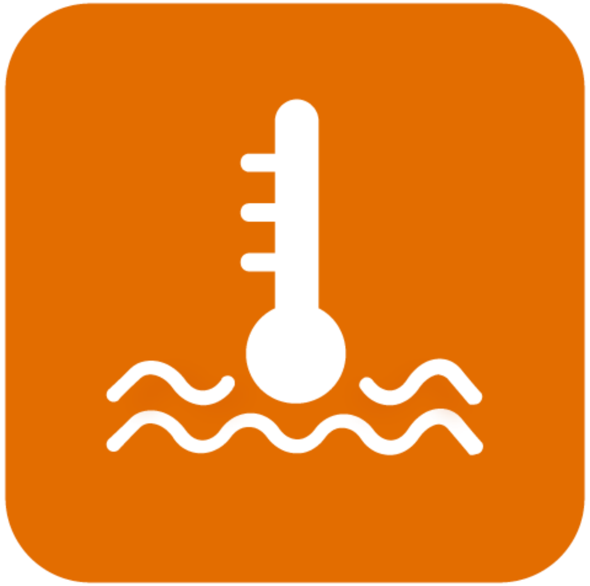
LIQUID COOLING LIBRARY

Overview

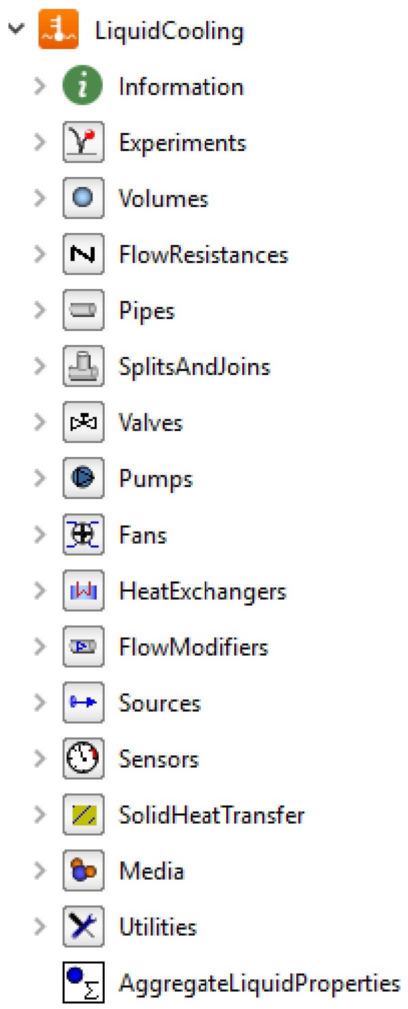
AGENDA

- ❑ About Liquid Cooling Library
- ❑ Key Features
- ❑ Key Capabilities
- ❑ Key Applications
- ❑ Library Contents
- ❑ Modelon Compatibility
- ❑ Latest Release



ABOUT LIQUID COOLING LIBRARY

- Modelica library for liquid heating and cooling application
- High performance modeling of incompressible flow, including closed circuits and real-time applications
- Suitable for a wide range of applications, ranging from automotive and aerospace to industrial equipment and process industry
- Highly customizable
- Realize non-standard circuits and add in-house IP

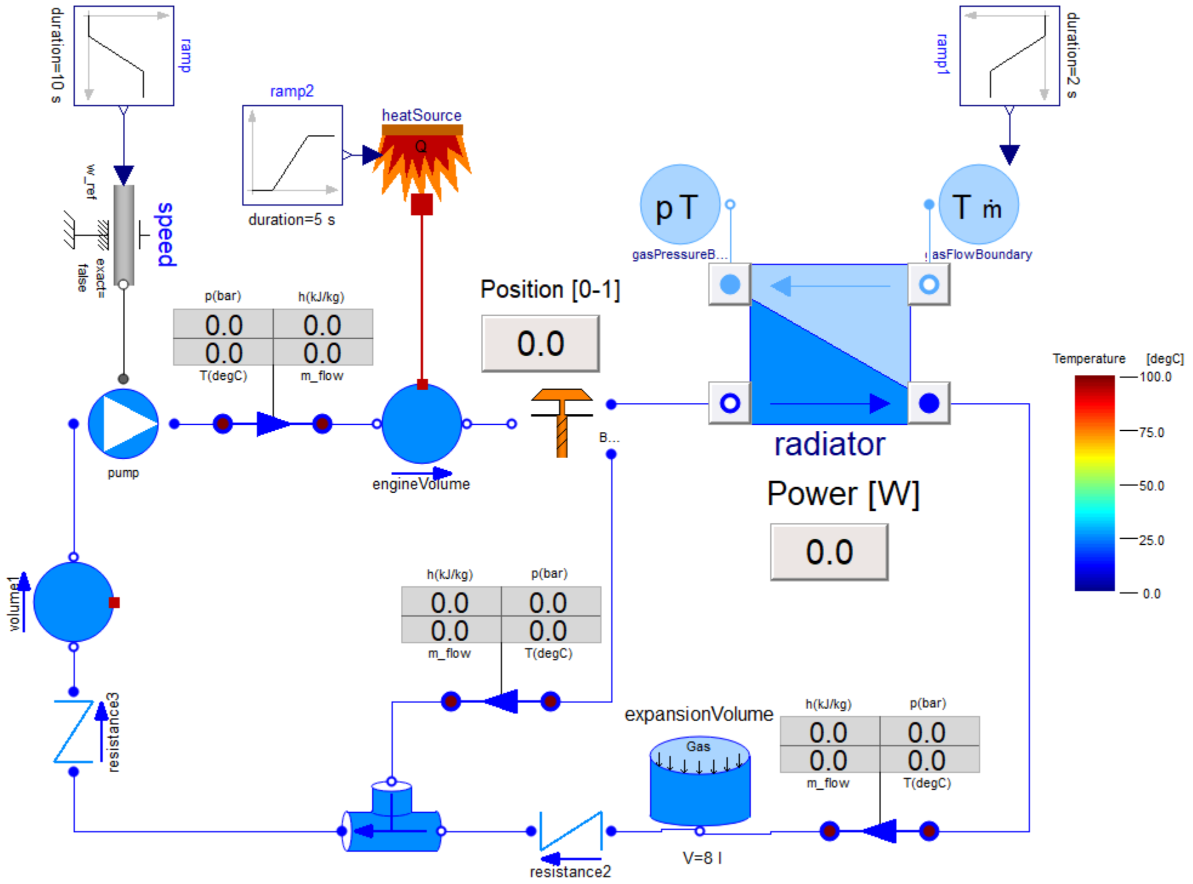


KEY BENEFITS

- Large set of fluid component models
  - Generic, customizable components
  - Geometry based components, The pressure loss is calculated based on geometrical parameters
- Medium property models
  - Water
  - Aqueous solutions of glycol, alcohols, glycerol, ammonia, chlorides and salts
  - Jet fuels and motor oil
- Plug-and-play compatible with other Modelon libraries for thermal management
- Very fast simulation of HeatExchanger Stack models

KEY CAPABILITIES

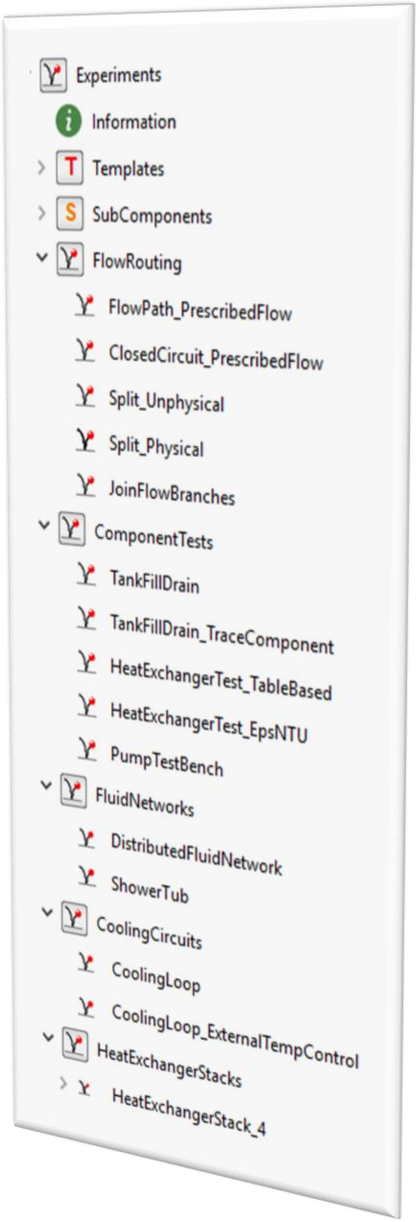
- Cooling systems for automotive and process industry
- Engine cooling
- Battery thermal management
- Component selection
- Pump dimensioning
- System performance studies
- Transient response studies
- Easy realization of non-standard circuits
- Support control system development and evaluation



KEY APPLICATIONS

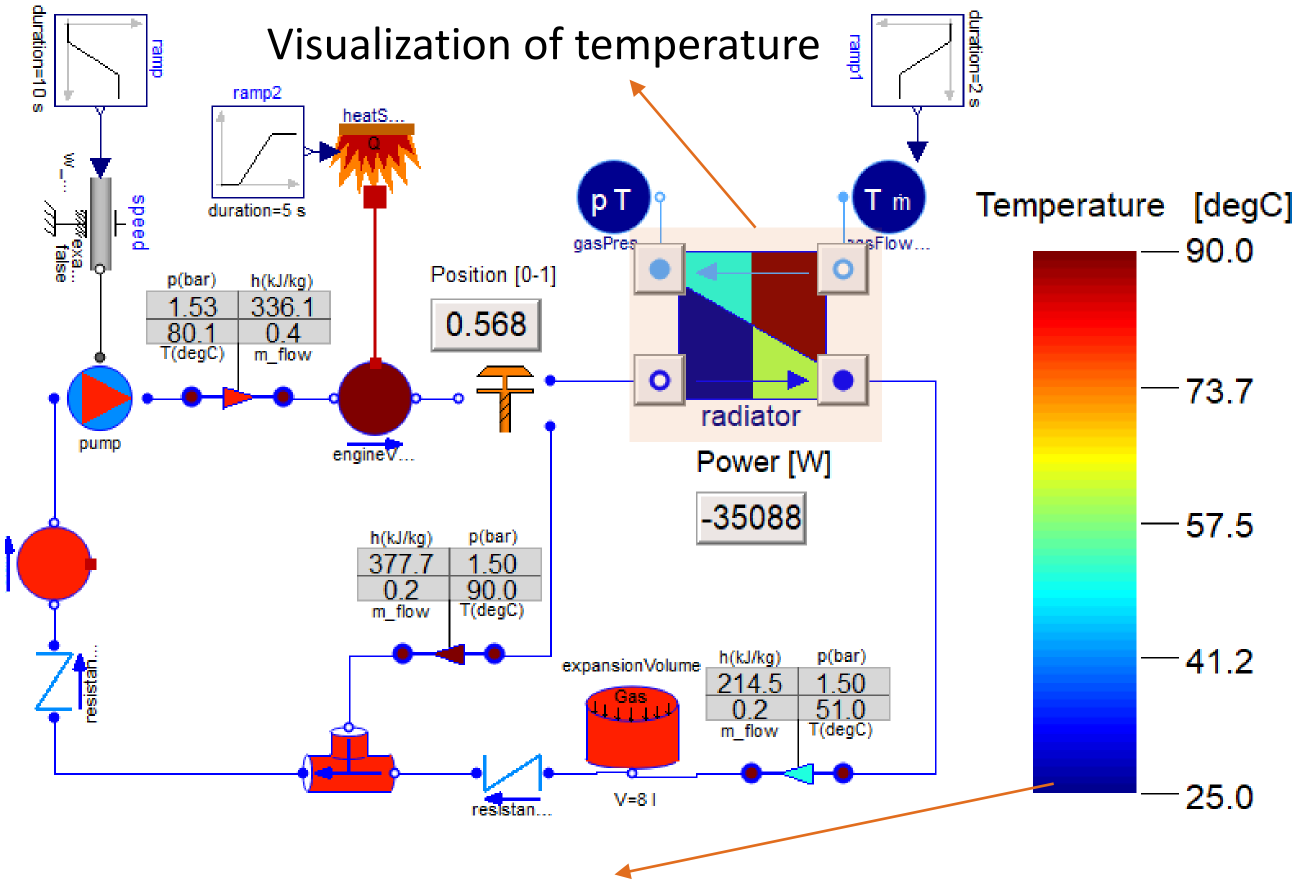
KEY APPLICATIONS

- Liquid Cooling Loop
- HeatExchanger Stack
- Distributed Fluid Network
- Vehicle Thermal Management (VTM)



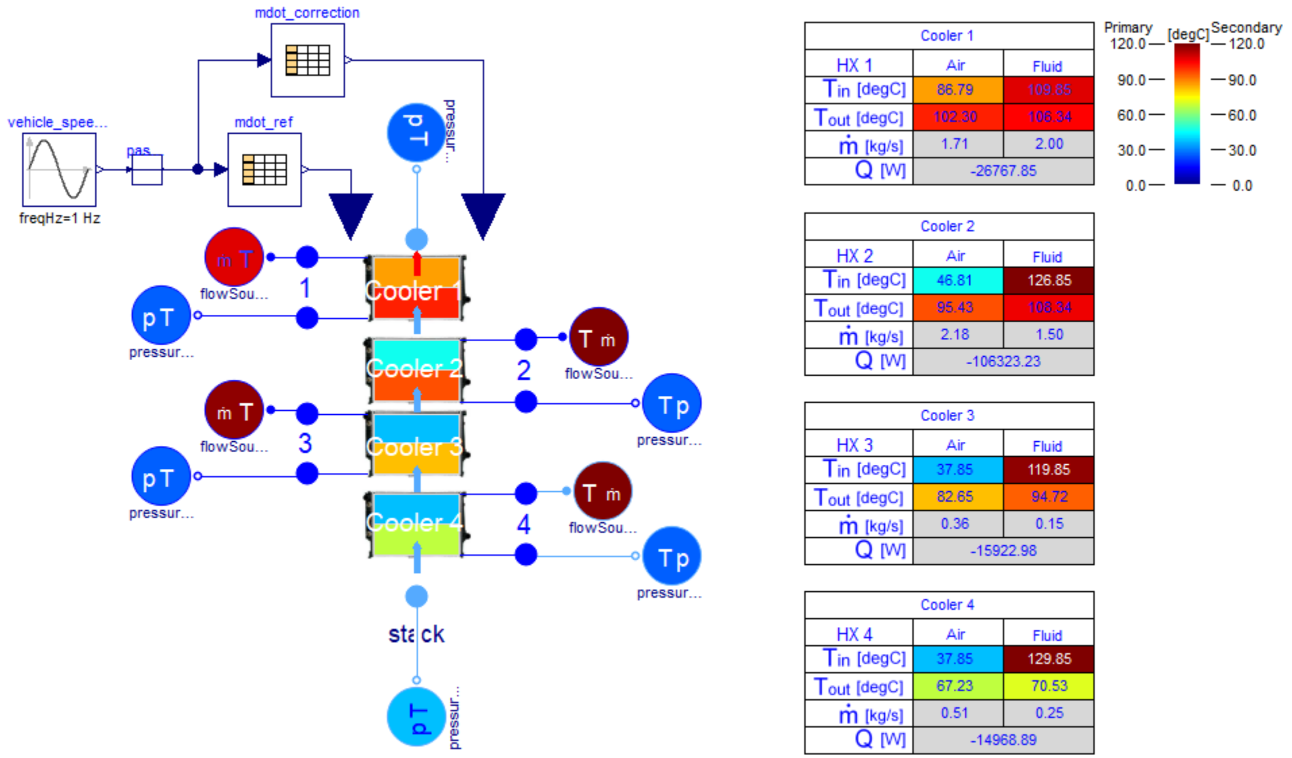
EXAMPLE: LIQUID COOLING LOOP

Dynamic model of a liquid cooling circuit. The flow is driven by a pump incorporating a table based pump curve. The external heat load is described by a ramp. A radiator with a thermostatic bypass valve cools the liquid coolant.



EXAMPLE:
HEATEXCHANGER STACK

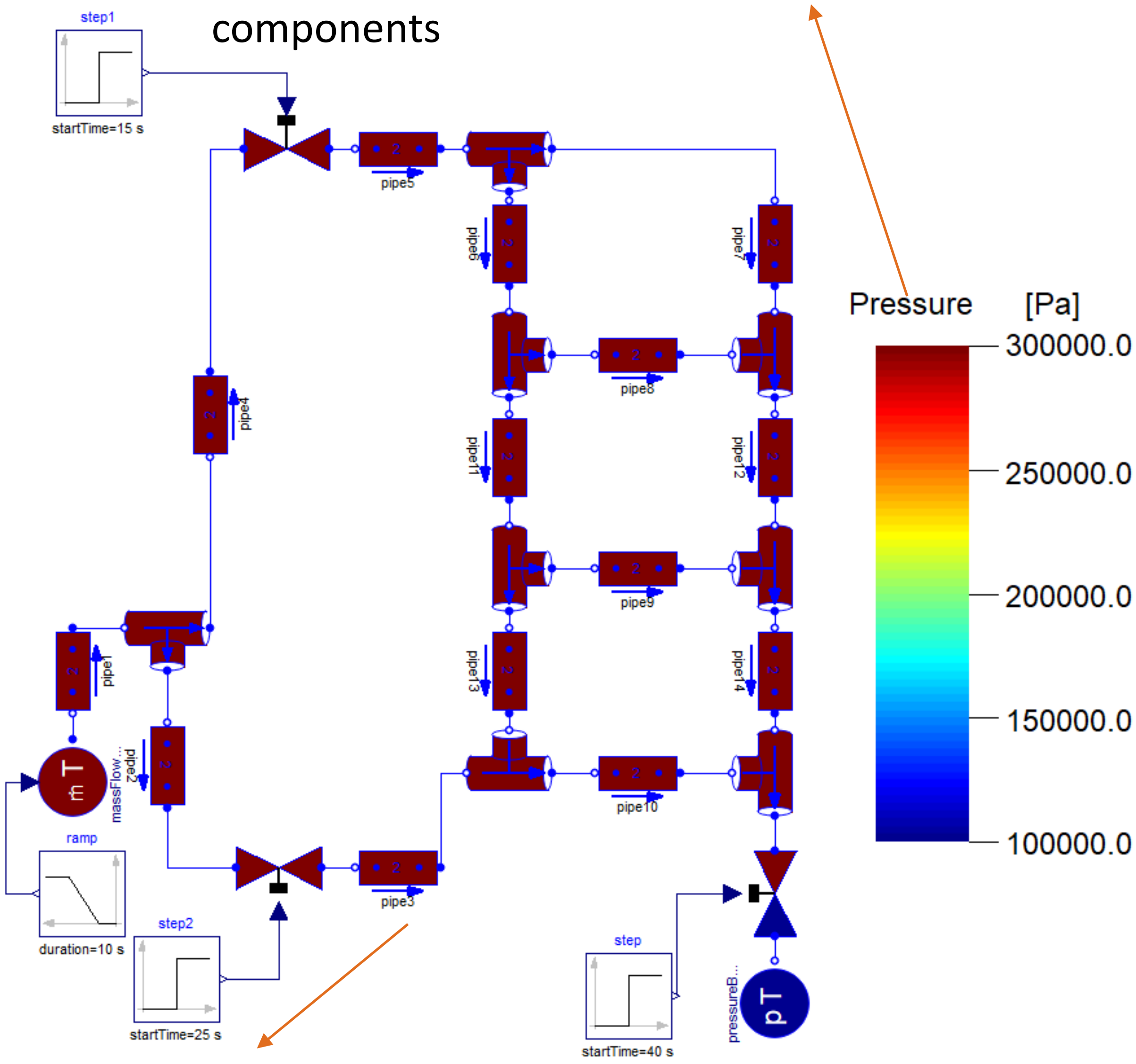
This is model for a stack with 4 heat exchangers. Vehicle speed, given by a sine block, is mapped to inlet air mass flow rate of the stack through a linear interpolation of a 1D table. The visualizers display inlet/outlet temperatures, coolant mass flow rate and cooling power of the heat exchangers.



EXAMPLE: DISTRIBUTED FLUID NETWORK

The purpose of this example is to illustrate how the dynamics introduced in the split components of LCL allows for explicit models of incompressible flow networks.

Color bar for visualization of pressure in different components



Visualization of Pressure

CASE STUDY

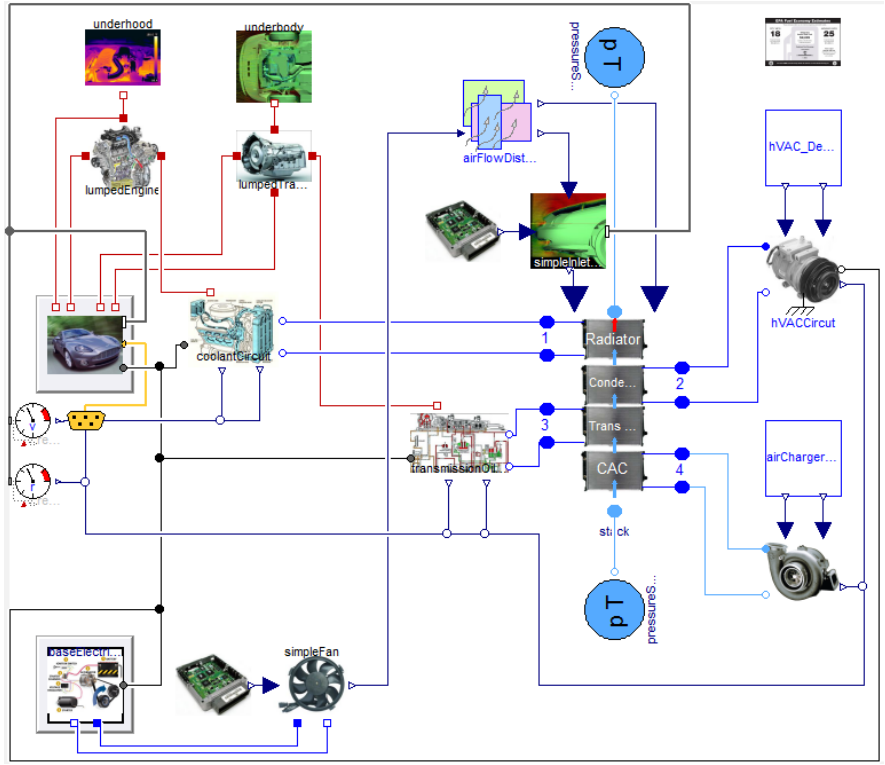
Vehicle Thermal Management (VTM)

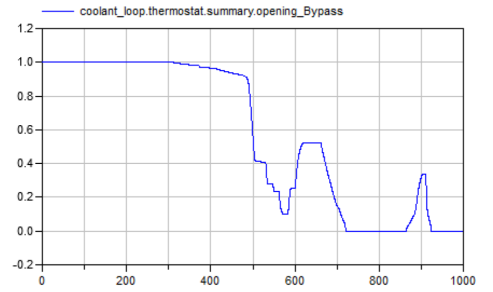
Objective

Balancing system level requirements for cooling and energy usage

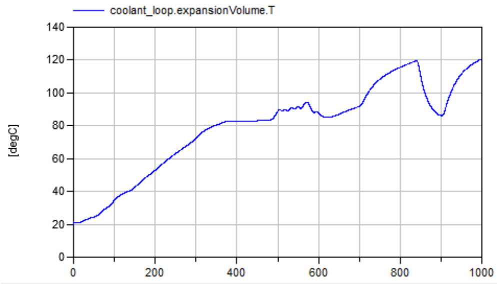
Results

- Multi-domain physical modeling approach for energy conservation across domains (mechanical, thermal, electrical, thermofluid) and vehicle thermal management
- Flexibility in integration of physical and controls models





Controlled temperature



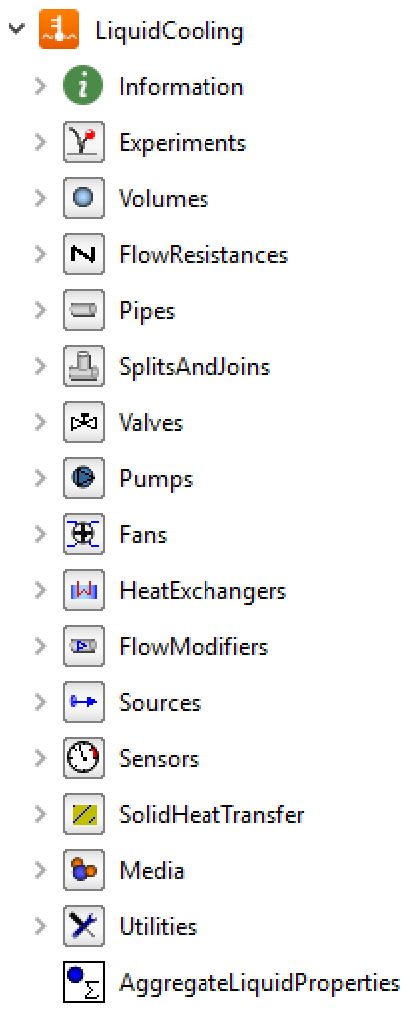
Actuator - thermostat

Modelon

LIBRARY CONTENTS

LIBRARY CONTENTS

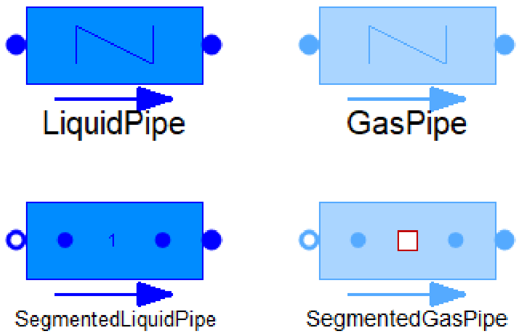
- Pipes and bends
- Flow resistances
- Volumes and tanks
- Junctions
- Pump and fan
- Heat exchangers and stacks
- Flow modifiers and sources
- Solid heat transfer
- Single-phase coolants and refrigerants

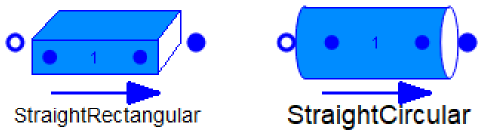


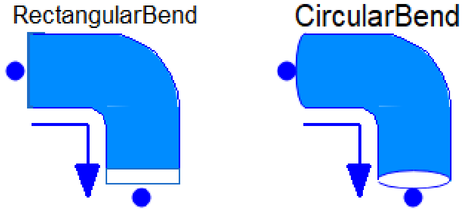
LIBRARY CONTENTS

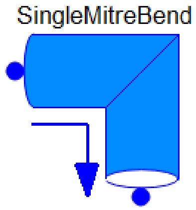
Pipes

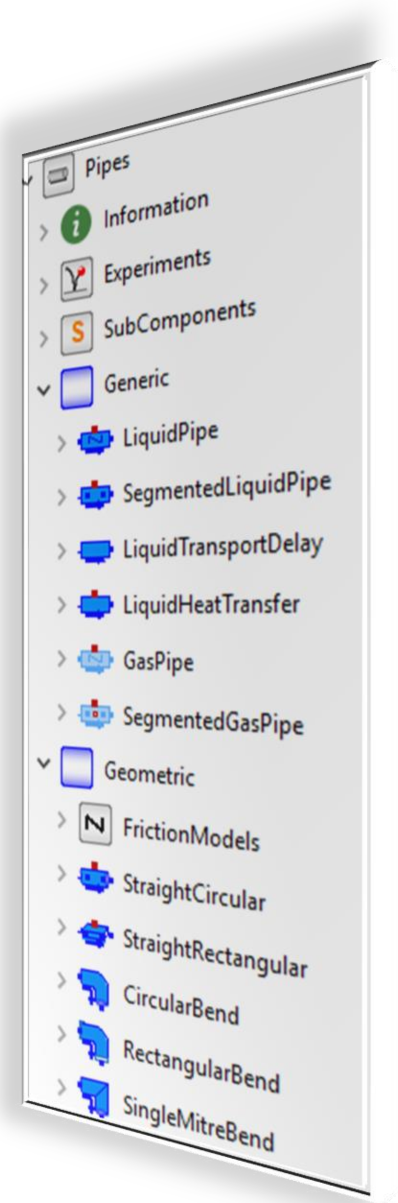
- Generic pipes with different fidelity and replaceable correlations
  - Lumped or discretized
  - Pressure drop
  - Heat transfer
  - Transport delay
- Components with geometric loss coefficient data:
  - Straight pipes
  - Circular bend
  - Rectangular bend
  - SingleMitre bend







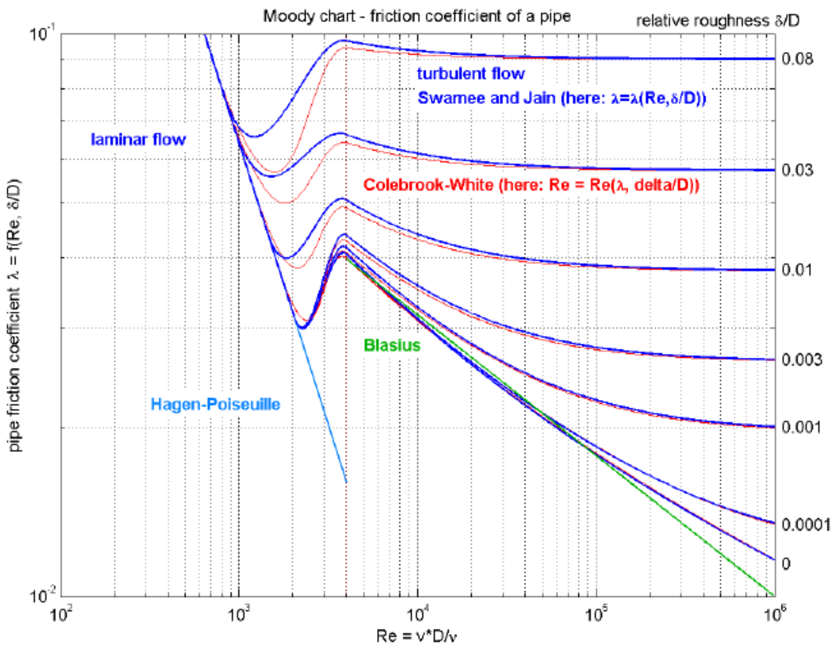




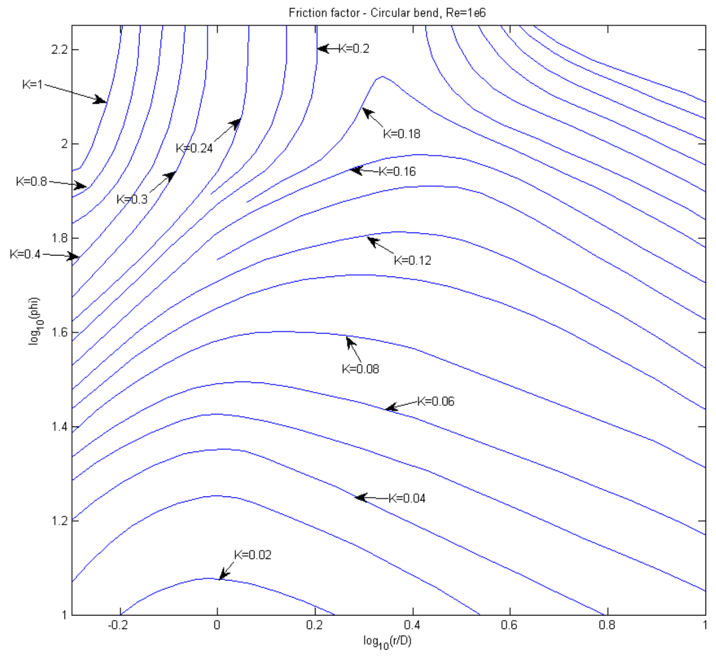
LIBRARY CONTENTS

Geometric Friction Models

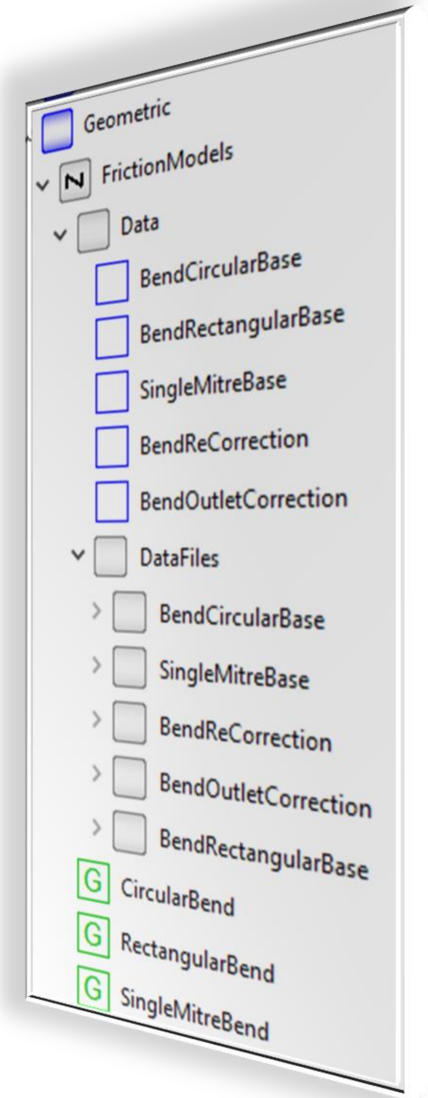
- The library includes loss coefficient data for all geometric components.
  Main reference: *Internal Flow Systems, D S Miller*



Straight pipe loss coefficient



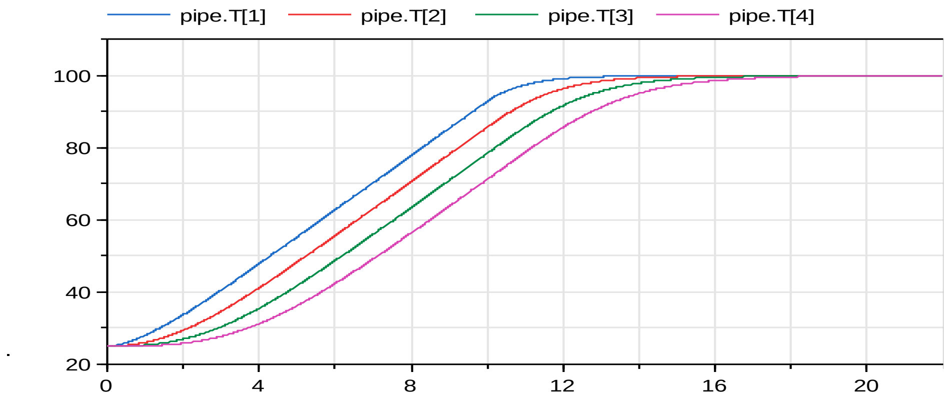
Circular bend loss coefficient



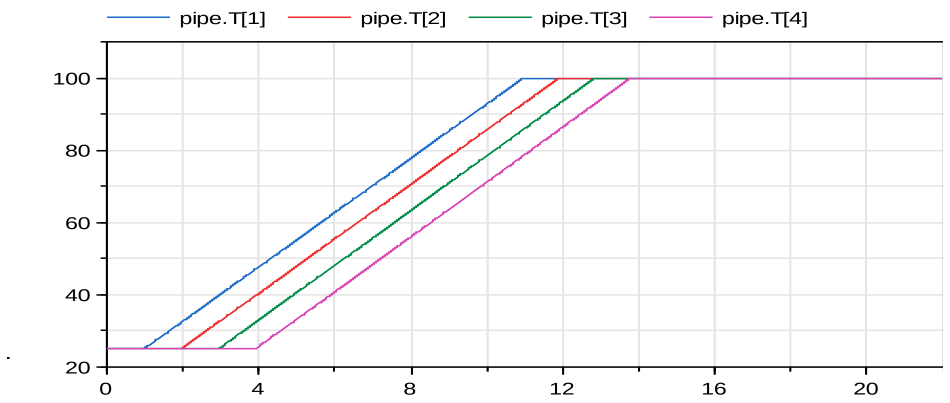
LIBRARY CONTENTS

Pipe segmentation

- The liquid pipe uses transport delay instead of internal control volumes. This is often more accurate for liquid flow at low discretization



Temperature profile for 4 volumes



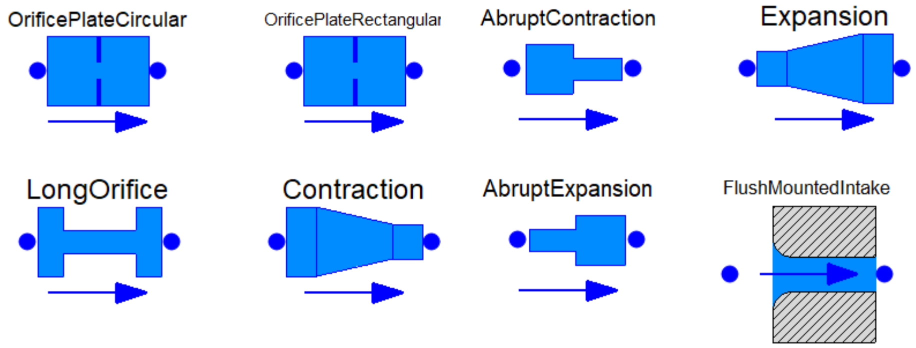
Temperature profile for 4 transport delays

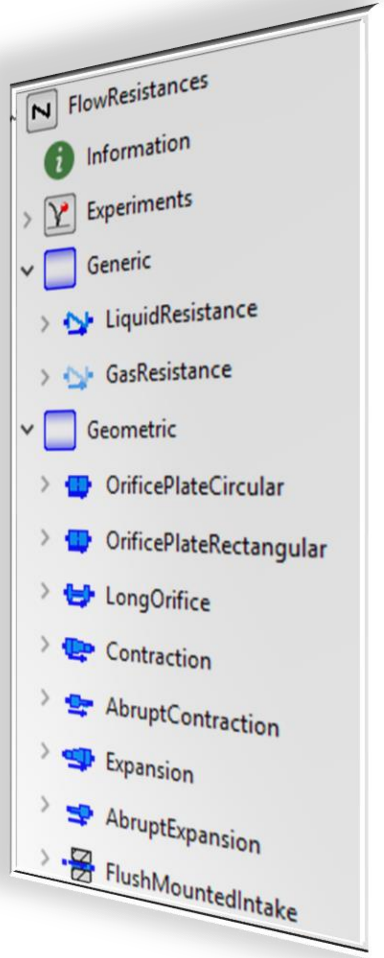
LIBRARY CONTENTS

Flow resistances

- Generic flow resistances
  - Replaceable friction model

- Geometric flow resistances with tabulated loss coefficient data
  - Orifice plate and long orifice
  - Abrupt contraction and expansions
  - Flush mounted intakes

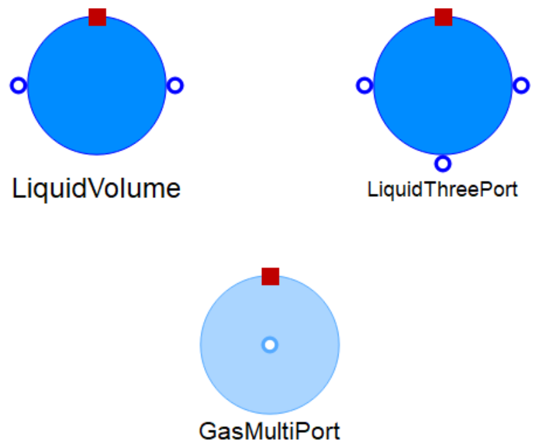


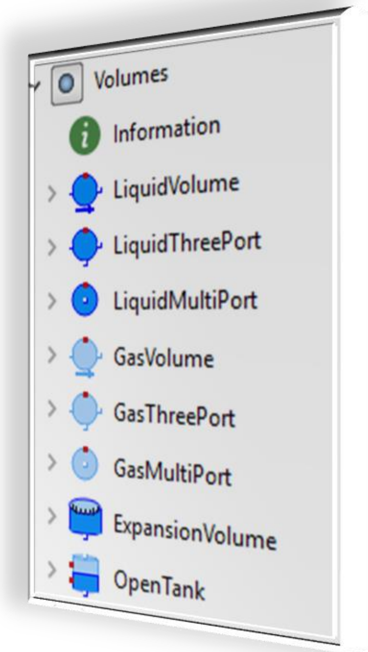


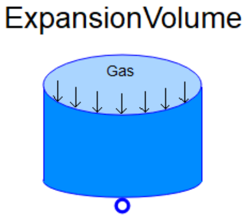
LIBRARY CONTENTS

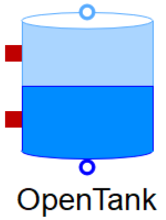
Volumes and Tanks

- Closed volumes
  - Energy storage
  - Different port configurations
  - Heat transfer and solid thermal mass
- Expansion volume
- Open tank





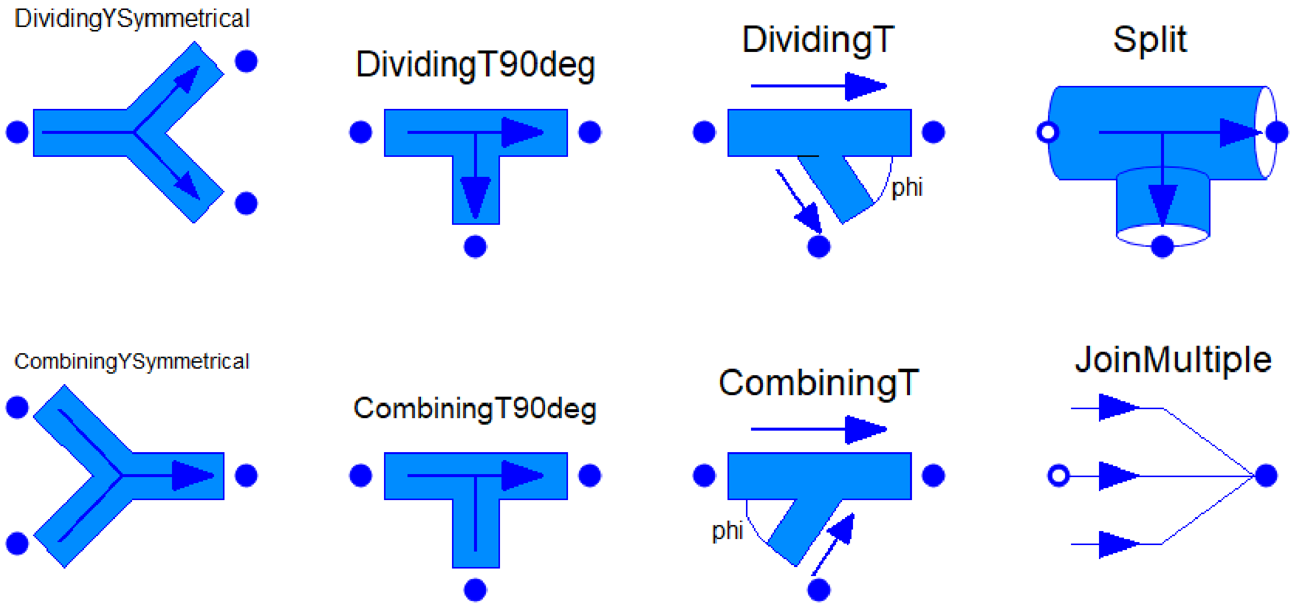


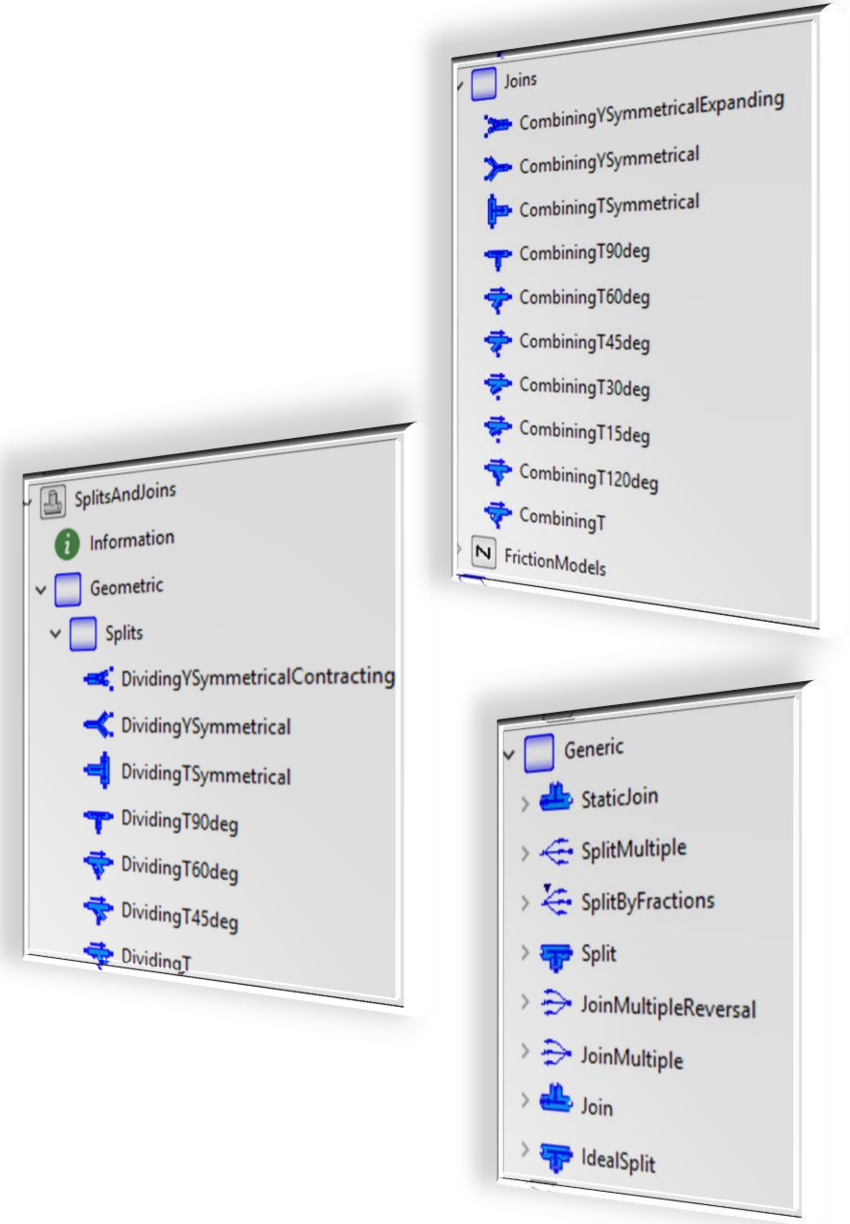


LIBRARY CONTENTS

Junctions

- Combining and dividing junctions
- Geometric loss coefficient data for many geometries

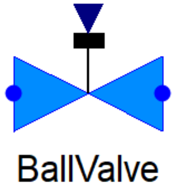




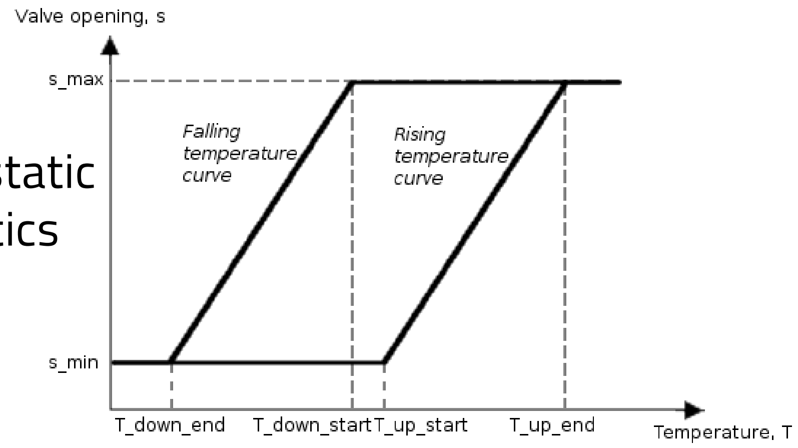
LIBRARY CONTENTS

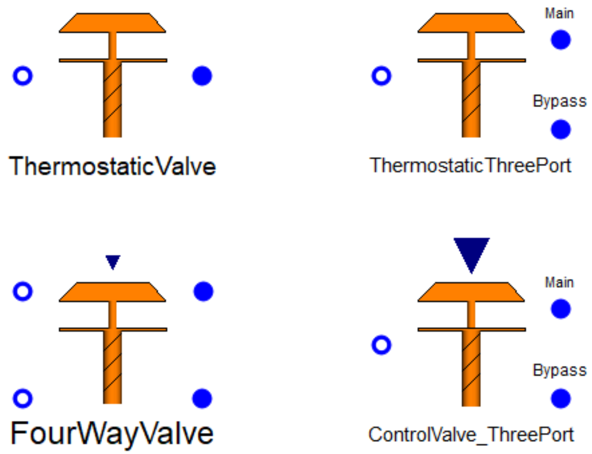
Valves

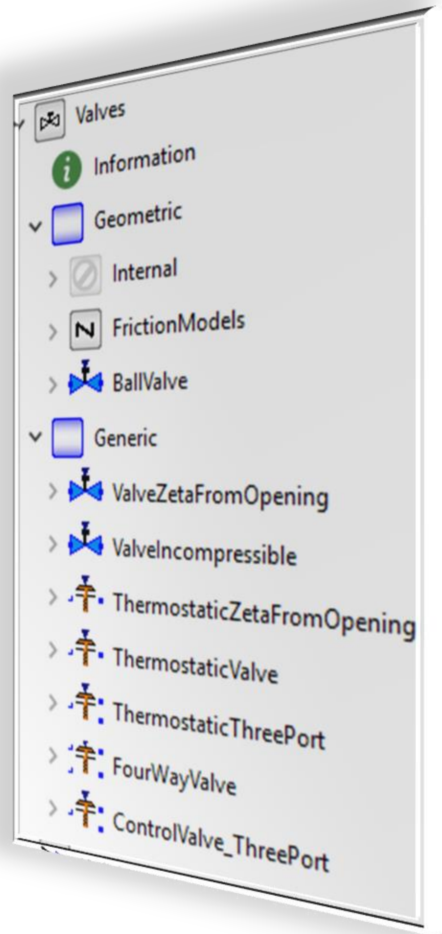
- Control valves
- Thermostatic valves
  - Two , Three-legged and Four way valve
  - Replaceable friction and opening characteristics
  - Possible to include hysteresis effects



Example thermostatic valve characteristics with hysteresis







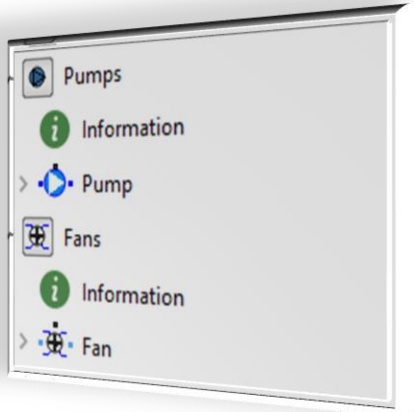
LIBRARY CONTENTS

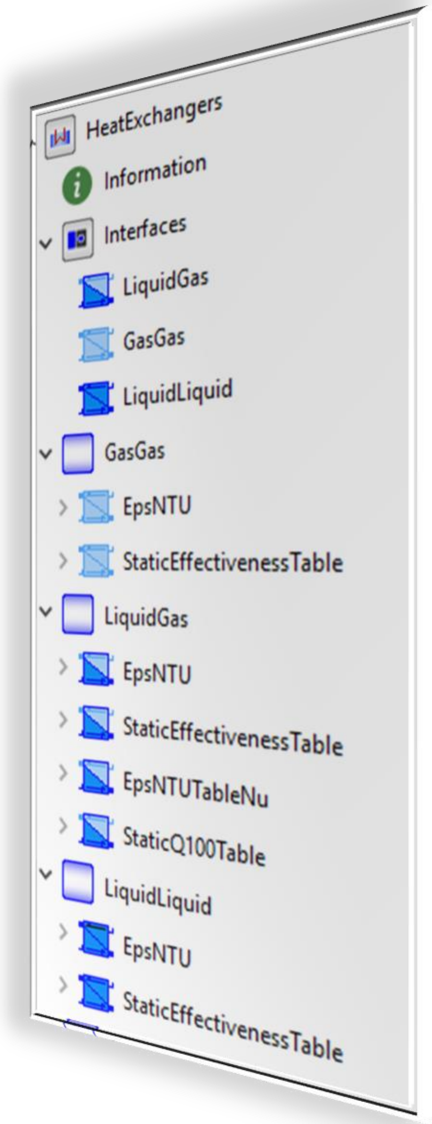
Pump and Fan

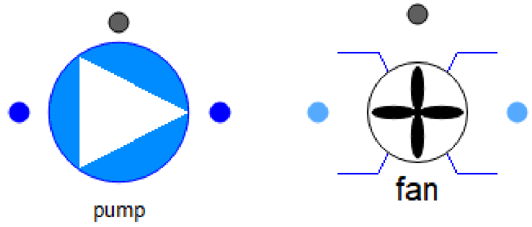
- Flexible parameterization
  - Multiple options for pump and fan curves

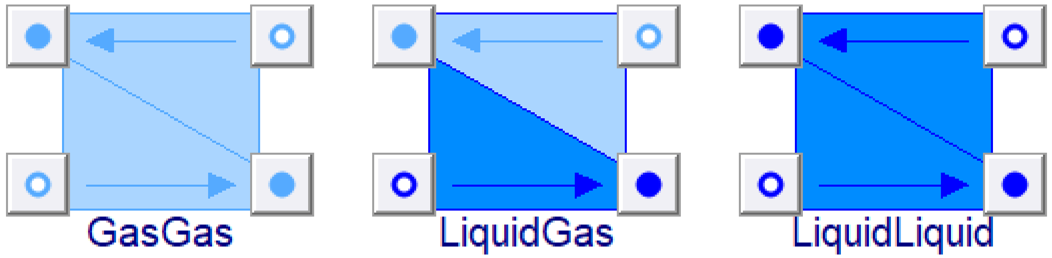
Heat exchangers

- Simplified heat exchanger models
  - Based on tabulated efficiency
  - e-NTU approach
- Possible configurations
  - Gas – Gas
  - Gas – Liquid
  - Liquid – Liquid









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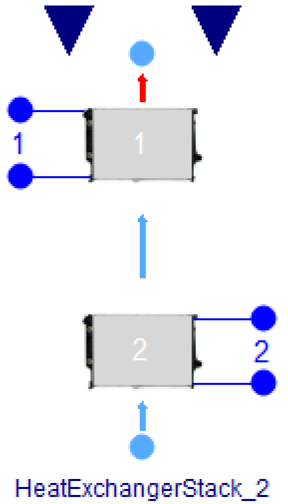
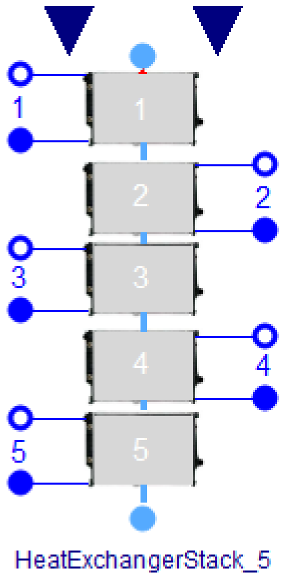
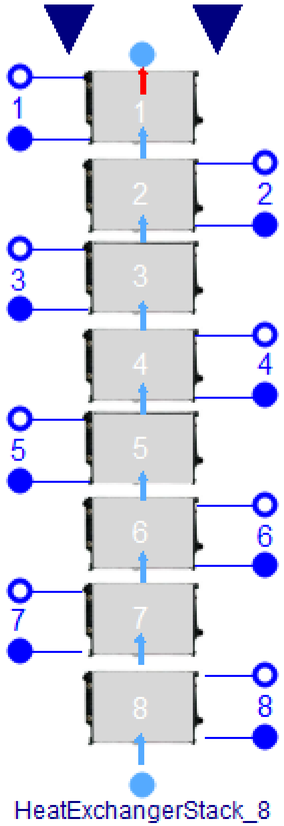
LIBRARY CONTENTS

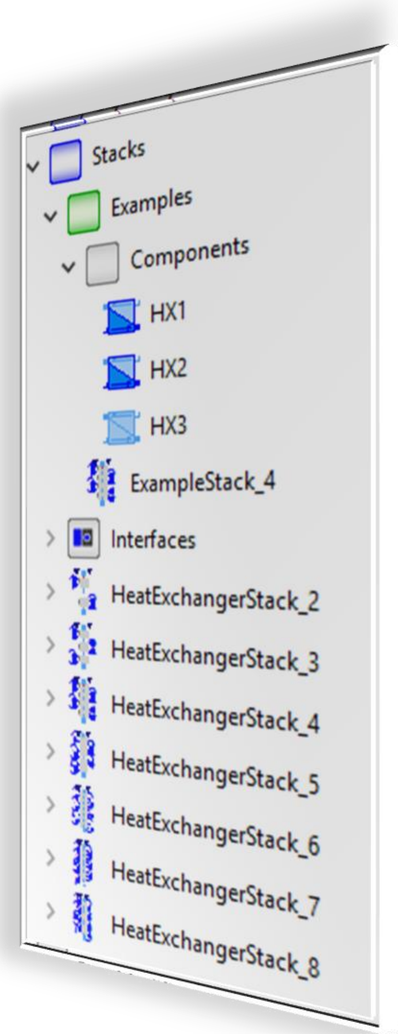
Stacks

- Containing 2 to 8 heat exchangers





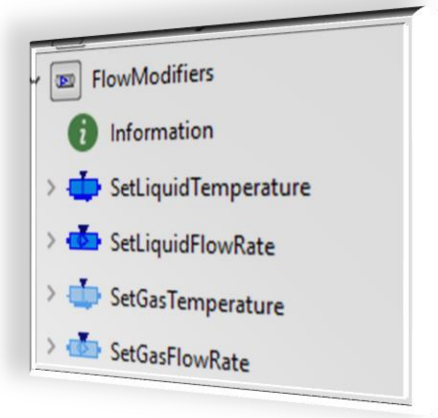


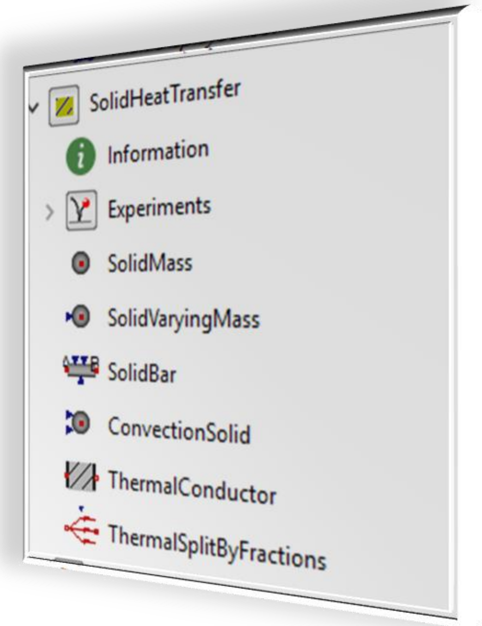


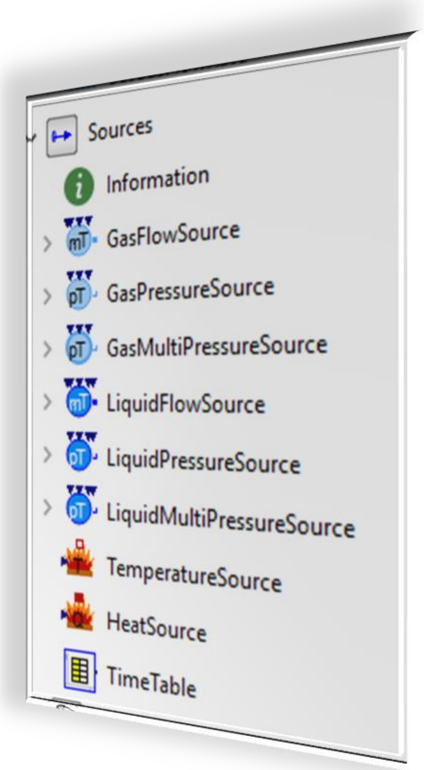
LIBRARY CONTENTS

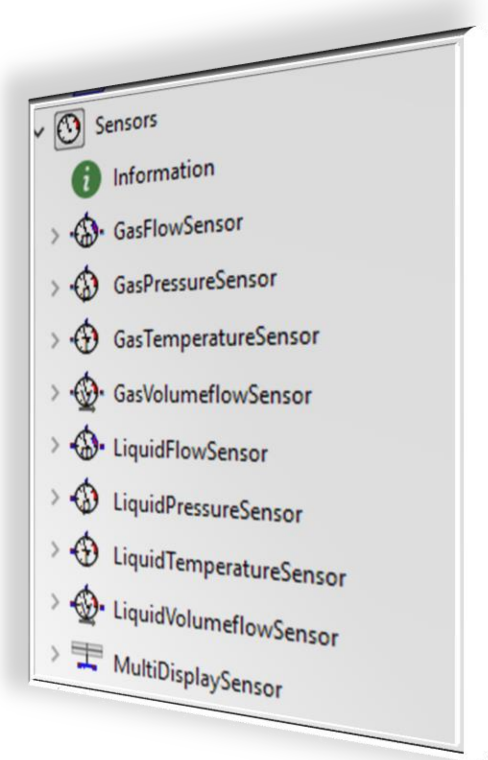
Basic Components

- The AggregateVolume object calculates the total liquid volume in the system – useful for dimensioning 







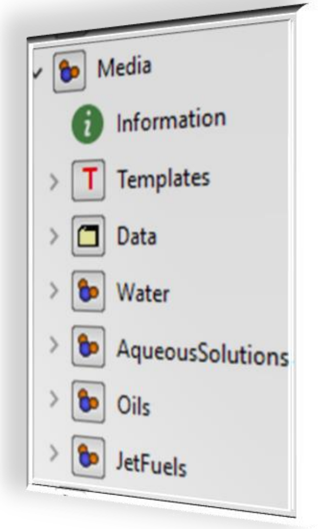


LIBRARY CONTENTS

Medium Properties

- LCL includes models for water, motor oil, jet fuels and aqueous solutions. For aqueous solutions, the concentration can be set anywhere between zero and the eutectic composition. List of available media (aqueous solutions):
  - Calcium chloride
  - Ethylene glycol
  - Propylene glycol
  - Ethyl alcohol
  - Methyl alcohol
  - Glycerol
  - Ammonia
  - Potassium carbonate
  - Magnesium chloride
  - Sodium chloride
  - Potassium acetate
  - Potassium formate
  - Lithium chloride

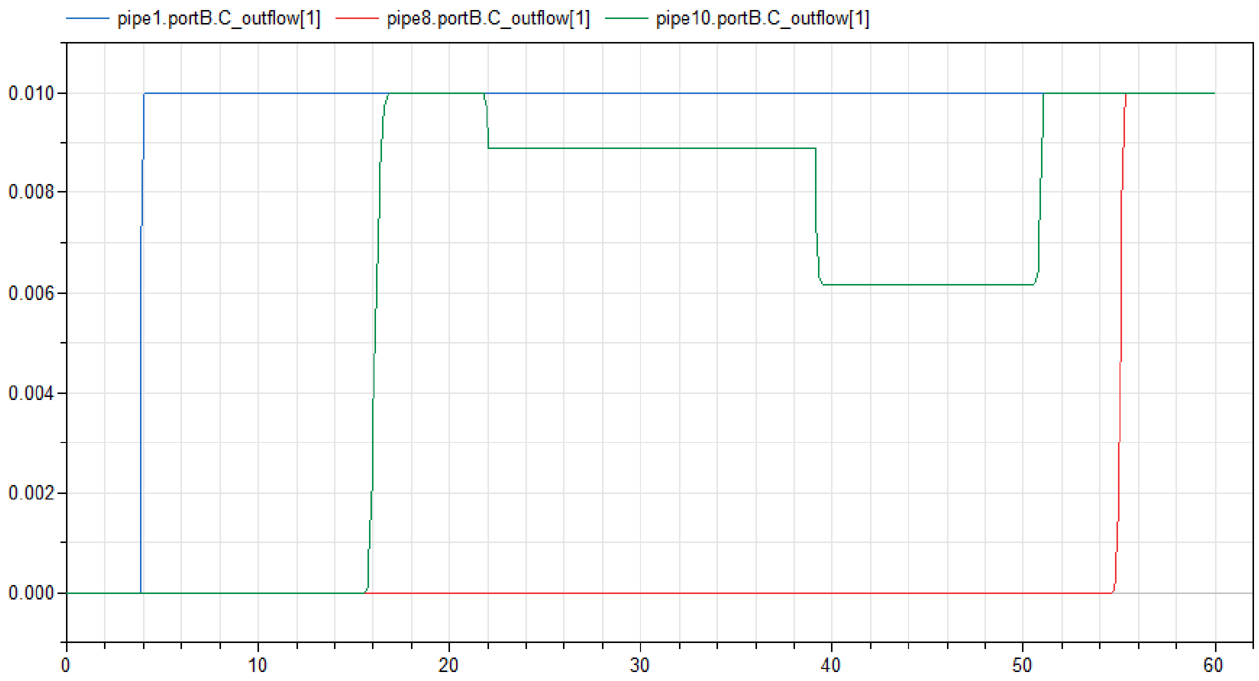
Reference: *International Institute of Refrigeration*, 2010

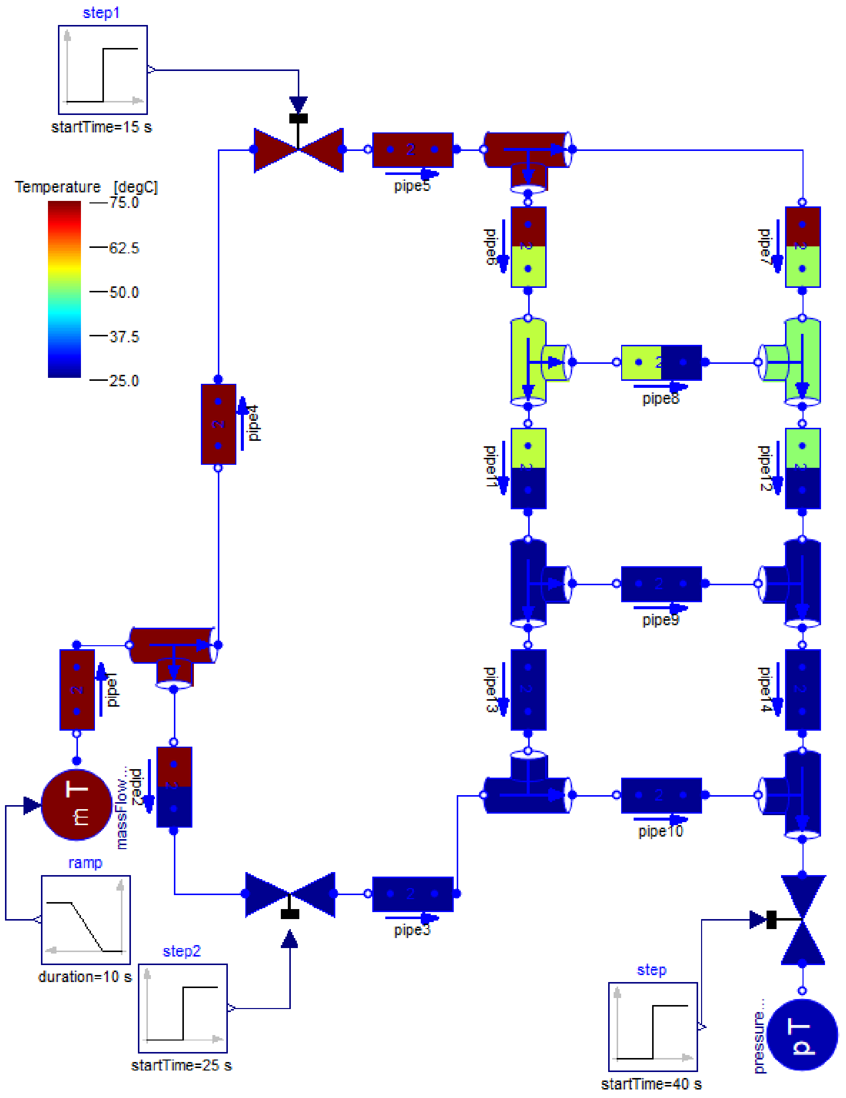


LIBRARY CONTENTS

Trace Variable

- In this example the trace component introduced in pipe1 can be followed in the system (in pipe 8 with time delay, and in pipe 10 controlled via valve)





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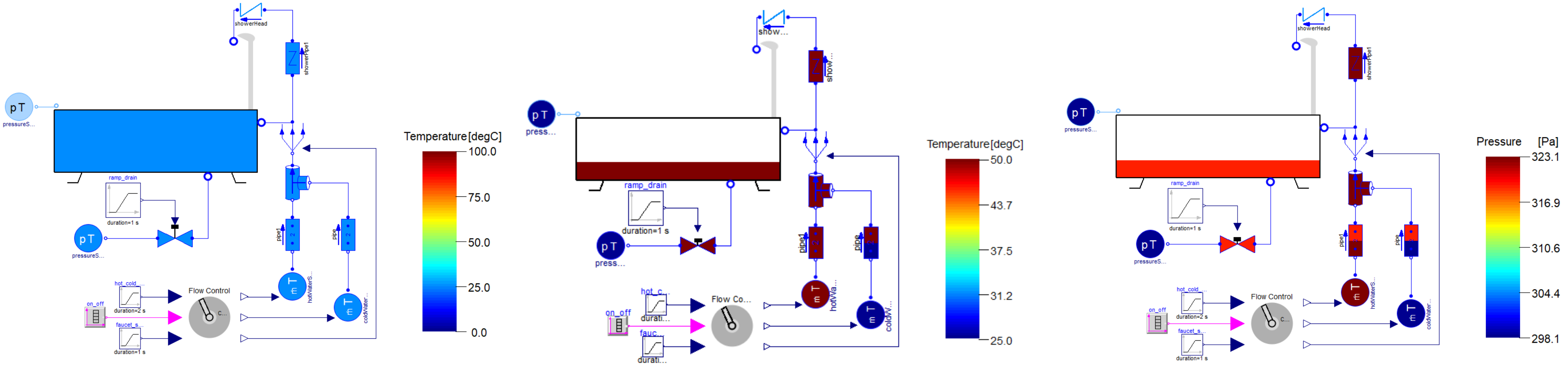
LIBRARY CONTENTS

Visualization

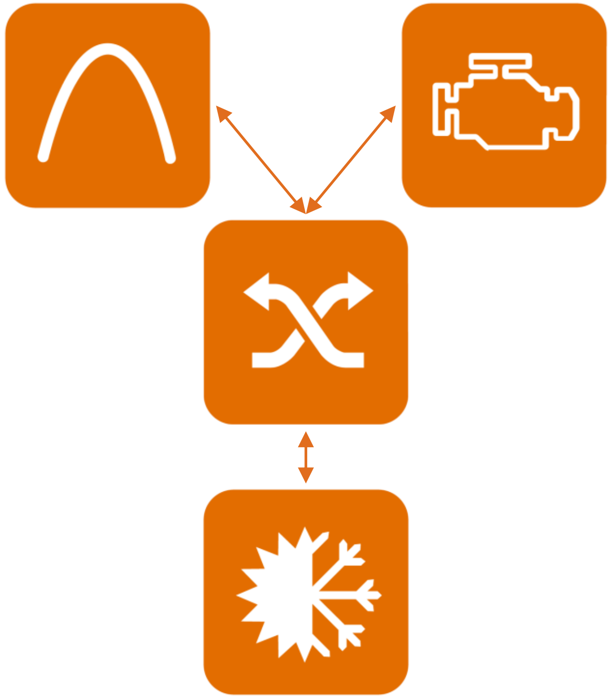
- It is possible to visualize the temperature and pressure of the components, the opening of valves and more.
- See bath tub example below.



MODELON COMPATIBILITY

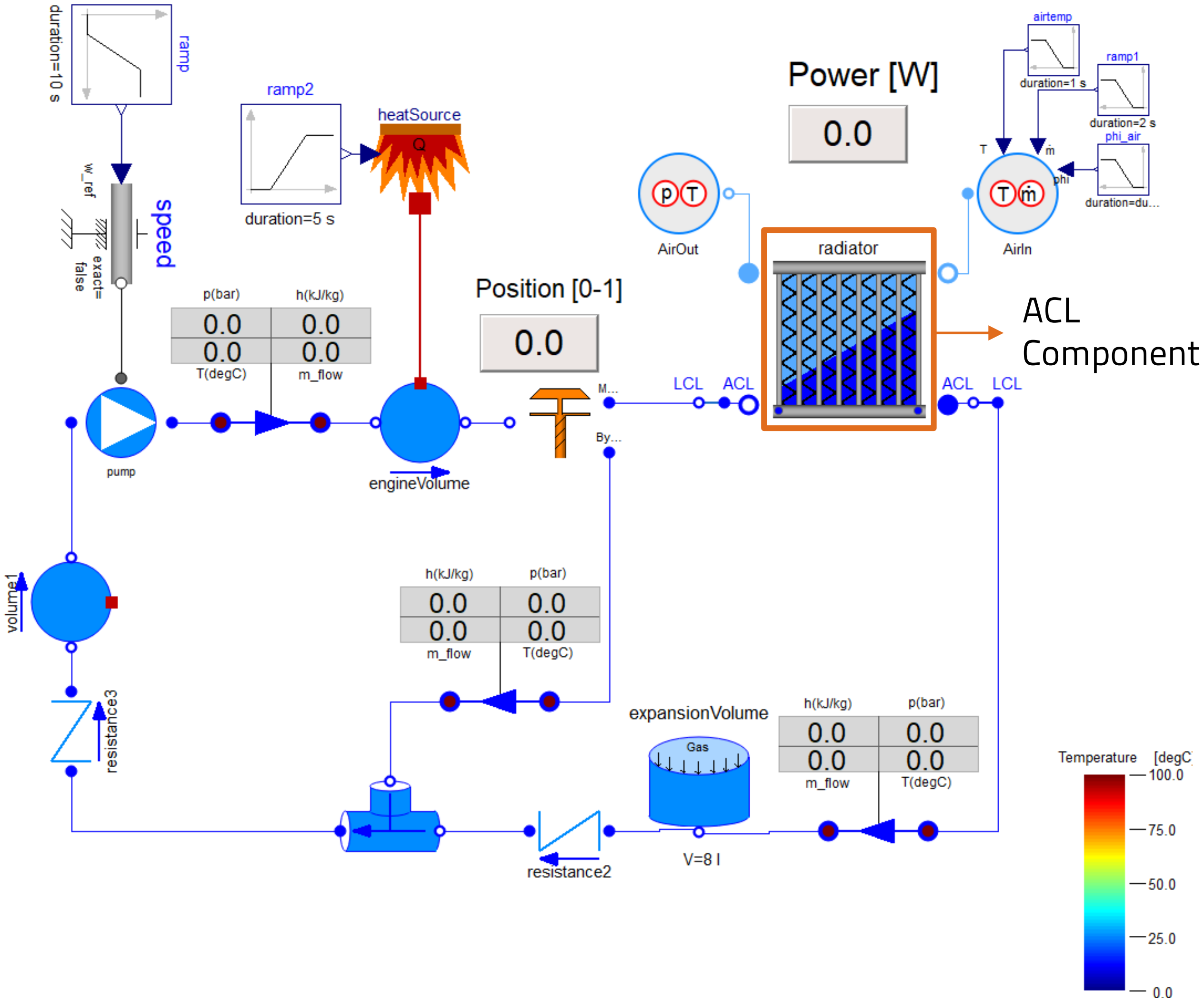
RECOMMENDED MODELON LIBRARY COMPATIBILITY

- Liquid cooling Library components are seamless compatible with HeatExchanger Library, VaporCycle Library, Engine Dynamics Library and Also with Air Conditioning Library via special adapter.
- Liquid Cooling Library compatible with Batch simulation in
  - MATLAB
  - Python
  - Excel



EXAMPLE : LCL - ACL INTERACTION

In this model, dynamic model of a liquid cooling circuit is combined with a radiator from the Air Conditioning Library. The flow is driven by a pump incorporating a table based pump curve. The external heat load is described by a ramp. A radiator along with a thermostatic bypass valve maintains the required coolant temperature.



EXAMPLE : BATCH SIMULATION IN FMI ADD-IN FOR EXCEL

The liquid cooling library models are compatible with batch simulation in Modelon product FMI Add-in for Excel (FMIE).

FUNCTIONAL MOCK-UP INTERFACE

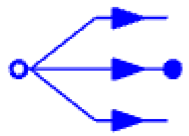
Model											
Sheet version	*Generated by Modelon FMI Add-In for Excel version 1.1.2*										
Model name	*DriveCycleVTM*										
Generation tool	*Dymola Version 2013 FD01 (32-bit), 2012-10-18*										
FMU kind	*CoSimulation_StandAlone*										
Number of processes	*8*										
Settings				**Default**	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**
Start time				0							
Stop time				1090	1000	240	1880	1090	1370	600	1440
FMU				C:\Users\jbg\working\DriveCycleVTM.fmu							
Log level				Info							
Enable				TRUE							
Output points				100	2000	2000	2000	2000	2000	2000	2000
Indata											
Name	**Variability**	**Type**	**Unit**								
driverVehicle.ground.k_x	parameter	Real		0							
driverVehicle.vehicle.driveline.rear_ratio	parameter	Real		4							
driverVehicle.vehicle.h_cg	parameter	Real	m	0.3							
driverVehicle.vehicle.body_mass	parameter	Real	kg	1600							
driverVehicle.vehicle.R0_front	parameter	Real	m	0.3							
driverVehicle.vehicle.R0_rear	parameter	Real	m	0.3							
driverVehicle.vehicle.wheel_i_xx_front	parameter	Real	kg.m2	1							
driverVehicle.vehicle.wheel_i_xx_rear	parameter	Real	kg.m2	1							
driverVehicle.vehicle.c_w_front	parameter	Real		0.38							
driverVehicle.vehicle.a_front	parameter	Real	m2	2.7							
driverVehicle.driveCycleScale	parameter	Real		1							
Tamb	parameter	Real	K	311							
fanController.loSpeedThresh	parameter	Real	K	360							
fanController.medSpeedThresh	parameter	Real	K	380							
fanController.hiSpeedThresh	parameter	Real	K	400							
fanController.maxSpeedThresh	parameter	Real	K	430							
grillController.closeThreshold	parameter	Real	m/s	18							
grillController.openThreshold	parameter	Real	m/s	15							
simpleInletConditions.airFlowGain	parameter	Real		1							
driveCycleNameIndex	parameter	Integer		2	23	11	9	16	19	18	15

LATEST RELEASE

RELEASE:2021.2

New Features

- A new split component was added, that allows direct specification of flow rate per path
- Added derivatives in Media base class and updated the derivative annotation, so that tools can generate analytic Jacobians



- New media added:
    - Hydraulic oil MIL-83282
    - Coolant MIL-87252
    - Lubricating oil MIL-23699
    - Lubricating oil Mobil Jet Oil II, a variant of MIL-23699
- New Heat exchangers added:
    - HeatExchangerTest_TableBasedQ - The rate of heat transfer is mapped directly from the mass flow rates of both media via a look-up table using linear interpolation.
    - Gas-Gas StaticEffectivenessTableFromQ Heat Exchanger
    - Liquid-Gas StaticEffectivenessTableFromQ Heat Exchanger
    - Liquid-Liquid StaticEffectivenessTableFromQ Heat Exchanger

Modelon

RELEASE:2021.2

Enhancements

- The following flow resistance models have been updated to account for bidirectional flow:
  - Contraction
  - AbruptContraction
  - Expansion
  - AbruptExpansion
  - FlushMountedIntake

- EpsNTU heat exchangers improved to use the counterFlowEps as a default calculation of effectiveness