchanger	[kg/h]
27	$T_{h4,o}$	outlet temperature of the fourth heat exchanger	[^{o}C]
28	$\dot{m}_{h4}$	mass flow rate of the fourth heat exchanger	[kg/h]
29	$\dot{Q}_{l,s}$	heat loss rate of the whole store to ambient	[kJ/h]
30	$\dot{Q}_{l,bot}$	heat loss rate of the store-bottom to ambient	[kJ/h]
31	$\dot{Q}_{l,top}$	heat loss rate of the store-top to ambient	[kJ/h]
32	$\dot{Q}_{l,s1}$	heat loss rate of the store-zone dz_1 to ambient	[kJ/h]

33	$\dot{Q}_{l,s2}$	heat loss rate of the store-zone dz_2 to ambient	[kJ/h]
34	$\dot{Q}_{l,s3}$	heat loss rate of the store-zone dz_3 to ambient	[kJ/h]
35	$\dot{Q}_{l,s4}$	heat loss rate of the store-zone dz_4 to ambient	[kJ/h]
36	$\dot{Q}_{d1}$	power through double port 1	[kJ/h]
37	$\dot{Q}_{d2}$	power through double port 2	[kJ/h]
38	$\dot{Q}_{d3}$	power through double port 3	[kJ/h]
39	$\dot{Q}_{d4}$	power through double port 4	[kJ/h]
40	$\dot{Q}_{d5}$	power through double port 5	[kJ/h]
41	$\dot{Q}_{d6}$	power through double port 6	[kJ/h]
42	$\dot{Q}_{d7}$	power through double port 7	[kJ/h]
43	$\dot{Q}_{d8}$	power through double port 8	[kJ/h]
44	$\dot{Q}_{d9}$	power through double port 9	[kJ/h]
45	$\dot{Q}_{d10}$	power through double port 10	[kJ/h]
46	T_{s1}	temperature at sensor 1	[^{o}C]
47	T_{s2}	temperature at sensor 2	[^{o}C]
48	T_{s3}	temperature at sensor 3	[^{o}C]
49	T_{s4}	temperature at sensor 4	[^{o}C]
50	T_{s5}	temperature at sensor 5	[^{o}C]
51	T_{aux}	temp. at the controller position for the aux. heater	[^{o}C]
52	$\dot{Q}_{aux}$	power supplied by the auxiliary heater	[kJ/h]
53	$\dot{Q}_{h1}$	power through the first heat exchanger	[kJ/h]
54	$\dot{Q}_{h1,s}$	power transferred between the first hx and the store	[kJ/h]
55	ΔU_{h1}	internal energy change of the first heat exchanger	[kJ]
56	Ex_{h1}	exergy stored in the first heat exchanger	[kJ]
57	$\dot{Q}_{l,h1}$	heat loss rate of the first heat exchanger to ambient (only if it is a mantle heat exchanger)	[kJ/h]
58	$T_{h1,m}$	mean temperature of the first heat exchanger	[^{o}C]
59	-	not used	[-]
60	$\dot{Q}_{h2}$	power through the second heat exchanger	[kJ/h]
61	$\dot{Q}_{h2,s}$	power transferred between second hx and the store	[kJ/h]
62	ΔU_{h2}	internal energy change of the second heat exchanger	[kJ]
63	Ex_{h2}	exergy stored in the second heat exchanger	[kJ]
64	$\dot{Q}_{L,h2}$	heat loss rate of the second heat exchanger to ambient (only if it is a mantle heat exchanger)	[kJ/h]
65	$T_{h2,m}$	mean temperature of the second heat exchanger	[^{o}C]
66	-	not used	[-]
67	$\dot{Q}_{h3}$	power through the third heat exchanger	[kJ/h]

68	$\dot{Q}_{h3,s}$	power transferred between the third hx and the store	[kJ/h]
69	ΔU_{h3}	internal energy change of the third heat exchanger	[kJ]
70	Ex_{h3}	exergy stored in the third heat exchanger	[kJ]
71	$\dot{Q}_{l,h3}$	heat loss rate of the third heat exchanger to ambient (only if it is a mantle heat exchanger)	[kJ/h]
72	$T_{h3,m}$	mean temperature of the third heat exchanger	[^{o}C]
73	-	not used	[-]
74	$\dot{Q}_{h4}$	power through the fourth heat exchanger	[kJ/h]
75	$\dot{Q}_{h4,s}$	power transferred between the fourth hx and the store	[kJ/h]
76	ΔU_{h4}	internal energy change of the fourth heat exchanger	[kJ]
77	Ex_{h4}	exergy stored in the fourth heat exchanger	[kJ]
78	$\dot{Q}_{l,h4}$	heat loss rate of the fourth heat exchanger to ambient (only if it is a mantle heat exchanger)	[kJ/h]
79	$T_{h4,m}$	mean temperature of the fourth heat exchanger	[^{o}C]
80	-	not used	[-]
81	ΔU_s	internal energy change of the tank (store)	[kJ]
82	Ex_s	exergy stored in the tank (store)	[kJ]
83	$T_{s,m}$	mean temperature of the tank (store)	[^{o}C]
84	ΔU_{ws}	internal energy change of the whole storage device (store and heat exchangers)	[kJ]
85	Ex_{ws}	exergy stored in whole storage device (store and hx)	[kJ]
86	$T_{s,1}$	temperature of store node 1 (i=1)	[^{o}C]
86+i	$T_{s,i}$	temperature of store node i	[^{o}C]
86+N_{max}	$T_{s,Nmax}$	temperature of store node N_{max}	[^{o}C]

6 Information flow diagram

Inputs: 30 Outputs: $86 + N_{max}$

Parameters: 126 Derivatives: 0

<u>Parameters</u>

1	H_s	33	$z_{d5,i}$	65	z_{aux}	97	V_{h3}
2	V_s	34	$z_{d5,o}$	66	z_{taux}	98	$c_{p,h3}$
3	$c_{p,s}$	35	d_{d5}	67	T_{set}	99	ρ_{h3}
4	ρ_s	36	sc_{d5}	68	T_{db}	100	$(UA)_{h3,s}$
5	λ_{con}	37	$z_{d6,i}$	69	$z_{h1,i}$	101	$b_{h3,1}$
6	not used	38	$z_{d6,o}$	70	$z_{h1,o}$	102	$b_{h3,2}$
7	T_{ini}	39	d_{d6}	71	V_{h1}	103	$b_{h3,3}$
8	$(UA)_{s,bot}$	40	sc_{d6}	72	$c_{p,h1}$	104	$(UA)_{h3,a}$
9	$(UA)_{s,top}$	41	$z_{d7,i}$	73	ρ_{h1}	105	sc_{h3}
10	dz_1	42	$z_{d7,o}$	74	$(UA)_{h1,s}$	106	sm_{h3}
11	$(UA)_{s,a1}$	43	d_{d7}	75	$b_{h1,1}$	107	S_{h3}
12	dz_2	44	sc_{d7}	76	$b_{h1,2}$	108	$z_{h4,i}$
13	$(UA)_{s,a2}$	45	$z_{d8,i}$	77	$b_{h1,3}$	109	$z_{h4,o}$
14	dz_3	46	$z_{d8,o}$	78	$(UA)_{h1,a}$	110	V_{h4}
15	$(UA)_{s,a3}$	47	d_{d8}	79	sc_{h1}	111	$c_{p,h4}$
16	$(UA)_{s,a4}$	48	sc_{d8}	80	sm_{h1}	112	ρ_{h4}
17	$z_{d1,i}$	49	$z_{d9,i}$	81	S_{h1}	113	$(UA)_{h4,s}$
18	$z_{d1,o}$	50	$z_{d9,o}$	82	$z_{h2,i}$	114	$b_{h4,1}$
19	d_{d1}	51	d_{d9}	83	$z_{h2,o}$	115	$b_{h4,2}$
20	sc_{d1}	52	sc_{d9}	84	V_{h2}	116	$b_{h4,3}$
21	$z_{d2,i}$	53	$z_{d10,i}$	85	$c_{p,h2}$	117	$(UA)_{h4,a}$
22	$z_{d2,o}$	54	$z_{d10,o}$	86	ρ_{h2}	118	sc_{h4}
23	d_{d2}	55	d_{d10}	87	$(UA)_{h2,s}$	119	sm_{h4}
24	sc_{d2}	56	sc_{d10}	88	$b_{h2,1}$	120	S_{h4}
25	$z_{d3,i}$	57	z_{s1}	89	$b_{h2,2}$	121	epstmp
26	$z_{d3,o}$	58	z_{s2}	90	$b_{h2,3}$	122	epsua
27	d_{d3}	59	z_{s3}	91	$(UA)_{h2,a}$	123	epsmix
28	sc_{d3}	60	z_{s4}	92	sc_{h2}	124	TDTSC
29	$z_{d4,i}$	61	z_{s5}	93	sm_{h2}	125	N_{max}
30	$z_{d4,o}$	62	HMOD	94	S_{h2}	126	fit
31	d_{d4}	63	HTOP	95	$z_{h3,i}$		
32	sc_{d4}	64	l_{aux}	96	$z_{h3,o}$		

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