

Thermodynamic Cycles with Simulink

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Abstract

Thermodynamic cycles can be hard to understand for undergraduate students. A Simulink model is proposed to address this issue, and simplify their understanding of ideal and complex cycles. After the user provides the thermodynamic cycle requirements, the simulator will provide the coefficient of performance and check for heat balance.

1 Introduction

1.1 Reasons Behind the Simulink Model

The Simulink model that is here proposed has been designed for the analysis of absorption refrigeration cycles. They are the most commonly studied thermodynamic cycles, and the possibility to implement such cycles in future applications is relatively high. The simulator has been successfully tested for cycles involving water and ammonia as the absorber and the refrigerant, respectively, and it has been designed to deal also with lithium bromide and water cycles. These two cycles have been chosen among many because they represent the best examples today of two different cycle studies: one for which equations of state have been developed (ammonia and water), and one where only tabular data is available (water and lithium bromide). The equations and the tabular data behind these two refrigeration cycles are quite complex. In order to allow even undergraduate students to check the output of the simulator, a simple Brayton ideal refrigeration cycle has also been modeled in a similar fashion.

1.2 The Absorption Refrigeration Cycle

Absorption refrigeration cycles are commonly used when an inexpensive thermal energy source at a temperature between 100 to 200°C is available. The performance of this kind of cycle drops of about 2.5% for each 6 degrees Celsius drop in source temperature. A careful economic study should therefore be made in case the available heat source is lower than 100 degrees Celsius [4]. In every absorption cycle there is a *refrigerant* being absorbed by a *transport medium*. The main mechanical components of an absorption refrigeration cycle are an absorber, a pump, a generator, a valve and a rectifier, as shown in the schematic of Figure 1. Cool vapor moves from the *evaporator*, through a *heat exchanger* into the *absorber*, where the absorption activity lowers the pressure and facilitates the vapor flow from the *evaporator*. Since the amount of refrigerant that can be absorbed increases as the temperature of the solution decreases, cooling liquid absorbent is circulated through the refrigerant vapor so

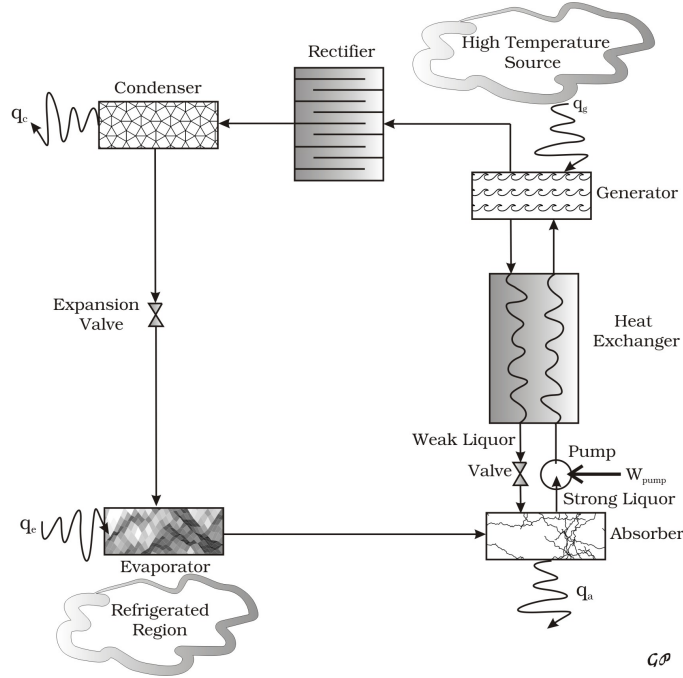


Figure 1: Absorption Refrigeration System

that the system is kept at the lowest temperature possible. The vapor releases its latent heat and heat of dilution as it goes into the liquid solution, and the process continues until the liquid solution reaches the equilibrium saturation condition. The formation of this liquid solution is an exothermic process. The liquid solution that comes out of the *absorber* is now rich in refrigerant and, for this reason, it is said to be a strong liquor. This solution now goes through the *pump* that raises its pressure and delivers it to the *heat exchanger*, and finally into the *generator*. The generator is heated by a heat source (steam, hot water, direct firing, solar cell), and it keeps heating the solution while driving ammonia vapor out of the solution in an endothermic process. The weak liquor leaves the *generator* and goes through the *heat exchanger*. Here the solution cools down, and in turn it warms the strong liquor. It now throttles into the *absorber*, and it cools down even more, while picking up more refrigerant to become again a strong liquor. The hot refrigerant vapor from the *generator* still contains some small amounts of absorbent vapor, that is taken away by the *rectifier* before going into the *condenser*. Now the solution is liquid refrigerant, and it drops in pressure after passing

through the *heat exchanger*. It finally enters the *evaporator* to complete the cycle [10].

1.3 Requirements, Performance, and Benefits

For any given thermodynamic cycles, the Simulink model will find the coefficient of performance and it will check for heat balance. The performance of an absorption cycle mainly depends on the thermodynamic properties of the combination absorbent-refrigerant. Most of the times we lack of an accurate set of thermodynamic data of the working fluid of the cycle, and an assessment of the performance of a certain cycle becomes inaccurate, if not impossible. In Chapter 2 of this paper two different ways of obtaining thermodynamic properties for $\{LiBr + H_2O\}$ and $\{H_2O + NH_3\}$ will be discussed.

The study of the performance of an absorption refrigeration cycle is complex because the system is irreversible. Some of the irreversibility comes from (but is not limited to) flow friction, and flow resistance of the working fluid. The COP is an indication of the performance of the system, and for an absorption refrigeration cycle it is defined as the ratio of the useful cooling output (in the evaporator) over the energy input (to the generator) and pump work. Therefore,

$$COP = \frac{q_e}{q_g + W_{pump}} \quad (1)$$

However, one of the major benefits of the absorption refrigeration cycle over the most commonly used vapor-compression cycle is that the compression of a liquid requires less work than the compression of a vapor. The pump work in the absorption refrigeration cycle can therefore be neglected without a major loss of accuracy. Thus,

$$COP = \frac{q_e}{q_g} \quad (2)$$

Assuming reversible conditions, (2) becomes

$$COP_{rev} = \frac{q_e}{q_g} = \left(1 - \frac{T_{environment}}{T_{source}}\right) \left(\frac{T_{cold}}{T_{environment} - T_{cold}}\right) \quad (3)$$

Therefore, when the heat source is 120 degrees Celsius, the desired cooling temperature of the refrigerated space is -10 degrees Celsius, and the environment is at 25 degrees Celsius, as

in [4], the COP for the reversible cycle comes out to be 1.8. However, the COP of an actual absorption refrigeration cycle with either $\{LiBr + H_2O\}$ or $\{H_2O + NH_3\}$ is usually below 0.7. This shows that the irreversibility of the system cannot be neglected, and that a more accurate thermodynamic analysis is needed, as shown in details in the next chapter.

2 Thermodynamic Properties of Binary Solutions

Binary solutions in real life can be hard to model theoretically, and most of the useful data we have today to assess their performance in thermodynamic cycles come from experimental results. The Simulink model is able to deal with two kinds of inputs: tabular data, like in the case of water and ammonia, and equations of state derived from experimental results, as in the case of lithium bromide and water. This section will briefly give an overview on how these two different sets of inputs can be obtained.

2.1 Tabular Data for $\{H_2O + NH_3\}$

In the mid 1930s Burgess H. Jennings and Francis P. Shannon became interested in the study of water-ammonia solutions, and they finally completed a enormous table of thermodynamic data in 1938 [10] mostly based on Wucherer's experimental results [15]. This table was made on purpose extremely large to avoid excessive interpolation, and it could not be entirely published in the paper *Refrigerating Engineering* for its dimensions. In his newer paper, Jennings [10] modified the size of his table to make it more suitable for use by engineers and scientists, and some accuracy errors were fixed. In particular temperature, pressure, and concentration values were checked for accuracy. Specific-volume data for the liquid phase at different weight concentrations was added to the original table, and enthalpy data of the liquid phase was extrapolated up to 2,800 kPa, from the original upper limit of 2,067 kPa. Also the enthalpy data of saturated vapor, strictly related to the molality of the solution, comes from Wucherer's experimental results [15]. Wucherer's results have been checked for accuracy by the more recent work of Macriss *et al.* [11], and they all agree with Wucherer

at least until an ammonia concentration of 95%. Furthermore, in calculating the enthalpy of the vapor, it was assumed that there was no heat of dilution with a vapor mixture [10], even though there must be when ammonia with steam is boiled off the liquid mixture.

The ordinates of Jennings' water-ammonia table [10] are pressures in kPa. In the abscissa there are the mass concentrations (x_f) of ammonia in the liquid water-ammonia solution. This goes from 0% (or pure water) up to 100% (or pure ammonia). For each pressure reading there are the saturation temperature in degrees Celsius for each concentration, the enthalpy (in kJ/kg) of the liquid-phase mixture (h_f), the enthalpy of the vapor (h_v) in saturation equilibrium with the liquid, and finally the mass concentration of the vapor (x_v) in saturation equilibrium with the liquid phase. Jennings [10] uses an enthalpy datum at 0 degrees Celsius, that, even though agrees with most of the steam tables, disagrees with ammonia tables, where the enthalpy is assumed to be zero at -40 degrees Celsius.

Jennings [10] continues his paper with an example on how to use this table. The key is to apply basic thermodynamic equations involving temperature, enthalpy, pressure, specific heat, and mass at each mechanical component of the absorption cycle discussed in Chapter 1. Once the heat exchange for each component has been determined by using the tables and some basic algebra, the COP of the water-ammonia cycle can be found by applying (2). The energy entering (evaporator, generator) and leaving the system (condenser, rectifier, absorber) should also closely match.

Most of the studies that have been done in the past focused on obtaining data for the water-ammonia solution to be used in engineering applications. Nevertheless, other authors in the literature, such as Tillner-Roth and Friend [14], successfully modeled the best data available today by using the Helmholtz Free Energy Formulation. A discussion on the tabular data for water-ammonia solution was preferred by the author over the free energy formulation because not enough data is available in the literature to verify the reliability of calculated thermodynamic properties in particular in the single-phase regions [14]. In the next section a method to obtain a free energy formulation will be discussed for $\{LiBr + H_2O\}$. For this

solution the data available in the literature does not cover a wide range of situations, and an equation modeled on the available data is extremely helpful in determining thermodynamic properties even when there is a lack of experimental data.

2.2 Gibbs Free Energy Formulation for $\{LiBr + H_2O\}$

Despite of an easily available table for a wide spectrum of temperature, pressure and compositions, as Jennings' table [10] for water-ammonia solutions, the data available for LiBr-water solutions is not as broad and accurate. Between 1985 and 1987 Herold [8] and Herold and Moran [9] presented a Gibbs free energy formulation for $LiBr + H_2O$ that is accurate over a wider range of temperatures, pressures, and compositions than other data compilations. The method they used is called *free energy surface method* because it involves the generation of a Gibbs free energy surface as a function of three independent thermodynamic variables (temperature, pressure, and composition) as a prerequisite to property calculations [9]. While for a pure substance two variables (temperature and pressure) are enough to define the Gibbs free energy surface, for a binary solution, such as $LiBr + H_2O$, a third variable is needed (composition). This means that the surface is three-dimensional, but in a four-dimensional variable space, and a graphic representation of the surface is difficult to visualize. Nevertheless, the free energy surface method follows the same steps for both, pure substances and binary solutions. Instead of the Gibbs free energy formulation, the Helmholtz free energy expression could have been found, as Tillner-Roth and Friend [14] did for water-ammonia solutions. However, the three independent variables involved in this formulation are density, temperature, and composition, with density data quite hard to obtain experimentally [8].

Herold started by using the laws of thermodynamics to define a general Gibbs free energy formulation for a binary solution in terms of the chemical potential (or partial molal Gibbs free energy of each component), composition (n), temperature (T), entropy (S), pressure (p), and volume (V). Thus,

$$dG = V dp - S dT + \left(\frac{\partial G}{\partial n_1} \right)_{T,p,n_j \neq 2} dn_1 + \left(\frac{\partial G}{\partial n_2} \right)_{T,p,n_j \neq 1} dn_2 \quad (4)$$

The chemical potential of component i is hence defined as

$$\mu_i = \left(\frac{\partial G}{\partial n_i} \right)_{T,p,n_{j \neq i}} \quad (5)$$

where G is the Gibbs free energy and n_i is the number of moles of the i^{th} component. In order to simplify some of the future calculations, the *fugacity* (f_i) will be now defined. Thus,

$$d(\ln f_i)_T = \frac{1}{RT} d(\mu_i)_T \quad (6)$$

Fugacity has the same unit as pressure, and it is limited by the following expression,

$$\lim_{p \rightarrow 0} \frac{f_i}{p_i} = 1 \quad (7)$$

where p_i is the pressure of component i , found by multiplying the mole fraction of component i by the system pressure. It is usually better to work with *relative fugacity* or *activity* (a_i) defined as

$$a_i = \frac{f_i}{f_i^o} \quad (8)$$

where the term with the superscript "o" refers to some specified standard state. Thus, the chemical potential can now be written as follow:

$$\mu_i = \mu_i^o + RT \ln a_i \quad (9)$$

From (4) with T and p held constant, the Gibbs-Duhem equation for a binary solution can be derived simply by integration and differentiation of the Gibbs free energy,

$$n_1 d\mu_1 + n_2 d\mu_2 = 0 \quad (10)$$

Equation (10) is a powerful relation, and it applies to any partial molal property. At this point the nature of the binary solution interested becomes crucial. Lithium-Bromide is a salt, and hence $LiBr + H_2O$ must be treated as an electrolyte solution, while the water-ammonia solution of the previous chapter was a non-electrolyte binary solution. In particular, $LiBr$ is a strong electrolyte, and dissociates almost completely in an aqueous solution. From this point on, all the quantities with the subscript 1 refers to H_2O , while the subscript 2 refers

to the electrolyte LiBr. The *standard state* also needs to be defined before continuing with the free energy surface method. The limiting relation for the electrolyte is

$$f_2^o = \lim_{m \rightarrow 0} \frac{f_2}{m^2} \quad (11)$$

where m is the molality of the solute defined as moles of electrolyte per kilogram of water. Once the electrolyte dissociates, also the activities of the ions must be considered. The *mean activity of the ions* (a_{\pm}) is hence defined as,

$$a_{\pm} = (a_2)^{1/2} \quad (12)$$

Thus, the chemical potential of LiBr from (9) with (12) can be written as,

$$\mu_2 = \mu_2^o + 2RT \ln a_{\pm} \quad (13)$$

The chemical potential of water can also be found at this point. Thus,

$$\mu_1 = \mu_1^o + \frac{2RT}{n_m} m \quad (14)$$

where n_m is the number of moles of solvent per kilogram of solvent. Therefore, the Gibbs free energy per kilogram of solvent can now be written as,

$$\frac{Gn_m}{n_1} = n_m \mu_1^o + m \mu_2^o - 2RTm + 2RTm \ln m + \frac{G_{ex}(T, p, m)}{n_1/n_m} \quad (15)$$

where the last term represents the *excess Gibbs free energy*, the non-ideal part of the equation.

This excess energy term can be approximated by the expression:

$$\frac{G_{ex}}{n_1/n_m} = 2mRT[1 - \phi_p + \ln \gamma_{\pm}] \quad (16)$$

where ϕ_p is the osmotic coefficient, a measure of the activity of water, and γ_{\pm} is the mean activity coefficient for the electrolyte. The osmotic coefficient for LiBr/Water is defined as:

$$\phi_p = -\frac{\ln a_1}{2mM_1} \quad (17)$$

where M_1 is the molecular weight of water. Debye-Huckel [5] studied and modeled the thermodynamic behavior of electrolytes, and their theory agrees with (16). The Debye-Huckel theory in particular deals with the dissociation of the electrolyte into ions, such as LiBr when it dissolves in water. The two major assumptions of the theory are: the dissociation is complete (all ions are free to move individually in the solution), and all ions have the same size and are suspended in a dielectric medium exhibiting the dielectric constant of a pure solvent. In 1923, by using these assumptions, Debye and Huckel [5] calculated the contribution to the Gibbs free energy from electrostatic forces, but their theory was valid only for concentration of electrolytes below 0.1 mole/kg.

Pitzer [12], in 1973, modified the Debye-Huckel theory by adding some more higher order empirical terms which extended the applicability of the expression to concentrations up to 0.5 mol/kg. Thus, the Debye-Huckel theory [5] after Pitzer's modification [12] for LiBr becomes:

$$\ln \gamma_{\pm} = f_{PDH}(m) + f_{CD}(m)m + Em^2 \quad (18)$$

with

$$f_{PDH}(m) = \ln \gamma_{\pm} = -A_{DH} \left[\frac{m^{1/2}}{1 + Bm^{1/2}} + \frac{2}{B} \ln (1 + Bm^{1/2}) \right] \quad (19)$$

with the Debye-Huckel constant defined as

$$A_{DH} = \frac{(e^o)^3 (2\pi\rho N_a m^o)^{1/2}}{(4\pi E_o k_* E_* T)^{3/2}} \quad (20)$$

and

$$f_{CD}(m) = 2C + \frac{2D}{\alpha^2 m} \left[1 - \left(1 + \alpha m^{1/2} - \frac{\alpha^2 m}{2} \right) e^{-\alpha m^{1/2}} \right] \quad (21)$$

where B, π and α are constants, ρ the density of water, N_a Avogadro's number, e^o the fundamental electric charge, E_o the permittivity of free space, k_* Boltzmann constant, E_o the dielectric constant of water, m^o the conventional molality of the standard state of LiBr, and m is the dimensionless molality defined as the ratio of the conventional molality (m^*) over m^o . C,D, and E are undetermined coefficients, functions of pressure and temperature created after a least square formulation method applied to all the available data on *LiBr* +

H_2O solutions. Three different least square computations were performed, and the one that fitted the data the best was developed in details by Fortier and Desnoyers [6]:

$$C(\theta, \pi) = \frac{C_1}{\theta} + C_2 + C_3\theta + C_4\theta^2 + C_5\pi\theta + C_6\pi + C_7\pi^2 + C_8\frac{\pi}{\theta} + C_9\frac{\pi^2}{\theta} + C_{10}\frac{\pi^3}{\theta} \quad (22)$$

where θ and π are the dimensionless temperature and pressure, respectively. They are defined as the ratio of the specific temperature (or pressure) over the temperature (or pressure) at the standard reference state chosen. The various C 's coefficient in (22) are found by the least square method used to fit the experimental data available in the literature. The expressions for D and E have the same form as (22). After replacing the excess free energy formulation (16) together with (18)-(22) into (15) and simplifying, it is possible to obtain the final form of the dimensionless Gibbs free energy formulation for $LiBr + H_2O$:

$$\begin{aligned} \frac{G(\theta, \pi, m)}{nRT_s} = & \frac{X_1\mu_1^o(\theta, \pi)}{RT_s} + \frac{X_2\mu_2^o(\theta, \pi)}{RT_s} - 2\theta X_2 + 2\theta X_2 \ln m + \\ & + \frac{4\theta X_2 A(\theta, \pi)}{B} \ln(1 + Bm^{1/2}) + \frac{4\theta X_2 D(\theta, \pi)}{\alpha^2} \left[1 - (1 + \alpha m^{1/2}) e^{-\alpha m^{1/2}} \right] + \\ & + \frac{2\theta X_2 E(\theta, \pi)}{3} m^2 + 2\theta X_2 C(\theta, \pi) m \end{aligned} \quad (23)$$

From the Gibbs free energy formulation it is now possible to obtain any thermodynamic property simply by differentiation. In fact, the specific volume, the enthalpy, the entropy, and the specific heat can be found, respectively:

$$v = \left(\frac{\partial g}{\partial p} \right)_T \quad (24)$$

$$h = g - T \left(\frac{\partial g}{\partial T} \right)_p \quad (25)$$

$$s = - \left(\frac{\partial g}{\partial T} \right)_p \quad (26)$$

$$c_p = -T \left(\frac{\partial^2 g}{\partial T^2} \right)_p \quad (27)$$

where g is the dimensionless Gibbs free energy as defined in (23).

2.3 Simulink Model for an Absorption Refrigeration Cycle

Herold [8] showed how all the thermodynamic properties of a binary solution such as $LiBr + H_2O$ can be found mathematically from an expression that can be easily integrated into absorption cycle computer models [9]. Previously, the thermodynamic properties of the solution $H_2O + NH_3$ were found by interpolation/extrapolation of huge data tables, as shown by Jennings [10]. This tabular method, besides giving less accurate results, is also more complicated to integrate in a computer model. Nevertheless, both methods (the tabular format and the Gibbs free energy formulation) have something in common: both give enthalpy and specific heat data, main information needed to find the COP of any absorption thermodynamic cycle, as discussed with a step-by-step approach in [10]. Jennings' method

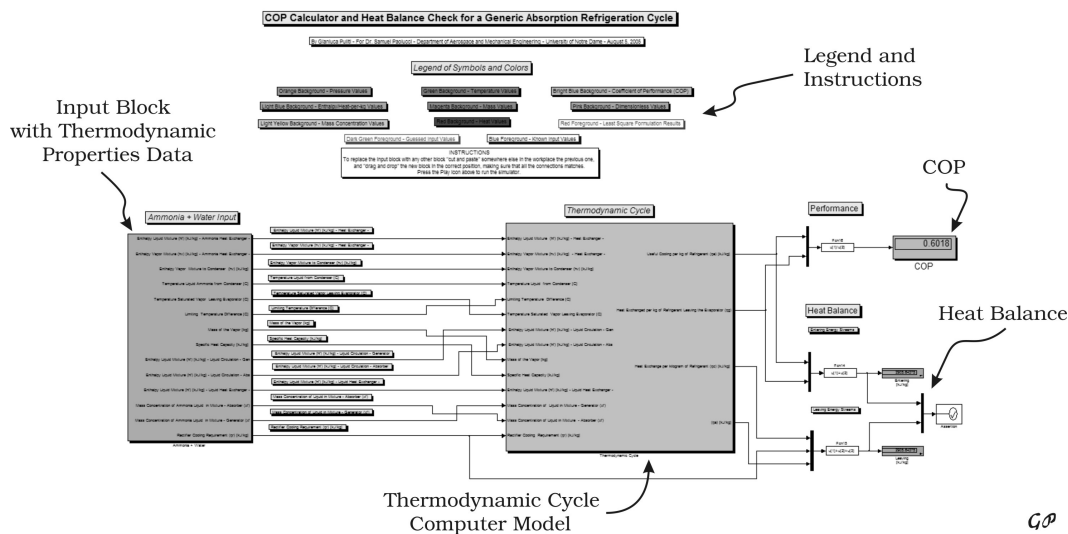


Figure 2: Absorption Refrigeration Cycle Simulink Model

was used by the author to build a Simulink model to simulate an absorption refrigeration cycle. This simulator finds the COP and checks for heat balance in and out of the system after a complete set of input data is given. The input data includes specific heat of the solution, enthalpy, and desired temperature/pressure at each mechanical part of the cycle, and mass of both refrigerant and absorbent. This data is easy to obtain since most of it is a design constrain, except for enthalpy and specific heat data that can now be calculated either by

differentiation of the Gibbs free energy [8] for LiBr-water or by interpolation/extrapolation of the tabular data given by Jennings [10] for water-ammonia solutions.

The main components of the Simulink model are illustrated in Figure 2, and a detailed view of each system and subsystem of the simulator together with the Matlab code used to find the thermodynamic properties by integration of the Gibbs free energy formulation can be found in the Appendix. The input data block for the water-ammonia has been checked for accuracy, but the LiBr-water block needed more data to be tested. It will be checked and eventually fixed in the near future, when the next version of the Simulink model will be designed.

3 Discussion and Conclusion

An absorption thermodynamic cycle has been modeled using Simulink together with Jennings's example [10]. The simulator finds the COP and checks for heat balance for a given set of input data applied to a standard absorption cycle as discussed in Chapter 1.

The input data can either be given in tabular format [10], or with an equation of state, such as the Helmholtz [14] or the Gibbs free energy [8]. In both cases, enthalpy, pressure, temperature, concentration, and specific heat data must be supplied (or calculated) for an accurate Simulink simulation. However, the model built by the author does not account for pressure or heat loss through the cycle, very likely to happen in a non ideal absorption cycle.

The most common absorption refrigeration cycles today involve a working fluid made of either $\{H_2O + NH_3\}$ or $\{LiBr + H_2O\}$. For water-ammonia solutions the literature is rich of tabular data information [10], while for Lithium Bromide-water Herold [8] derived a Gibbs free energy formulation, from which all the thermodynamic properties similar to the ones available in Jennings' tables [10] can be derived by differentiation and simple algebra.

With progress in the scientific research, new possible working fluids for an absorption cycle have been found. Ionic liquids, a special kind of salts with a melting point below the boiling temperature of water, have been reconsidered lately as a possible absorbent to be

used in an absorption cycle with carbon dioxide as the refrigerant. ILs are characterized by an almost absent vapor pressure, and this would make them very safe to work with, since they do not release any toxic vapor, and they have also the special feature of absorbing gases (such as CO_2) without phase contamination.

More solubility information is needed for $CO_2 +$ Ionic Liquids, before reaching any conclusion, but this working fluid could be a terrific breakthrough in the history of absorption refrigeration cycles because of its unique features, easy availability, safety, and its respect for the environment.

Once enough data becomes available for the solution (vapor pressure, isobaric specific heat, density, and mean activity coefficient), an equation of state could be derived with a least square method formulation to fit the data, and all the thermodynamic properties could be easily found. The data could then be plugged into the Simulink model built by the author to check for the feasibility of such an absorption cycle.

The mechanical components of the cycle could also be modified to increase the performance, and decrease the cost. For instance, the rectifier could be avoided (as it is usually done for $LiBr + H_2O$) since the carbon dioxide can be extracted from the IL with no phase contamination. Similarly, the pump could also be completely erased from the cycle, because the gaseous nature of carbon dioxide could facilitate the mass and heat transfer through the cycle.

Most of the good properties of a refrigerant/absorbent cycle (high mutual solubility, low viscosity, low absorbent volatility, and high refrigerant volatility) applies to $CO_2 +$ Ionic Liquids, but more experimental data on its solubility is still needed for any further analysis.

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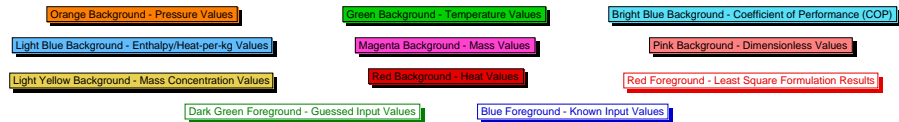
Appendix

Simulink Model

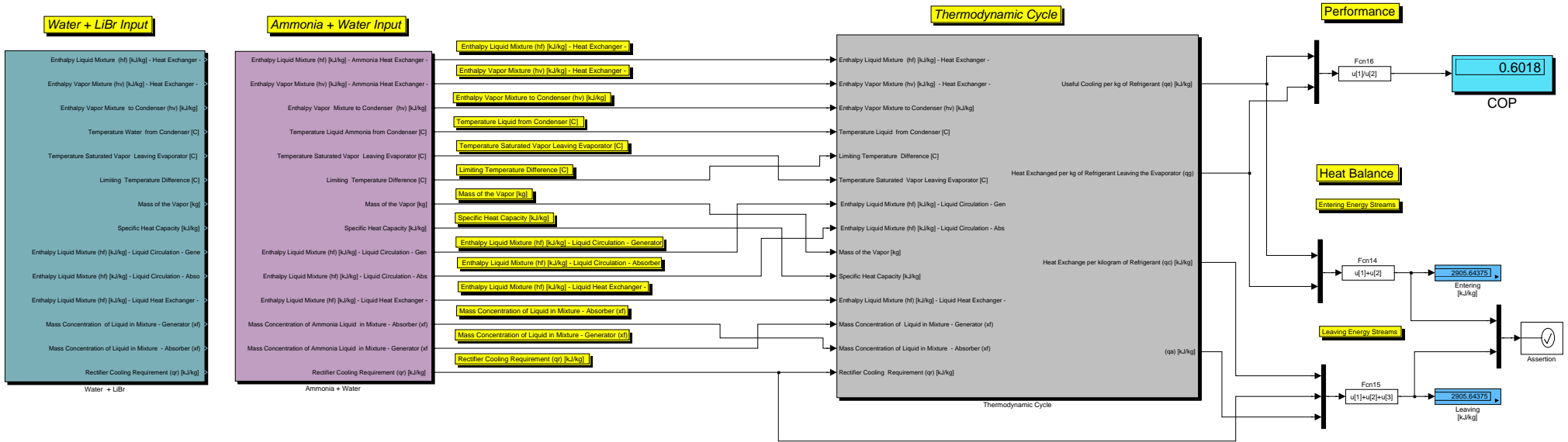
COP Calculator and Heat Balance Check for a Generic Absorption Refrigeration Cycle

By Gianluca Pulti - For Dr. Samuel Paolucci - Department of Aerospace and Mechanical Engineering - University of Notre Dame - August 5, 2005

Legend of Symbols and Colors



INSTRUCTIONS
 To replace the input block with any other block "cut and paste" somewhere else in the workplace the previous one, and "drag and drop" the new block in the correct position, making sure that all the connections matches. Press the Play icon above to run the simulator.



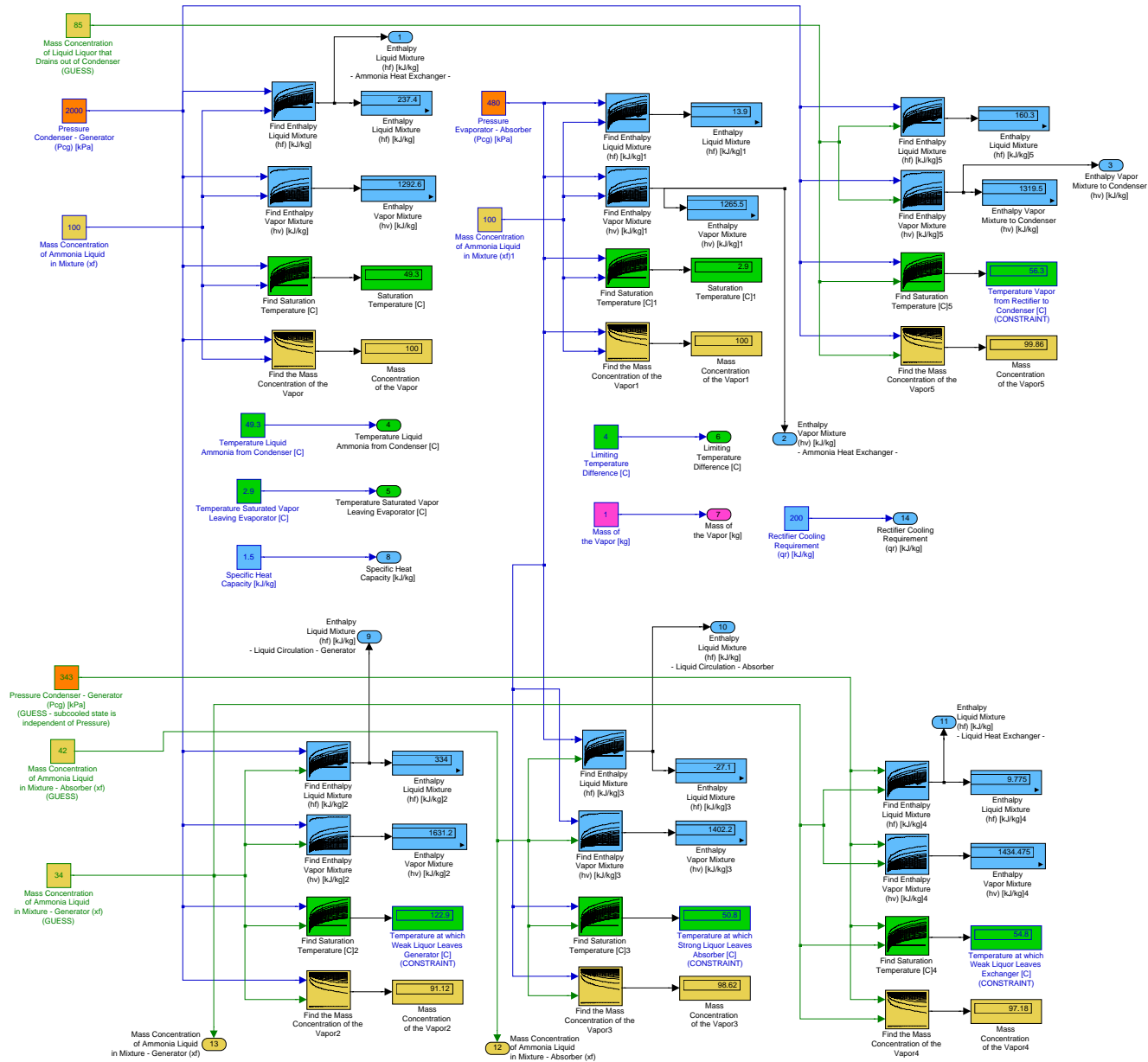
Input Thermodynamics Properties Compuator for {NH3 + Water} Absorption Cycle

Based on Tabular Data and Methodology of Jennings' Article, Source: ASHRAE

By Gianluca Puliti - For Dr. Samuel Paolucci - Department of Aerospace and Mechanical Engineering - University of Notre Dame - July 8, 2005

Legend of Symbols and Colors

- Orange Background - Pressure Values
- Green Background - Temperature Values
- Bright Blue Background - Coefficient of Performance (COP)
- Light Blue Background - Enthalpy/Heat-per-kg Values
- Magenta Background - Mass Values
- Pink Background - Dimensionless Values
- Light Yellow Background - Mass Concentration Values
- Red Background - Heat Values
- Red Foreground - Least Square Formulation Results
- Dark Green Foreground - Guessed Input Values
- Blue Foreground - Known Input Values

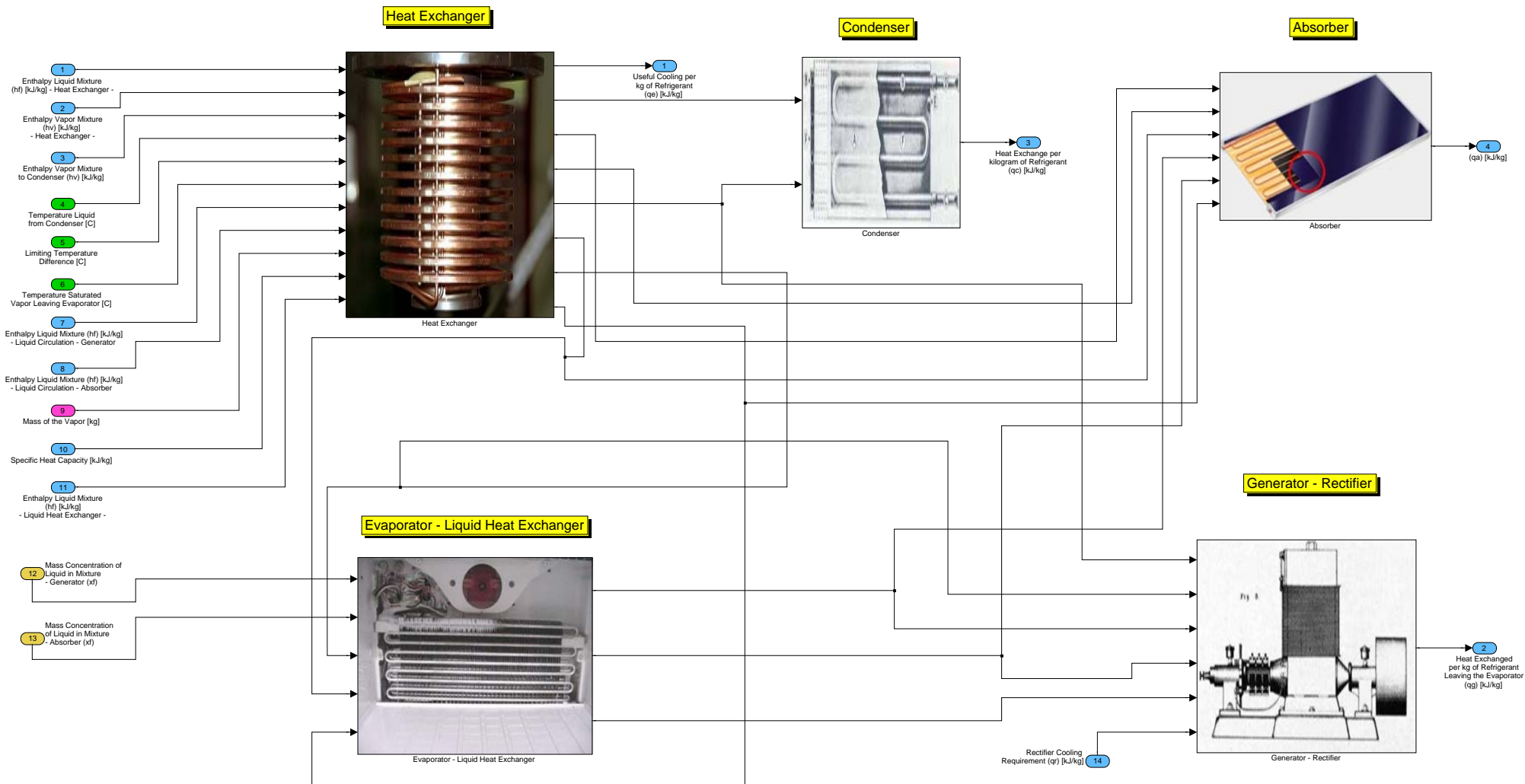


Thermodynamic Absorption Refrigeration Cycle

By Gianluca Puliti - For Dr. Samuel Paolucci - Department of Aerospace and Mechanical Engineering - University of Notre Dame - July 27, 2005

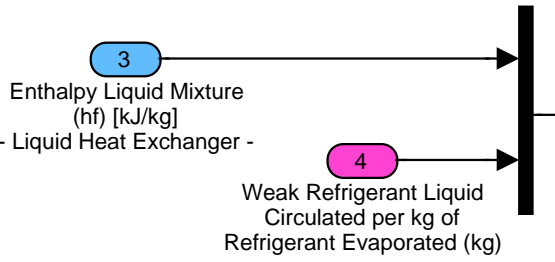
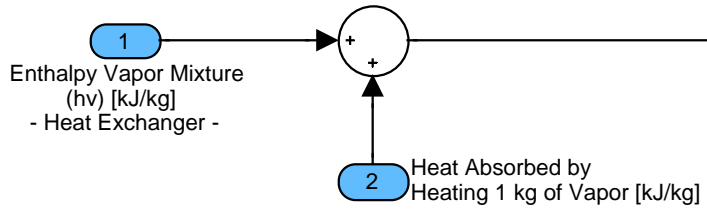
Legend of Symbols and Colors

- Orange Background - Pressure Values
- Green Background - Temperature Values
- Bright Blue Background - Coefficient of Performance (COP)
- Light Blue Background - Enthalpy/Heat-per-kg Values
- Magenta Background - Mass Values
- Pink Background - Dimensionless Values
- Light Yellow Background - Mass Concentration Values
- Red Background - Heat Values
- Red Foreground - Least Square Formulation Results
- Dark Green Foreground - Guessed Input Values
- Blue Foreground - Known Input Values



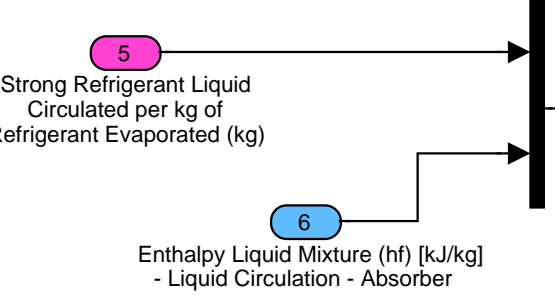
Absorber

Entering Energy Streams



Fcn11
 $u[1]*u[2]$

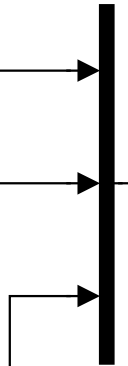
Leaving Energy Streams



Fcn12
 $u[1]*u[2]$

70.87
Weak Liquor Entering [kJ/kg]

1329
Enthalpy of 1 kg of Vapor Leaving Heat Exchanger [kJ/kg]

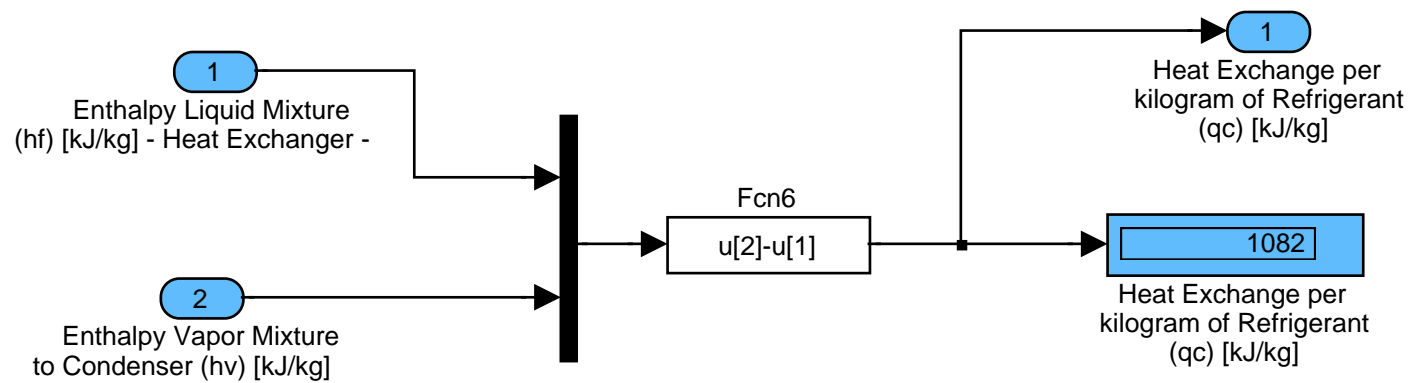


Fcn13
 $f(u)$

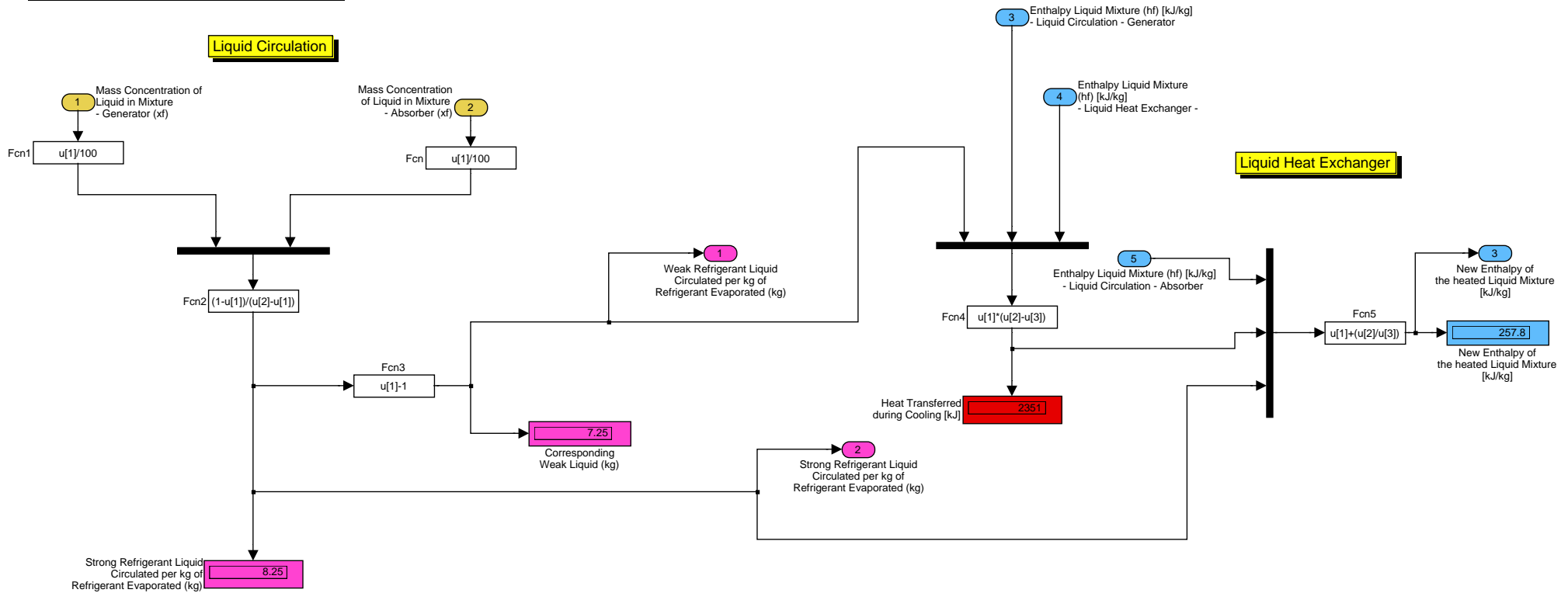
1624
Combining (qa) [kJ/kg]

1
(qa) [kJ/kg]

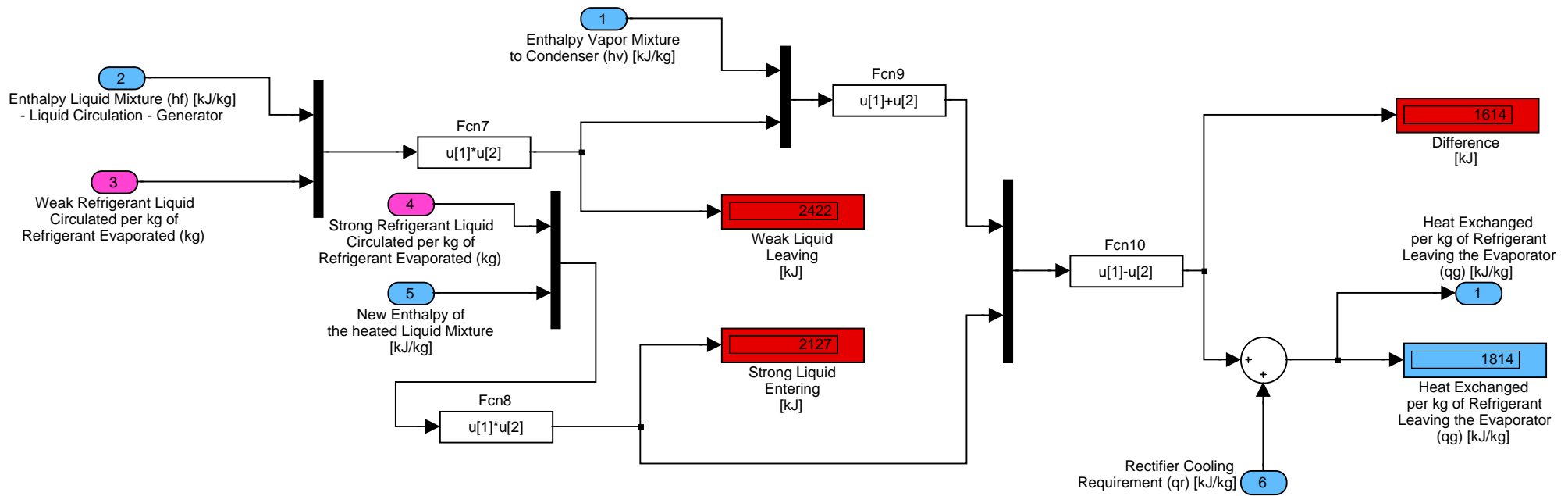
Condenser



Evaporator - Liquid Heat Exchanger



Generator - Rectifier



Heat Exchanger

