TYPE 683: ROTARY DESICCANT DEHUMIDIFIER

General Description

This component models a rotary desiccant dehumidifier containing nominal silica gel whose performance is based on equations for F1-F2 potentials developed by Jurinak [3]. The model determines the regeneration temperature at ambient humidity ratio which will dehumidify process air to the a user specified humidity ratio. The process stream and regeneration stream outlet conditions are determined as well. A schematic of the rotary wheel desiccant dehumidifier modeled by this Type is shown in Figure 1 below.

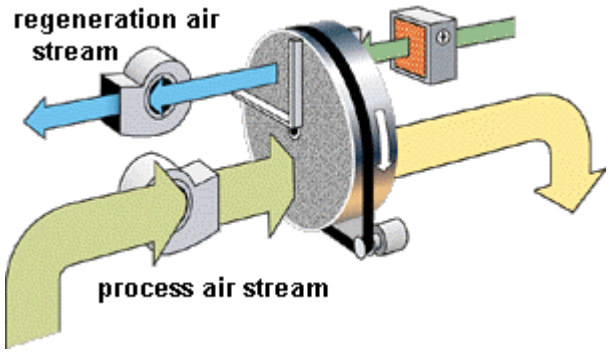


Figure 1: Rotary Wheel Desiccant Dehumidifier Schematic

Nomenclature

F1, F2	[-]	Isopotential curve fits of wave front propagation through the desiccant matrix.
T	[K]	Temperature
ω	[$kgH_20/kgAir$]	Humidity ratio
ε_{F1}, ε_{F2}	[-]	Effectiveness modifiers to the ideal isopotential curves.

Detailed Description

Desiccant dehumidifiers are devices that remove moisture from air but do so without cooling the air below its dew point [1]. Instead, they rely on the ability of hygroscopic materials (a desiccant such as silica) to adsorb water onto their surfaces. In the process of adsorption, a thin layer of molecules of one substance (usually a liquid or a gas) adheres to the surface of another substance (usually a liquid or a solid). In the case of a desiccant dehumidifier, water vapor from a process stream of moist air adsorbs onto the surface of a desiccant material. Eventually the desiccant material becomes saturated with water and must be regenerated through a drying process. There are two common configurations of desiccant dehumidifier. In the first, process air flows over a bed of desiccant until the desiccant becomes saturated. Periodically, regeneration air is passed across the bed to dry the desiccant, allowing it to then adsorb more water from the process stream. In the other configuration, the process and regeneration air streams operate at the same time and a wheel of desiccant material rotates between the streams. At any given time, a portion of the desiccant is being regenerated while the remainder is adsorbing water from the process stream. Often, the regeneration air comes from the same source as the process air and is heated to lower its relative humidity. Consequently the desiccant dehumidifier requires only a source of heat to dehumidify the process air stream.

The ideal process for adsorption is shown on psychrometric coordinates in Figure 2 below as the line from state "Pin" to "Pout."

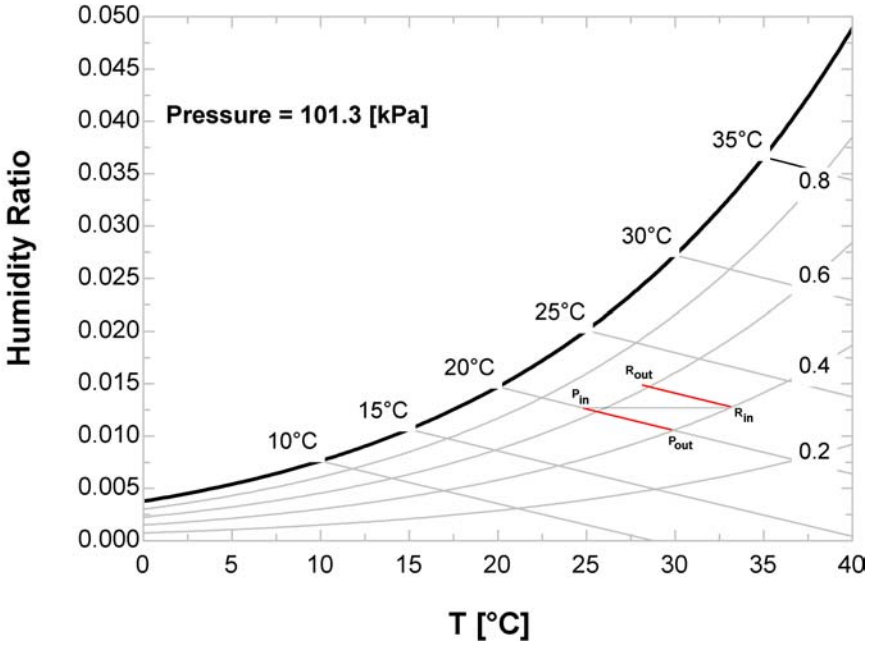


Figure 2: Ideal Desiccant Dehumidification Processes

The process air enters the dehumidifier at a certain state (usually relatively cool and moist.) As water adsorbs onto the desiccant, it gives up its heat of sorption, warming the surrounding air. The process air leaves the dehumidifier drier and warmer than it entered. The above figure also shows the ideal regeneration process from R_{in} to R_{out}. It is assumed in the figure that the air source for the regeneration stream and the process stream is the same and that the regeneration stream has been sensibly heated. The regeneration stream goes through an opposite process to the process stream. Moisture on the desiccant is subjected to low relative humidity warm air and consequently desorbs, taking the heat of sorption out of the surrounding air. The regeneration stream exits the dehumidifier cooler and more moist than it entered.

As can be seen in Figure 2 above, the ideal dehumidifier dries the process stream and adds moisture to the regeneration stream isenthalpically. In reality, the sorption and desorption processes are not isenthalpic because "waves" of moisture, temperature and enthalpy travel through the desiccant matrix contained in the wheel. Suppose the desiccant matrix is initially dry but is not being regenerated. Moist air flows over the matrix during which time, the desiccant heats up and increases in moisture content. Eventually the entire desiccant matrix becomes saturated with moisture and the outlet process air state tends towards the inlet state. The desiccant, however, does not saturate all at once. Instead, the desiccant nearest the moist air inlet becomes saturated first. Thus, a wave front travels (fairly slowly) through the desiccant behind which is saturated matrix and in front of which is unsaturated matrix. A second, much faster moving wave front moves through the desiccant just as the process air and regeneration air streams begin to flow. When the process stream is not flowing, the air in the dehumidifier comes to an equilibrium; no moisture is being added to the desiccant by the process stream and the regeneration stream, while hot does not completely dry the desiccant. When the process air begins to flow again, the hot humid air that was trapped in the dehumidifier is purged. The speed at which the wheel is designed to turn in a rotary system is adjusted in order to maintain the outlet conditions somewhere between the

two wave fronts. The fast moving wave must be purged when the humidifier comes on (requiring a lower wheel rotation speed) but the desiccant must not be allowed to saturate (requiring a high wheel speed.)

To account for the wave front propagation through the desiccant matrix, Howe [2] and Jurinak [3] developed a set of two potential functions that are in essence, curve fits of the derived wave front propagation characteristics for a given desiccant. Figure 3 shows an example of these isopotential lines (F1 and F2) for silica gel.

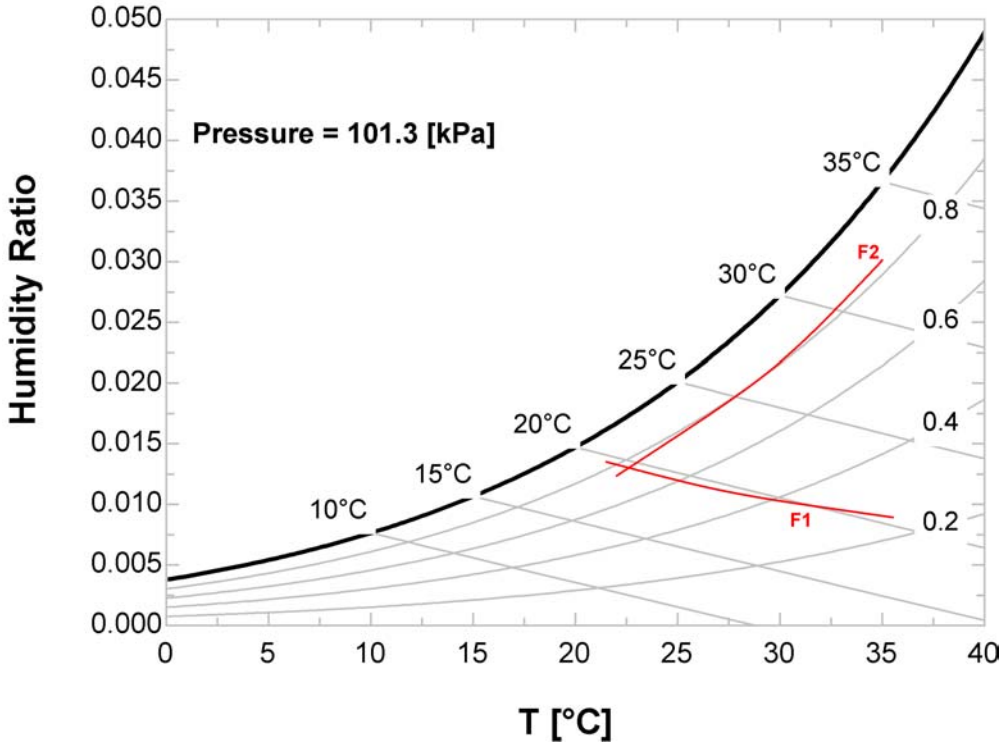


Figure 3: F1 and F2 Potential Lines Account for Wave Effects

The curvature of the F1 and F2 isopotential lines is exaggerated over the range shown in Figure 3 above to illustrate the difference in their shape as compared to that of the lines of constant relative humidity and enthalpy. The F1 and F2 equations derived by Jurinak [3] for a silica gel desiccant are

$$F1 = \frac{-2865}{T^{1.490}} + 4.344\omega^{0.8624} \qquad \text{(Eq. 683.1)}$$

$$F2 = \frac{T^{1.490}}{6360} - 1.127\omega^{0.07969} \qquad \text{(Eq. 683.2)}$$

in which T is measured in K and ω is measured in kgH_20/kgAir. Using the F1 and F2 lines of isopotential the desiccant dehumidification process is shown in Figure 4 below. Process air enters the dehumidifier at a state designated by point P, is warmed and dehumidified along the F1P potential line, exiting the humidifier at the air state labeled D*. On the regeneration side, air enters the dehumidifier at

state R and is cooled and humidified along the potential line F1R, exiting the dehumidifier at the state corresponding to the intersection of the isopotential lines labeled F2P and F1R.

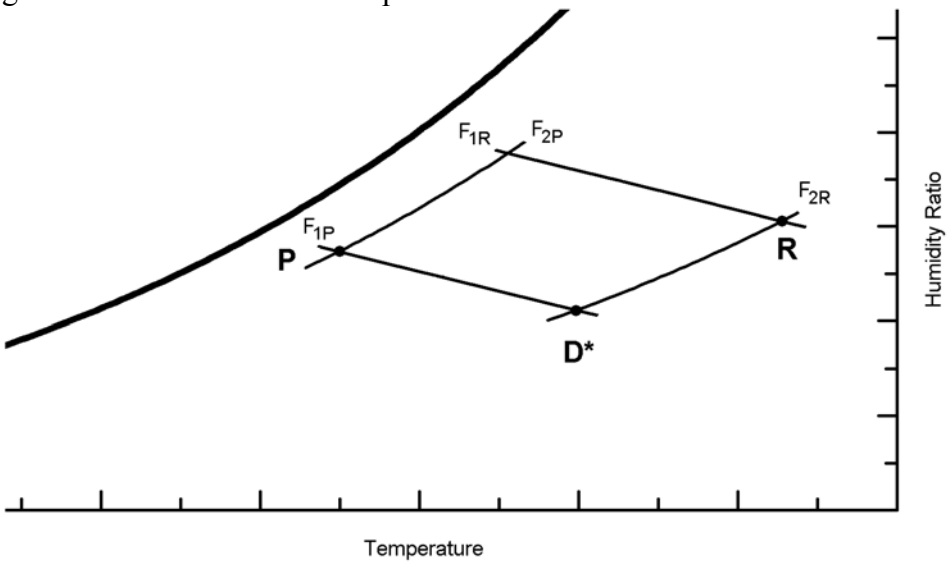


Figure 4: Dehumidifier Process Paths Using Isopotential Lines

The F1 and F2 isopotential lines are further modified for non idealities in the system by the use of two effectiveness values ε1 and ε2 as proposed by Banks [4] and defined by:

$$\varepsilon_{F1} = \frac{F1_D - F1_P}{F1_R - F1_P} \qquad \text{(Eq. 683.3)}$$

$$\varepsilon_{F2} = \frac{F2_D - F2_P}{F2_R - F2_P} \qquad \text{(Eq. 683.4)}$$

where D is the actual outlet state. The actual process can then be drawn as shown in Figure 5 where D* is the ideal outlet state and D is the actual outlet state.

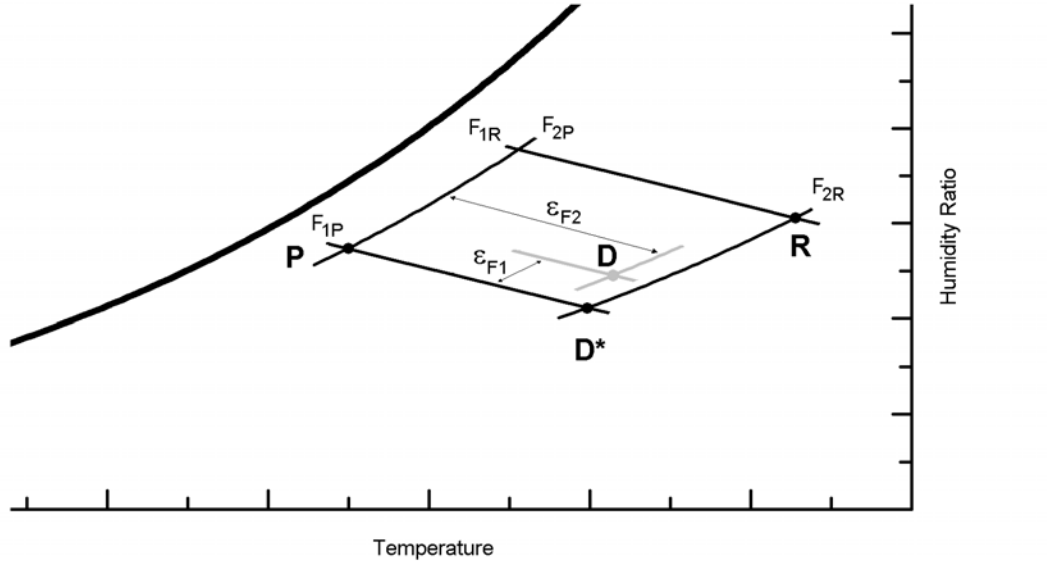


Figure 5: F1 and F2 Effectivenesses for Actual Dehumidifier Paths

Type 683 uses an iterative process to locate the actual outlet condition state (point D). The dehumidifier is not capacity limited, meaning that the user specified process air outlet humidity ratio is always met provided that the humidifier is on. The model determines the regeneration air stream temperature required to meet the humidity ratio set point. The solution technique is described below.

The user provides the model with certain known values. These are the process air and regeneration air stream mass flow rates, the process stream inlet conditions (dry bulb temperature and absolute humidity ratio), the desired process stream outlet humidity ratio, and the regeneration stream inlet absolute humidity ratio.

The model first computes the values of the F1 and F2 potential functions of the process air stream inlet. Because the value of the F1 potential function is the same at points P and D* in the figure above, the ideal outlet temperature of the process air can then be determined. Thus the temperature at point D* is now known and the value of the potential function F2 at D* can be computed. Since this value is the same as the F2 potential function at point R in the figure above, the required temperature of the regeneration air would be known. The effectivenesses (ε1 and ε2) of the dehumidifier have not yet been taken into account. Modified values of the potential functions F1 and F2 at D* are computed, corresponding to the value of the potential function at D.

Using the values of F1 and F2 at D, the model then iterates to find a corresponding value of humidity ratio at the process outlet. Once the guessed humidity ratio falls within a certain tolerance, the corresponding temperature is computed. The state of the air exiting the regeneration stream is computed using a mass balance on the entire dehumidifier and the newly calculated information about process inlet and outlet conditions and the regeneration inlet conditions.

References

[1] Mitchell, J.W. and J.E. Braun, Design, Analysis, and Control of Space Conditioning Equipment and Systems, 1997.

[2] Howe, R.R., "Model and Performance Characteristics of a Commercially-Sized Hybrid Air Conditioning System Which Utilizes a Rotary Desiccant Dehumidifier," MS Thesis, University of Wisconsin – Madison, 1983.

[3] Jurinak, J.J., "Open Cycle Desiccant Cooling – Component Models and System Simulations," PhD Thesis, University of Wisconsin – Madison, 1982.

[4] Schultz, K.J., "The Performance of Desiccant Dehumidifier Air-Conditioning Systems Using Cooled Dehumidifiers," MS Thesis, University of Wisconsin – Madison, 1983.