TYPE 676: DOUBLE-EFFECT STEAM-FIRED ABSORPTION CHILLER

General Description

Type676 uses a normalized catalog data lookup approach to model a double-effect steam-fired absorption chiller. "Steam-Fired" indicates that the energy supplied to the machine's generator comes from a steam source. Because the data files are normalized, the user may model any size chiller using a given set of data files. Example files are provided.

Nomenclature

$Capacity$	[kJ/hr]	Mass flow rate of air entering the "fresh air" side of the device.
$f_{FullLoadCapacity}$	[0..1]	Fraction of the device's full load capacity during operation under current conditions.
$f_{NominalCapacity}$	[0..1]	Fraction of the device's nominal capacity during operation under current conditions.
$Capacity_{Rated}$	[kJ/hr]	Rated cooling capacity of the device
$\dot{Q}_{remove}$	[kJ/hr]	Amount of energy that must be removed from the chilled water stream in order to reach the set point temperature
$T_{chw,set}$	[ºC]	"Chilled water" stream set point.
f_{design}	[0..1]	Fraction of design capacity at which the machine is currently operating.
COP_{Rated}	[-]	Machine's rated Coefficient of Performance.
$f_{DesignEnergyInput}$	[0..1]	Fraction of design energy input currently required by the machine.
$T_{hw,out}$	[ºC]	Temperature of fluid exiting the "hot water" stream
$T_{hw,in}$	[ºC]	Temperature of fluid entering the "hot water" stream
$\dot{Q}_{hw}$	[kJ/hr]	Energy removed from the "hot water" stream
$\dot{m}_{hw}$	[kg/hr]	Mass flow rate of the "hot water" stream fluid
Cp_{hw}	[kJ/kg.K]	Specific heat of the "hot water" stream fluid.
$T_{chw,out}$	[ºC]	Temperature of fluid exiting the "chilled water" stream
$T_{chw,in}$	[ºC]	Temperature of fluid entering the "chilled water" stream
$\dot{Q}_{chw}$	[kJ/hr]	Energy removed from the "chilled water" stream
$\dot{m}_{chw}$	[kg/hr]	Mass flow rate of the "chilled water" stream fluid
Cp_{chw}	[kJ/kg.K]	Specific heat of the "chilled water" stream fluid.
$T_{cw,out}$	[ºC]	Temperature of fluid exiting the "cooling water" stream
$T_{cw,in}$	[ºC]	Temperature of fluid entering the "cooling water" stream
$\dot{Q}_{cw}$	[kJ/hr]	Energy added to the "cooling water" stream
$\dot{m}_{cw}$	[kg/hr]	Mass flow rate of the "cooling water" stream fluid
Cp_{cw}	[kJ/kg.K]	Specific heat of the "cooling water" stream fluid.
$\dot{Q}_{aux}$	[kJ/hr]	Energy draw of parasitics (solutions pumps, controls, etc.)
COP	[-]	Coefficient of Performance for the device.

Detailed Description

In a "conventional" refrigeration cycle, refrigerant returns as low pressure vapor from the evaporator (ideally near the saturated gas line of the vapor dome). This vapor then passes through an electrically driven compressor in which it is turned into a higher pressure gas before being passed to the condenser. Both the work of pressurizing the vapor and the work of pumping the refrigerant through the system is done by the compressor. In a "single effect" absorption machine, the refrigerant (typically water) returning from the evaporator is absorbed in a medium (often aqueous ammonia or lithium bromide) and is cooled to a liquid state, rejecting its heat to a cooling fluid stream. This liquid is then pumped into a device called a generator, where heat is added from an energy source to desorb the refrigerant from its solution. In a "steam fired" chiller, the energy source is steam. Once the refrigerant is revaporized, it enters the condenser and follows a standard refrigerant cycle (condenser, expansion valve, evaporator). In a double-effect machine, two individual absorption cycles are used; a high temperature absorption machine rejects energy from its condenser to the generator of a low temperature machine. A double effect absorption cycle is shown schematically in Figure 1.

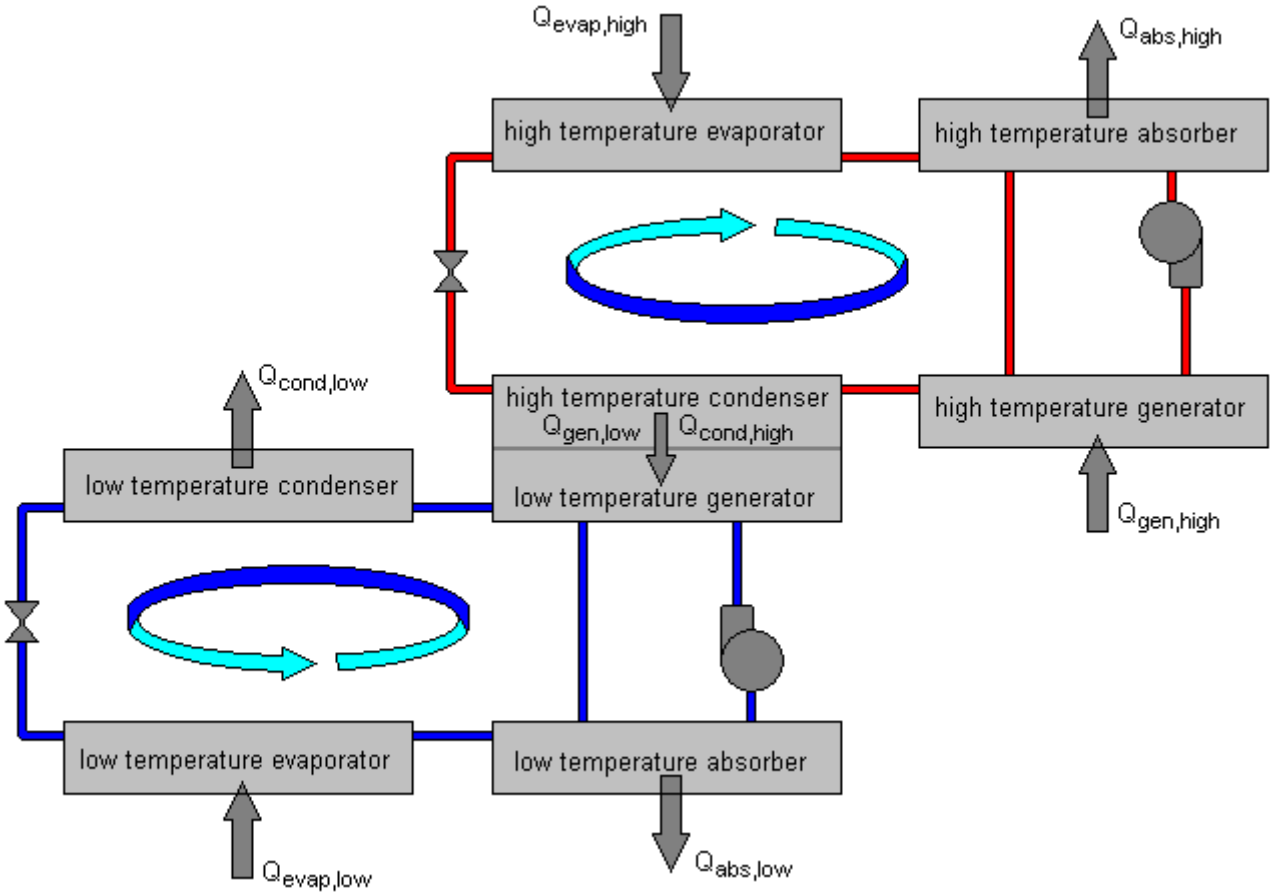


Figure 1: Double-Effect Absorption Chiller Device Schematic

The benefit of an absorption refrigerant cycles is that the energy required to pump the fluid from a low pressure in the absorber to a higher pressure in the generator is comparatively small and the remainder of the work (vaporizing the refrigerant) can be accomplished with heat instead of electricity. This fact makes absorption chillers especially valuable in cogeneration systems where waste heat from steam and other processes is abundant.

Type676 uses a catalog data lookup approach to predict the performance of a double effect, steam water fired absorption chiller. In this design, the heat required to desorb the refrigerant is provided by a steam source. The energy of the refrigerant absorption process is rejected to a cooling water stream and the machine is designed to chill a third fluid stream to a user designated set point temperature. Because of the catalog data lookup approach, Type676 is not applicable over every range of inlet conditions. As with other components that rely on catalog data, the performance of the machine can be predicted and interpolated within the range of available data but cannot be extrapolated beyond the range. One beneficial feature to this model is that the data, taken directly from manufacturer's catalogs available online is normalized so that once a data file has been created, it may be used to model absorption machines other than the specific size for which the data was intended. In creating example data files for distribution with this component, the developers noted that there was very little variability between data files once they were normalized. Using normalized data and the model's first two parameters (design coefficient of performance and design capacity) the user can adjust the size of the machine being modeled to whatever is appropriate to the system being simulated.

Type676 requires four data files, all to be specified in the standard TRNSYS data format. Since example data files are included with this component, every effort should be made to preserve the syntactical format of the data. The first file (example in: \Catalog_Data\ABSCHLs\Double-Effect\Steam-Fired\Sample\S1.dat) contains values of normalized fraction of full load capacity for various values of entering steam gauge pressure (in kPa). The second data file (example located in: \Catalog_Data\ABSCHLs\Double-Effect\Steam-Fired\Sample\S2.dat) provides values of fraction of nominal capacity for various values of chilled water set point and entering cooling water temperature (each specified in ºC). The third file (example located in: \Catalog_Data\ABSCHLs\Double-Effect\Steam-Fired\Sample\S3.dat) provides values of fraction of design energy input for various values of entering cooling water temperature (ºC) and fraction of design load at current conditions. The final file (example located in: \Catalog_Data\ABSCHLs\Double-Effect\Steam-Fired\Sample\S4.dat) provides values of condensate drain temperature for various values of steam inlet gauge pressure (in kPa). In essence the first data file provides the user with the machine's nominal capacity given the conditions of the steam source. The second provides the user with the fraction of that nominal capacity available given the conditions of the cooling water stream and the desired chilled water set point. The third file provides the user with the fraction of the rated input energy that will be required in order to carry out the process and the fourth provides information about the state of the condensate that drains from the steam source. The example files are duplicated at the end of this document for reference.

Upon determining that the absorption chiller is ON based on the value of the control signal, Type676 first calls the TRNSYS Dynamic Data subroutine with the user specified entering steam gauge pressure. Dynamic Data reads the appropriate data file and returns the fraction of the machine's rated capacity that is available given the entering steam conditions. The current capacity is referred to as the nominal capacity. Type676 then queries Dynamic Data a second time to obtain the fraction of nominal capacity that is available given the entering cooling water temperature and the chilled water set point from the second data file. The capacity of the machine at any given time, therefore is given by equation 676.1.

$$Capacity = f_{FullLoadCapacity} * f_{NominalCapacity} Capacity_{Rated} \quad \text{(Eq. 676.1)}$$

The total amount of energy that must be removed from the chilled water stream by the machine is given by 676.2

$$\dot{Q}_{remove} = \dot{m}_{chw} Cp_{chw} \left(T_{chw,in} - T_{chw,set} \right) \quad \text{(Eq. 676.2)}$$

In order to read the third data file, the fraction of design load must be known. The fraction of design load is simply the amount of energy that must be removed from the chilled fluid stream divided by the machine's rated capacity (in other words the maximum amount of energy that the machine is capable of removing from the chilled fluid stream.) It is calculated using equation 676.3.

$$f_{DesignLoad} = \frac{\dot{Q}_{remove}}{Capacity_{Rated}} \quad \text{(Eq. 676.3)}$$

Dynamic Data is queried a third time, this time with the fraction of design energy removal required (as calculated by 676.3) and the cooling water inlet temperature that is specified as an input to the model. The energy delivered to the chiller by the steam source is then calculated using equation 676.4

$$\dot{Q}_{steam} = \frac{Capacity_{Rated}}{COP_{Rated}} f_{DesignEnergyInput} \quad \text{(Eq. 676.4)}$$

where $f_{\text{DesignEnergyInput}}$ is the value returned by the third call to Dynamic Data and is the value specified in the example S3 data file.

The final call to Dynamic Data is made to determine the temperature of condensate flowing from the steam source given the entering steam pressure. Type676 performs some calculations to determine the entire state of the exiting steam. The TRNSYS Steam Properties utility subroutine is called with the user specified entering steam conditions (steam temperature and pressure). The Steam Properties routine returns values of steam temperature, pressure, enthalpy, and quality. A returned steam quality less than 1 indicates that the user has specified unsaturated steam conditions. In this case, Type676 resets the entering steam condition to a saturated conditions at the entering temperature and warns the user.

The steam exits the absorption chiller at the condensate temperature corresponding to the inlet pressure and indicated in the fourth data file. Steam fired absorption chillers are designed in such a way that the steam source exits at saturated liquid conditions. The exiting steam conditions (condensate temperature, pressure and enthalpy) are therefore determined by calling the TRNSYS Steam Properties routine with the temperature returned by Dynamic Data and with a quality of zero.

The flow rate of steam required to meet the current load at current conditions is given by equation 676.5.

$$\dot{m}_{steam} = \frac{\dot{Q}_{steam}}{\left(h_{steam,in} - h_{cond,out} \right)} \quad \text{(Eq. 676.5)}$$

The chilled water outlet temperature, which should be the set point temperature but may be greater if the machine is capacity limited, is then calculated as

$$T_{chw,out} = T_{chw,in} - \frac{MIN\left(\dot{Q}_{remove}, Capacity \right)}{\dot{m}_{chw} Cp_{chw}} \quad \text{(Eq. 676.6)}$$

In order for energy to balance in the device, the energy rejection to the cooling water stream is given by 676.7

$$\dot{Q}_{cw} = \dot{Q}_{chw} + \dot{Q}_{steam} + \dot{Q}_{aux} \quad \text{(Eq. 676.7)}$$

The term Q_{aux} accounts for the energy consumed by the various parasitics in the system such as solution pumps, fluid stream pumps, controls. The auxiliary energy requirement of the device is specified among the model's parameters. Type676 assumes that the entire auxiliary energy requirement is used whenever the device is in operation, regardless of whether or not it is operating at full capacity.

Lastly, the temperature of the exiting cooling water stream can be calculated using equation 676.8.

$$T_{cw,out} = T_{cw,in} + \frac{\dot{Q}_{cw}}{\dot{m}_{cw} Cp_{cw}} \quad \text{(Eq. 676.8)}$$

The device COP is defined as shown in equation 676.9

$$COP = \frac{\dot{Q}_{chw}}{\dot{Q}_{aux} + \dot{Q}_{steam}} \quad \text{(Eq. 676.9)}$$

The following tables contain example data from the three files required by Type676.

Sample S1.dat

```
103.42 137.90 206.84 275.79 344.74 413.69 482.63 551.58 620.53 689.48 758.42 792.90   !Steam Inlet Gauge
Pressure (kPa)
0.0                     !Fraction of Full-Load Capacity at 103.42 kPa
0.20                    !Fraction of Full-Load Capacity at 137.90 kPa
0.35                    !Fraction of Full-Load Capacity at 206.84 kPa
0.47                    !Fraction of Full-Load Capacity at 275.79 kPa
0.58                    !Fraction of Full-Load Capacity at 344.74 kPa
0.65                    !Fraction of Full-Load Capacity at 413.69 kPa
0.73                    !Fraction of Full-Load Capacity at 482.63 kPa
0.80                    !Fraction of Full-Load Capacity at 551.58 kPa
0.86                    !Fraction of Full-Load Capacity at 620.53 kPa
0.92                    !Fraction of Full-Load Capacity at 689.48 kPa
0.98                    !Fraction of Full-Load Capacity at 758.42 kPa
1.00                    !Fraction of Full-Load Capacity at 792.90 kPa
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Sample S2.dat

```
4.4444  5.5556  6.6667  7.7778  8.8889       !Chilled Water Setpoint (C)
23.8889  26.6667  29.4444  32.2222  35.0000  !Entering Cooling Water Temperature (C)
1.12                              !Fraction of Nominal Capacity at 4.4444 and 23.8889
1.00                              !Fraction of Nominal Capacity at 4.4444 and 26.6667
0.84                              !Fraction of Nominal Capacity at 4.4444 and 29.4444
0.66                              !Fraction of Nominal Capacity at 4.4444 and 32.2222
0.48                              !Fraction of Nominal Capacity at 4.4444 and 35.0000
1.12                              !Fraction of Nominal Capacity at 5.5556 and 23.8889
1.08                              !Fraction of Nominal Capacity at 5.5556 and 26.6667
0.92                              !Fraction of Nominal Capacity at 5.5556 and 29.4444
0.74                              !Fraction of Nominal Capacity at 5.5556 and 32.2222
0.56                              !Fraction of Nominal Capacity at 5.5556 and 35.0000
1.12                              !Fraction of Nominal Capacity at 6.6667 and 23.8889
1.12                              !Fraction of Nominal Capacity at 6.6667 and 26.6667
1.00                              !Fraction of Nominal Capacity at 6.6667 and 29.4444
0.83                              !Fraction of Nominal Capacity at 6.6667 and 32.2222
0.65                              !Fraction of Nominal Capacity at 6.6667 and 35.0000
1.12                              !Fraction of Nominal Capacity at 7.7778 and 23.8889
1.12                              !Fraction of Nominal Capacity at 7.7778 and 26.6667
1.06                              !Fraction of Nominal Capacity at 7.7778 and 29.4444
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0.90                                    !Fraction of Nominal Capacity at 7.7778 and 32.2222
0.73                                    !Fraction of Nominal Capacity at 7.7778 and 35.0000
1.12                                    !Fraction of Nominal Capacity at 8.8889 and 23.8889
1.12                                    !Fraction of Nominal Capacity at 8.8889 and 26.6667
1.12                                    !Fraction of Nominal Capacity at 8.8889 and 29.4444
0.97                                    !Fraction of Nominal Capacity at 8.8889 and 32.2222
0.80                                    !Fraction of Nominal Capacity at 8.8889 and 35.0000
```

Sample S3.dat

```
12.7778  18.3333  23.8889  29.4444                    !Entering Cooling Water Temperatures (C)
0.0 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 1.00 !Fraction of Design Load at Current Conditions (-)
0.00                            !Fraction of Design Energy Input at 12.778 & 0.0 Fraction of Design Load
0.08                            !Fraction of Design Energy Input at 12.778 & 0.1 Fraction of Design Load
0.14                            !Fraction of Design Energy Input at 12.778 & 0.2 Fraction of Design Load
0.20                            !Fraction of Design Energy Input at 12.778 & 0.3 Fraction of Design Load
0.26                            !Fraction of Design Energy Input at 12.778 & 0.4 Fraction of Design Load
0.32                            !Fraction of Design Energy Input at 12.778 & 0.5 Fraction of Design Load
0.39                            !Fraction of Design Energy Input at 12.778 & 0.6 Fraction of Design Load
0.45                            !Fraction of Design Energy Input at 12.778 & 0.7 Fraction of Design Load
0.51                            !Fraction of Design Energy Input at 12.778 & 0.8 Fraction of Design Load
0.57                            !Fraction of Design Energy Input at 12.778 & 0.9 Fraction of Design Load
0.63                            !Fraction of Design Energy Input at 12.778 & 1.0 Fraction of Design Load
0.00                            !Fraction of Design Energy Input at 18.333 & 0.0 Fraction of Design Load
0.10                            !Fraction of Design Energy Input at 18.333 & 0.1 Fraction of Design Load
0.16                            !Fraction of Design Energy Input at 18.333 & 0.2 Fraction of Design Load
0.23                            !Fraction of Design Energy Input at 18.333 & 0.3 Fraction of Design Load
0.30                            !Fraction of Design Energy Input at 18.333 & 0.4 Fraction of Design Load
0.38                            !Fraction of Design Energy Input at 18.333 & 0.5 Fraction of Design Load
0.45                            !Fraction of Design Energy Input at 18.333 & 0.6 Fraction of Design Load
0.53                            !Fraction of Design Energy Input at 18.333 & 0.7 Fraction of Design Load
0.62                            !Fraction of Design Energy Input at 18.333 & 0.8 Fraction of Design Load
0.71                            !Fraction of Design Energy Input at 18.333 & 0.9 Fraction of Design Load
0.80                            !Fraction of Design Energy Input at 18.333 & 1.0 Fraction of Design Load
0.00                            !Fraction of Design Energy Input at 23.889 & 0.0 Fraction of Design Load
0.14                            !Fraction of Design Energy Input at 23.889 & 0.1 Fraction of Design Load
0.20                            !Fraction of Design Energy Input at 23.889 & 0.2 Fraction of Design Load
0.26                            !Fraction of Design Energy Input at 23.889 & 0.3 Fraction of Design Load
0.34                            !Fraction of Design Energy Input at 23.889 & 0.4 Fraction of Design Load
0.42                            !Fraction of Design Energy Input at 23.889 & 0.5 Fraction of Design Load
0.50                            !Fraction of Design Energy Input at 23.889 & 0.6 Fraction of Design Load
0.59                            !Fraction of Design Energy Input at 23.889 & 0.7 Fraction of Design Load
0.68                            !Fraction of Design Energy Input at 23.889 & 0.8 Fraction of Design Load
0.78                            !Fraction of Design Energy Input at 23.889 & 0.9 Fraction of Design Load
0.90                            !Fraction of Design Energy Input at 23.889 & 1.0 Fraction of Design Load
0.00                            !Fraction of Design Energy Input at 29.444 & 0.0 Fraction of Design Load
0.16                            !Fraction of Design Energy Input at 29.444 & 0.1 Fraction of Design Load
0.23                            !Fraction of Design Energy Input at 29.444 & 0.2 Fraction of Design Load
0.32                            !Fraction of Design Energy Input at 29.444 & 0.3 Fraction of Design Load
0.40                            !Fraction of Design Energy Input at 29.444 & 0.4 Fraction of Design Load
0.48                            !Fraction of Design Energy Input at 29.444 & 0.5 Fraction of Design Load
0.56                            !Fraction of Design Energy Input at 29.444 & 0.6 Fraction of Design Load
0.64                            !Fraction of Design Energy Input at 29.444 & 0.7 Fraction of Design Load
0.75                            !Fraction of Design Energy Input at 29.444 & 0.8 Fraction of Design Load
0.86                            !Fraction of Design Energy Input at 29.444 & 0.9 Fraction of Design Load
1.00                            !Fraction of Design Energy Input at 29.444 & 1.0 Fraction of Design Load
```

Sample S4.dat

```
100  200  300  400  500  600  700       !Steam Inlet Gauge Pressure (kPa)
71.0                                    !Condensate Drain Temperature at 100 kPa
77.0                                    !Condensate Drain Temperature at 200 kPa
79.0                                    !Condensate Drain Temperature at 300 kPa
82.0                                    !Condensate Drain Temperature at 400 kPa
85.0                                    !Condensate Drain Temperature at 500 kPa
91.0                                    !Condensate Drain Temperature at 600 kPa
96.0                                    !Condensate Drain Temperature at 700 kPa
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