New Software for Simulation of Drying and Evaporation Systems

ZHENXIANG GONG

Simprotek Corporation, 7375 Rollingdell Dr., Suite 41, Cupertino,
California, 95014 USA, email: zhenxiang_gong@simprotek.com

This paper presents capabilities of a new drying software package, entitled Simprosys. The basic features of this user-friendly software, designed for practicing engineers as well as instructors and students in process design courses. Some illustrations are included to demonstrate the application of this package.

1. Introduction

Drying related process simulation requires intensive calculations of not only the states of humid gas for convective dryers, which constitute over 90 percent of all industrial dryers, but also special state variables such as wet-bulb temperature as well as absolute and relative humidity. Due to the nonlinearity of these calculations, humidity charts were developed a century ago and have been widely used. However, using the century old humidity charts for drying related calculations is obviously inadequate in this electronic age.

Given the high price of oil during the past few years and the likelihood that this will not change, energy conservation technology will once again become a focal point for both industry and academia. Thus it is important to design and operate dryers optimally and respond to changes in process variable.

Simprosys, perhaps the first software of its kind, was developed by Simprotek Coporation (www.simprotek.com) specifically for drying and evaporation based flowsheets.

2. Motivation and Development of Simprosys

Hysys is a successful software package for oil and gas related process simulations. With Hysys it is easy for engineers to lay out a flowsheet and do the necessary heat/mass balance calculations. They can thus easily study the effects of input parameters on output parameters in a complex flowsheet that contains dozens of unit operations.

As is well known, Hysys was designed for materials of very well defined chemical compositions and its calculations are mainly based on gas state equations. Therefore, its foundation, the stream model, is based on temperature, pressure, and enthalpy. It may not readily deal with drying-related simulations since such simulations need specific state variables such as wet bulb temperature as well as relative and absolute humidity that are difficult to incorporate into the Hysys stream model.

Simprosys was developed using the most advanced software technology, Microsoft .Net and C#, to fill the void of process simulation for materials that do not have a clear definition of compositions. It is started with drying and evaporation as its typical target processes. However, this does not limit the software only to such processes.

The drying models incorporated in Simprosys are based on extensive studies of the most authoritative handbooks by Mujumdar [1], Masters [2] and Perry [3] etc. and many advanced drying literatures such as by Kemp [4, 5]. The other unit operation models in Simprosys are based on Perry [4], Ibarz and Barbosa-Canovas [6] and Chopey [7], Reynolds [8] etc. and many other handbooks.

3. Applications of Simprosys

Using the unit operation modules provided by Simprosys, one can construct any drying and evaporation related process for design and analyze it. One can also readily explore different arrangements of unit operations and experiment with different operating conditions to optimize alternate designs and operations.

Two examples are presented here to demonstrate the applications of Simprosys.

Example 1 -- A Drying Flowsheet with Recycled Exhaust Gas Stream

The material to be dried is wet solid particles. Feed moisture content = 0.05 kg/kg wet basis. Feed temperature = 10 ^{o}C. Product temperature = 50 ^{o}C. Product moisture content = 0.002 kg/kg wet basis. Specific heat of the absolute dry material = 1.26 kJ/kg ^{o}C. Mass flow rate wet basis = 2000 kg/hr.

Drying air: Initial pressure = 101.3 kPa. Initial temperature (dry-bulb) = 10 ^{o}C. Initial relative humidity = 0.3. Mass flow rate wet basis = 6400 kg/hr.

Drying air goes through an air filter with a pressure drop of 0.3 kPa. Assume dust volume concentration is 0.1 g/m^3, collection efficiency of the air filter is 99.8% and filtration velocity is 2.5 m/s. Drying air then goes through a fan (the efficiency is 0.7) to gain 3 kPa static pressure, then through a heater to be heated to 90 ^{o}C before going to the dryer. Pressure drop of air in heater is 0.8 kPa. Pressure drop of air in dryer is 1.2 kPa. The exhaust air entrains 0.1% of the total material. It goes through a cyclone to collect 95% of the entrained dust material. Pressure drop of the cyclone is 0.6 kPa. Half of the exhaust gas from the cyclone goes through a fan (the efficiency of the fan is 0.7) to gain 1.8 kPa static pressure and then is recycled back to the dryer's gas inlet.

The established flowsheet using Simprosys is displayed in Figure 1. The simulated result is shown in Figure 2.

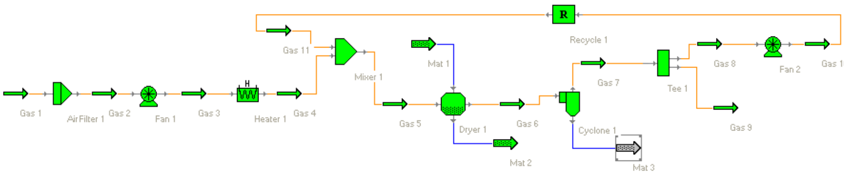
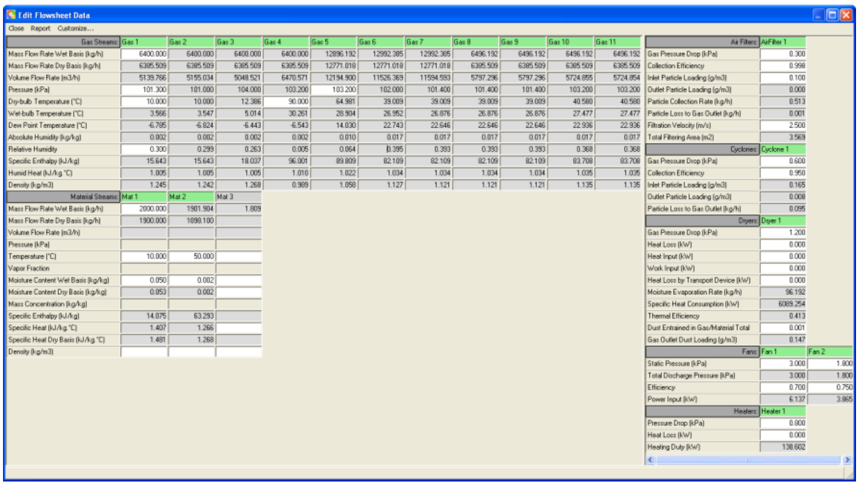


Figure 1. A Flowsheet with Recycled Exhaust Gas Stream



Gas Streams:	Gas 1	Gas 2	Gas 3	Gas 4	Gas 5	Gas 6	Gas 7	Gas 8	Gas 9	Gas 10	Gas 11
Mass Flow Rate Wet Basis (kg/h)	6400.000	6400.000	6400.000	6400.000	12896.192	12992.385	12992.385	6496.192	6496.192	6496.192	6496.192
Mass Flow Rate Dry Basis (kg/h)	6385.509	6385.509	6385.509	6385.509	12771.018	12771.018	12771.018	6385.509	6385.509	6385.509	6385.509
Volume Flow Rate (m3/h)	5139.766	5155.034	5048.521	6470.571	12194.900	11526.369	11594.593	5797.296	5797.296	5724.855	5724.854
Pressure (kPa)	101.300	101.000	104.000	103.200	103.200	102.000	101.400	101.400	101.400	103.200	103.200
Dry-bulb Temperature (°C)	10.000	10.000	12.386	90.000	64.981	39.009	39.009	39.009	39.009	40.580	40.580
Wet-bulb Temperature (°C)	3.566	3.547	5.014	30.261	28.904	26.952	26.876	26.876	26.876	27.477	27.477
Dew Point Temperature (°C)	-6.785	-6.824	-6.443	-6.543	14.030	22.743	22.646	22.646	22.646	22.936	22.936
Absolute Humidity (kg/kg)	0.002	0.002	0.002	0.002	0.010	0.017	0.017	0.017	0.017	0.017	0.017
Relative Humidity	0.300	0.299	0.263	0.005	0.064	0.395	0.393	0.393	0.393	0.368	0.368
Specific Enthalpy (kJ/kg)	15.643	15.643	18.037	96.001	89.809	82.109	82.109	82.109	82.109	83.708	83.708
Humid Heat (kJ/kg.°C)	1.005	1.005	1.005	1.010	1.022	1.034	1.034	1.034	1.034	1.035	1.035
Density (kg/m3)	1.245	1.242	1.268	0.989	1.058	1.127	1.121	1.121	1.121	1.135	1.135

Material Streams:	Mat 1	Mat 2	Mat 3
Mass Flow Rate Wet Basis (kg/h)	2000.000	1901.904	1.809
Mass Flow Rate Dry Basis (kg/h)	1900.000	1898.100	
Volume Flow Rate (m3/h)			
Pressure (kPa)			
Temperature (°C)	10.000	50.000	
Vapor Fraction			
Moisture Content Wet Basis (kg/kg)	0.050	0.002	
Moisture Content Dry Basis (kg/kg)	0.053	0.002	
Mass Concentration (kg/kg)			
Specific Enthalpy (kJ/kg)	14.075	63.293	
Specific Heat (kJ/kg.°C)	1.407	1.266	
Specific Heat Dry Basis (kJ/kg.°C)	1.481	1.268	
Density (kg/m3)			

Air Filters:	AirFilter 1
Gas Pressure Drop (kPa)	0.300
Collection Efficiency	0.998
Inlet Particle Loading (g/m3)	0.100
Outlet Particle Loading (g/m3)	0.000
Particle Collection Rate (kg/h)	0.513
Particle Loss to Gas Outlet (kg/h)	0.001
Filtration Velocity (m/s)	2.500
Total Filtering Area (m2)	3.569

Cyclones:	Cyclone 1
Gas Pressure Drop (kPa)	0.600
Collection Efficiency	0.950
Inlet Particle Loading (g/m3)	0.165
Outlet Particle Loading (g/m3)	0.008
Particle Loss to Gas Outlet (kg/h)	0.095

Dryers:	Dryer 1
Gas Pressure Drop (kPa)	1.200
Heat Loss (kW)	0.000
Heat Input (kW)	0.000
Work Input (kW)	0.000
Heat Loss by Transport Device (kW)	0.000
Moisture Evaporation Rate (kg/h)	96.192
Specific Heat Consumption (kW)	6089.254
Thermal Efficiency	0.413
Dust Entrained in Gas/Material Total	0.001
Gas Outlet Dust Loading (g/m3)	0.147

Fans:	Fan 1	Fan 2
Static Pressure (kPa)	3.000	1.800
Total Discharge Pressure (kPa)	3.000	1.800
Efficiency	0.700	0.750
Power Input (kW)	6.137	3.865

Heaters:	Heater 1
Pressure Drop (kPa)	0.800
Heat Loss (kW)	0.000
Heating Duty (kW)	138.602

Figure 2. Simulation Results of Example 1

With Simprosys it is easy specify the absolute humidity of the fresh air in stead of relative humidity, or specify the heating duty of the heater rather than the air inlet temperature of the dryer to simulate the flowsheet. One can also change the material inlet temperature and/or moisture content to see how the air outlet temperature and humidity change.

Example 2 -- A Drying Flowsheet with Recycled Material Stream

The material being dried is solid particles. Initial moisture content = 0.25 kg/kg wet basis. Initial temperature = 20 ^{o}C. Product temperature = 75 ^{o}C. Product moisture content = 0.002 kg/kg wet basis. Specific heat of the absolute dry material = 1.26 kJ/kg ^{o}C. Mass flow rate wet basis = 1000 kg/hr.

Drying air has the following conditions: Initial pressure = 101.3 kPa. Initial temperature = 20 ^{o}C. Initial Relative Humidity = 0.3. Mass Flow Rate wet basis = 10000 kg/hr

Drying air needs to go through an air filter first. Pressure drop in the air filter is 0.3 kPa. Assume dust volume concentration is 0.1 g/m^3, collection efficiency of the air filter is 99.8% and filtration velocity is 2.5 m/s. Drying air then goes through a fan (the efficiency of the fan is 0.7) to gain 3 kPa static pressure, then through a heater with a heating duty of 246 kW. Pressure drop of air in heater and dryer is 0.8 kPa and 1.2 kPa respectively. The exhaust air of the dryer entrains 0.1% of the total material into the dryer's gas outlet stream. The gas outlet stream needs to go through a cyclone to collect the entrained dust material. Collection efficiency of the cyclone is 95%. Pressure drop of air in the cyclone is 0.6 kPa.

The dryer requires that the feed moisture content (wet basis) is less than 0.15 kg/kg. As is known, initial moisture content (wet basis) of the material is 0.25 kg/kg. One solution is to mix a portion of the dried material product with the fresh material to decrease the moisture content to the required moisture content level and then feed the dryer.

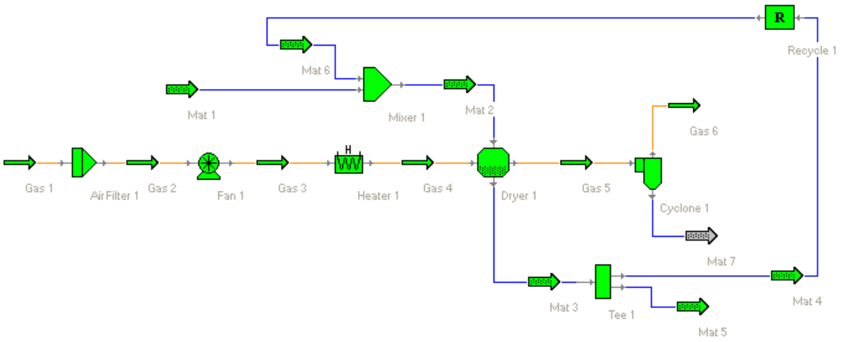
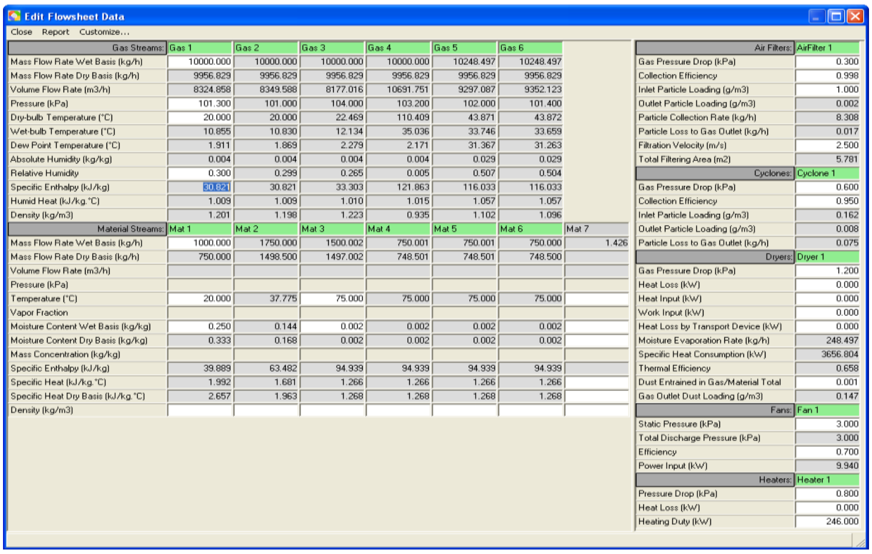


Figure 3. A Flowsheet with Recycled Material Stream



Gas Streams:	Gas 1	Gas 2	Gas 3	Gas 4	Gas 5	Gas 6
Mass Flow Rate Wet Basis (kg/h)	10000.000	10000.000	10000.000	10000.000	10248.497	10248.497
Mass Flow Rate Dry Basis (kg/h)	9956.829	9956.829	9956.829	9956.829	9956.829	9956.829
Volume Flow Rate (m3/h)	8324.858	8349.588	8177.016	10691.751	9297.087	9352.123
Pressure (kPa)	101.300	101.000	104.000	103.200	102.000	101.400
Dry-bulb Temperature (°C)	20.000	20.000	22.469	110.409	43.871	43.872
Wet-bulb Temperature (°C)	10.855	10.830	12.134	35.036	33.746	33.659
Dew Point Temperature (°C)	1.911	1.869	2.279	2.171	31.367	31.263
Absolute Humidity (kg/kg)	0.004	0.004	0.004	0.004	0.029	0.029
Relative Humidity	0.300	0.299	0.265	0.005	0.507	0.504
Specific Enthalpy (kJ/kg)	30.821	30.821	33.303	121.863	116.033	116.033
Humid Heat (kJ/kg.°C)	1.009	1.009	1.010	1.015	1.057	1.057
Density (kg/m3)	1.201	1.198	1.223	0.935	1.102	1.096

Material Streams:	Mat 1	Mat 2	Mat 3	Mat 4	Mat 5	Mat 6	Mat 7
Mass Flow Rate Wet Basis (kg/h)	1000.000	1750.000	1500.002	750.001	750.001	750.000	1.426
Mass Flow Rate Dry Basis (kg/h)	750.000	1498.500	1497.002	748.501	748.501	748.500	
Volume Flow Rate (m3/h)							
Pressure (kPa)							
Temperature (°C)	20.000	37.775	75.000	75.000	75.000	75.000	
Vapor Fraction							
Moisture Content Wet Basis (kg/kg)	0.250	0.144	0.002	0.002	0.002	0.002	
Moisture Content Dry Basis (kg/kg)	0.333	0.168	0.002	0.002	0.002	0.002	
Mass Concentration (kg/kg)							
Specific Enthalpy (kJ/kg)	39.889	63.482	94.939	94.939	94.939	94.939	
Specific Heat (kJ/kg.°C)	1.992	1.681	1.266	1.266	1.266	1.266	
Specific Heat Dry Basis (kJ/kg.°C)	2.657	1.963	1.268	1.268	1.268	1.268	
Density (kg/m3)							

Air Filters:	AirFilter 1
Gas Pressure Drop (kPa)	0.300
Collection Efficiency	0.998
Inlet Particle Loading (g/m3)	1.000
Outlet Particle Loading (g/m3)	0.002
Particle Collection Rate (kg/h)	8.308
Particle Loss to Gas Outlet (kg/h)	0.017
Filtration Velocity (m/s)	2.500
Total Filtering Area (m2)	5.781
Cyclones:	**Cyclone 1**
Gas Pressure Drop (kPa)	0.600
Collection Efficiency	0.950
Inlet Particle Loading (g/m3)	0.162
Outlet Particle Loading (g/m3)	0.008
Particle Loss to Gas Outlet (kg/h)	0.075
Dryers:	**Dryer 1**
Gas Pressure Drop (kPa)	1.200
Heat Loss (kW)	0.000
Heat Input (kW)	0.000
Work Input (kW)	0.000
Heat Loss by Transport Device (kW)	0.000
Moisture Evaporation Rate (kg/h)	248.497
Specific Heat Consumption (kW)	3656.804
Thermal Efficiency	0.658
Dust Entrained in Gas/Material Total	0.001
Gas Outlet Dust Loading (g/m3)	0.147
Fans:	**Fan 1**
Static Pressure (kPa)	3.000
Total Discharge Pressure (kPa)	3.000
Efficiency	0.700
Power Input (kW)	9.940
Heaters:	**Heater 1**
Pressure Drop (kPa)	0.800
Heat Loss (kW)	0.000
Heating Duty (kW)	246.000

Figure 4. Simulation Results of Example 2

A tee is required to split the product material into two streams. One goes through a recycle and mixes with the fresh material in a mixer and then introduced into the dryer material inlet. The established flowsheet is displayed in Figure 3. The simulated result is shown in Figure 4.

Simulation results indicate that one half of the dry product from the dryer needs to be mixed with the original material to satisfy the material inlet moisture content requirement.

With Simprosys the designer can specify the absolute humidity of the fresh air instead of the relative humidity, or specify the air inlet temperature of the dryer rather than the heating duty of the heater to simulate the flowsheet. It is also possible to change the material inlet temperature and/or moisture content, or the dry product ratio recycled (e.g. 40% or 60% dry product to be recycled) to see how the air outlet temperature and humidity are affected.

4. Potential Roles of Simprosys in Practice

Based on design requirements an engineer can quickly layout his/her flowsheet and compute heat/mass/pressure balances for their designed plant using Simprosys and obtain the necessary process parameters e.g. air flow rate to the dryer, the capacity and power requirements of the blower, the heat duty of the heater, the exhaust dust concentration of the cyclone or scrubber, etc. He/she can then specify appropriate equipment based on the simulation results.

A process engineer can simulate an existing plant by easily laying out the plant on a flowsheet with Simprosys and input the operating conditions of the plant to see how efficient the operation is. Then he/she can try different operating conditions and optimize the energy efficiency of the operation.

University instructors will find Simprosys an efficient teaching tool for undergraduate and postgraduate teaching of process design in chemical engineering, food and agricultural engineering, etc. With this software package students can readily perform extensive what-if analysis which will otherwise take an unrealistically long time to accomplish. They can also use Simprosys to demonstrate effects of various input parameters on the output parameters for a typical plant. Practicing engineers and scientists can use Simprosys as a self-learning tool.

5. Concluding Remarks

Examples presented here show only a very small part of the functionalities Simprosys possesses. Interested readers may visit www.simprotek.com to download a free trial version of Simprosys and follow the examples in the tutorial of the software package.

Acknowledgments

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