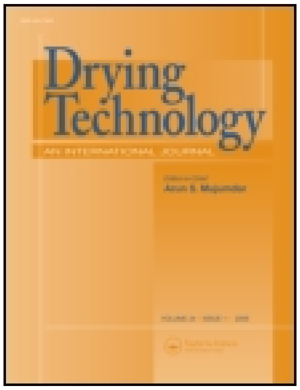

Drying Technology: An International Journal
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/ldrt20

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Published online: 09 Mar 2011.

Drying Technology, 29: 408–418, 2011

ISSN: 0737-3937 print/1532-2300 online
DOI: 10.1080/07373937.2010.498069

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This article presents a case study of Simprosys applied to the energy efficiency evaluation of an exisisting fiberboard drying production line. An energy examination of the dryer and the drying system under current operating conditions was performed using Simprosys 2.1 (Simprotek, Cupertino, CA). Detailed parametric studies of the drying system were carried out. Possible improvements for the enegry efficiency of the dryer itself and the drying system are proposed and discussed.

Keywords Dryer design; Drying simulation; Energy efficiency; Fiberboard drying; Simprosys

INTRODUCTION

Thermal drying is an energy-intensive operation to produce almost everything we need in our everyday lives. Energy audits have shown that 13–20% of industrial energy consumption goes into thermal drying operations in developed countries. With industrial dryer efficiencies ranging from just 30 to 60%, there is great potential for improvement, especially in view of rising energy costs, sustainability issues related to the carbon footprint, as well as environmental constraints on greenhouse gas emissions from burning of fossil fuels.

To improve the energy efficiency of an existing thermal drying system, appropriate process data need to be measured and/or collected as a first step. Then heat and mass balance calculations of the dryer itself as well as the drying system as a whole need to be carried out to determine the thermal efficiency of the dryer and the specific heat consumption of the drying product. Based on the calculation results, an energy efficiency target can be set. Then detailed parametric studies are necessary for possible process improvements such as recycling part of the exhaust gas and heat recovery from the exhaust gas. Note that such improvements may or may not require additional capital outlays.

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As is well known, drying-related thermal calculations are sophisticated and tedious. However, contemporary software tools such as the Simprosys software developed by Simprotek Corporation (Cupertino, CA) have made such calculations very simple and fast. Simprosys can take into consideration not only the process parameters (including the thermal efficiency of the dryer and specific heat consumption of the drying product) of the dryer itself but also the drying system as a whole, including pre- and postdryer operations such as fans, heaters, cyclones, scrubber/condenser, etc. It is a cost-effective and easy-to-use tool to evaluate and optimize dryers and drying systems. With the help of such a software tool, engineers can focus on the process itself and not worry about the complicated calculations. It can be used to improve an existing flow sheet and to evaluate alternate energy-saving strategies at the design stage itself—a highly recommended step.

This article demonstrates how to use Simprosys to evaluate drying systems and perform possible process improvements using an existing fiberboard drying production line of Smrečina Hofatex, a.s., Slovakia, as an example. Readers will no doubt find newer possibilities to improve existing plant operations and also evaluate alternate design strategies at the design stage itself.

AVAILABLE DRYING SYSTEM MODELING SOFTWARE

Available commercial software for dryers and drying operations is very limited for various reasons.[1] A literature study found only three commercial software packages specifically intended for drying. They are Simprosys, dryPAK, and DrySel. dryPAK is a DOS-based software package that does dryer design calculations including heat and mass balance and drying kinetics calculations.[2] DrySel is an expert system for dryer selection.[3] It is a proprietary software package.

Simprosys is a Windows-based process simulation software package designed for the thermal calculations of not only the dryer itself but also the drying system, including pre- and postdrying operations such as evaporation and exhaust gas processing operations.[4,5] The dryer model and other unit operation models of Simprosys are based on the most authoritative handbooks[6–12] as well as extensive research studies and expert knowledge of two of the authors in not only drying but also process modeling and simulations. The Simprosys database is based on publicly available data from standard references such as Perry,[8] Yaws,[13] and Yaws and Gabbula.[14]

Simprosys can deal with not only the most common air–water system but 11 additional nonaqueous drying systems as well.[15]

For more information about the drying software, please refer to Gong and Mujumdar,[5] Kemp,[1] Kemp et al.,[3] and Menshatina and Kudra.[16] It is worthwhile to mention that a software package called DrySPEC2 developed by NIZO food research (Ede, The Netherlands) is available for modeling spray dryers.[17,18] In addition, attempts to use Microsoft Excel to carry out dryer-related calculations have been reported in recent years,[19,20] although this is not a mainstream drying software.

ENERGY COMSUMPTION EVALUATION OF A FIBERBOARD PRODUCTION LINE

The case of this study is an existing fiberboard drying production line of Smrečina Hofatex, a.s, Slovakia. The fiberboard products are thermo-insulating boards with length/width dimensions of dry boards at 5/2.5 m. The thickness of the products is in the range of 8–22 mm and the specific weight from 160 to 250 kg/m^3 depending on each product.

Softwood logs are cut into chips, which are treated using a thermomechanical process in a water–fiber suspension. The suspension is dewatered on a wired dewatering machine into a cake with a dryness of 35–45%. Then it is cut into boards and fed to the production line at about 35°C. Final moisture content of the dry boards is about 5%. Figure 1 shows a process diagram of the drying system. The bottom light blue color section in the diagram is the drying section. It is composed of two sections. One is the wet section (the left part) and the other is the dry section (the right part). A wet board enters the production line from the left end and comes out from the right end as a dry product.

Fresh air is preheated to about 55°C by the exhaust air (in the recovery unit for the dryer in Fig. 1). Then it is heated by hot water to the required inlet temperature at about 120°C in the air heater. The remaining heat required for the production line is provided by hot water through coil tubes under the production line. The heat from the hot water coil tubes is carried away by circulating air and delivered to the fiberboard on the production line. Drying time varies significantly (e.g., from 50 to 350 min) depending on product thickness.

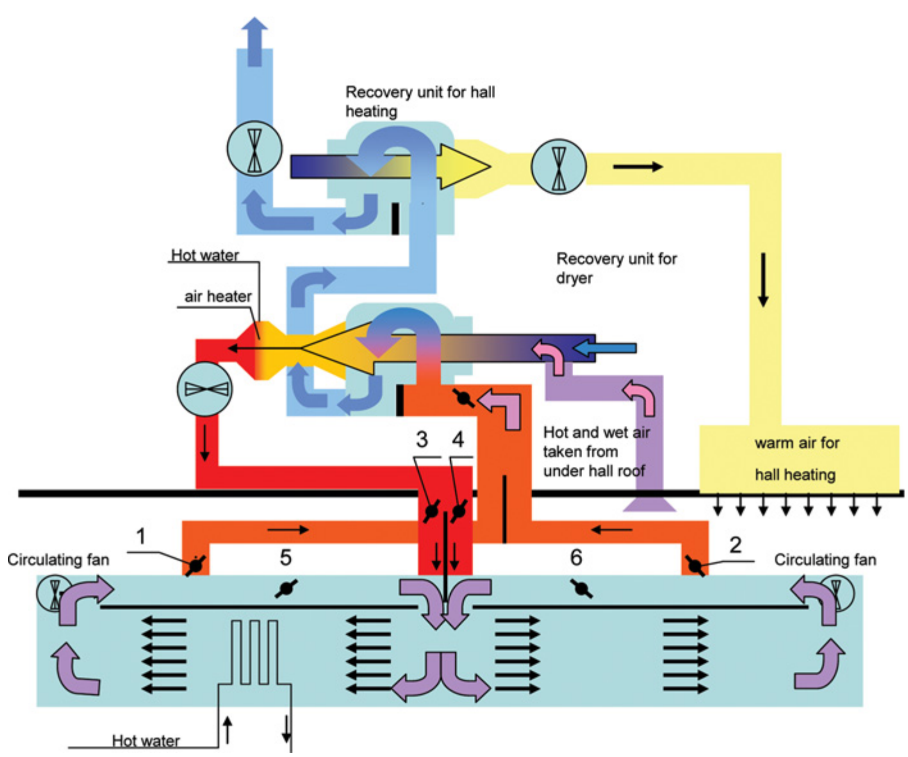


FIG. 1. Process diagram of fiberboad drying production line.

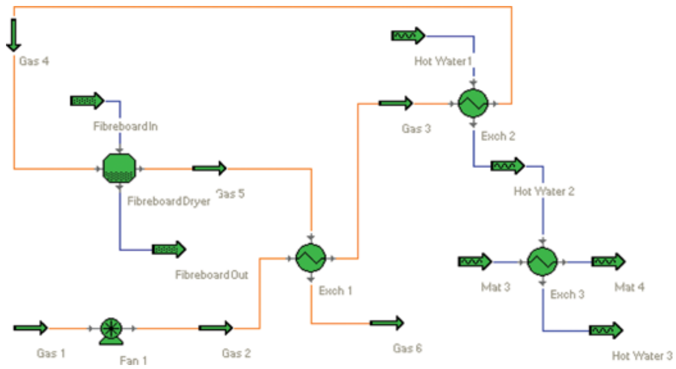


FIG. 2. Fiberboard drying plant flow sheet.

The process parameters of the fiberboad product in this study were measured and are listed below:

1. Volume flow rate at the dryer outlet = 5.4 m^3/h.
2. Specific weight at the dryer outlet = 245 kg/m^3.
3. Dryness at the dryer inlet = 0.43 kg/kg, equivalent to a moisture content of 0.57 kg/kg (wet basis).
4. Moisture content at the dryer outlet = 0.02 kg/kg (wet basis).
5. Temperature at the dryer inlet = 38°C.
6. Temperature at the dryer outlet = 79°C.
7. Drying time = 300 min.

The process parameters of the air and heating system were measured and are listed as follows:

1. Hot water volume flow rate = 310 m^3/h.
2. Hot water inlet temperature = 182.9°C.
3. Hot water outlet temperature = 176.7°C.
4. Fresh air temperature at the dryer inlet = 122°C.
5. Fresh air volume flow rate at the dryer inlet = 4,728.3 m^3/h (at 122°C).
6. Fresh air is preheated from 38 to 56°C by dryer exhaust air.
7. Fresh air is then heated from 56 to 122°C by hot water before being sent to the dryer.
8. Exhaust air temperature = 147°C.

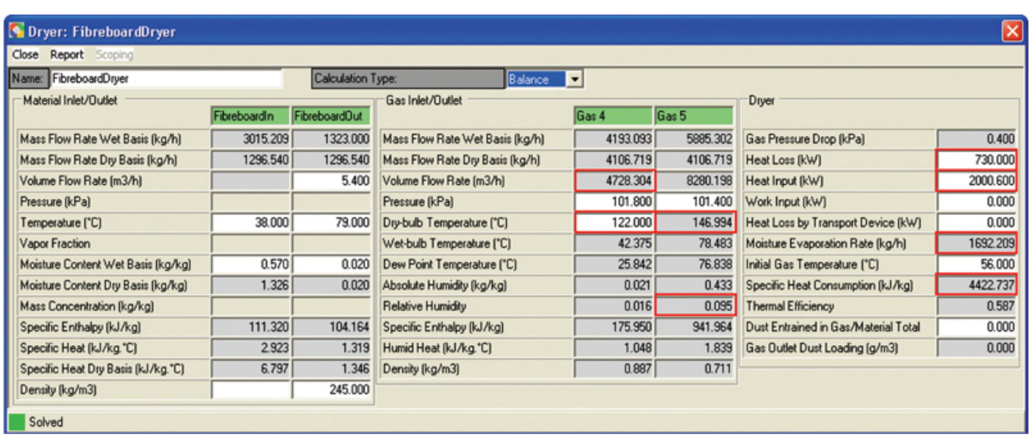
To do the necessary heat and mass balance calculations for the drying operation, a simple drying flow sheet was designed as displayed in Fig. 2. It was created using Simprosys 2.1. Due to lack of more detailed process data, the two (the wet and dry) sections of the production line can only be modeled as a one-stage drying process in this study. This is not a limitation of the software, however.

In Fig. 2, fresh air (Gas 1) goes into the drying system through the fan (Fan 1). It is then preheated by the dryer exhaust (Gas 5) in a heat exchanger (Exch 1). Then it is further heated by hot water in a heat exchanger (Exch 2) to the required inlet temperature before going into the dryer (FiberboardDryer). A heat exchanger (Exch 3) is used to calculate the heat loss of the hot water. The calculated heat loss is taken as the heat input of the dryer.

The net heat recovered from exhaust air to preheat fresh air from 38 to 56°C is calculated by Exch 1 as 21.4 kW. The net heat obtained from the hot water to heat the fresh air from 56 to 122°C is calculated by Exch 2 as 78.6 kW. The heat input of the dryer from the hot water in addition to that from the fresh air is calculated by Exch 3 as 2,000.6 kW. The total heat that the dryer obtains from the hot water is 78.6 + 2,000.6 = 2,079.2 kW.

Because we do not have all the necessary parameter values to close the heat and mass balance calculations, the following parameter values are assumed:

1. Specific heat of bone-dry fiberboard = 1.26 kJ/kg · °C.
2. Fresh air pressure at the dryer inlet = 101.8 kPa.
3. Fresh air pressure at the dryer outlet = 101.4 kPa.
4. Fresh air relative humidity at the fan inlet = 50% which is equivalent to 0.021 kg/kg absolute humidity at 38°C.



Dryer: FibreboardDryer

Close Report Scoping

Name: FibreboardDryer Calculation Type: Balance

Material Inlet/Outlet

	FibreboardIn	FibreboardOut
Mass Flow Rate Wet Basis (kg/h)	3015.209	1323.000
Mass Flow Rate Dry Basis (kg/h)	1296.540	1296.540
Volume Flow Rate (m3/h)		5.400
Pressure (kPa)		
Temperature (°C)	38.000	79.000
Vapor Fraction		
Moisture Content Wet Basis (kg/kg)	0.570	0.020
Moisture Content Dry Basis (kg/kg)	1.326	0.020
Mass Concentration (kg/kg)		
Specific Enthalpy (kJ/kg)	111.320	104.164
Specific Heat (kJ/kg.°C)	2.923	1.319
Specific Heat Dry Basis (kJ/kg.°C)	6.797	1.346
Density (kg/m3)		245.000

Gas Inlet/Outlet

	Gas 4	Gas 5
Mass Flow Rate Wet Basis (kg/h)	4193.093	5885.302
Mass Flow Rate Dry Basis (kg/h)	4106.719	4106.719
Volume Flow Rate (m3/h)	4728.304	8280.198
Pressure (kPa)	101.800	101.400
Dry-bulb Temperature (°C)	122.000	146.994
Wet-bulb Temperature (°C)	42.375	78.483
Dew Point Temperature (°C)	25.842	76.838
Absolute Humidity (kg/kg)	0.021	0.433
Relative Humidity	0.016	0.095
Specific Enthalpy (kJ/kg)	175.950	941.964
Humid Heat (kJ/kg.°C)	1.048	1.839
Density (kg/m3)	0.887	0.711

Dryer

Gas Pressure Drop (kPa)	0.400
Heat Loss (kW)	730.000
Heat Input (kW)	2000.600
Work Input (kW)	0.000
Heat Loss by Transport Device (kW)	0.000
Moisture Evaporation Rate (kg/h)	1692.209
Initial Gas Temperature (°C)	56.000
Specific Heat Consumption (kJ/kg)	4422.737
Thermal Efficiency	0.587
Dust Entrained in Gas/Material Total	0.000
Gas Outlet Dust Loading (g/m3)	0.000

Solved

FIG. 3. Heat and mass balance data of dryer with current operating conditions.

Parametric studies showed that the impact of the inaccuracy from the assumed values on the analysis results is trivial and negligible.

The heat and mass balance results of the dryer were calculated by Simprosys and are displayed in Fig. 3.

From Fig. 3 the following major dryer parameters were obtained:

1. Moisture evaporation rate = 1,692.2 kg/h.
2. Specific heat consumption = 4,422.7 kJ/kg water removed. This is equivalent to 1.39 GJ/m^3 dried fiberboard after correction for preheating by exhaust air from 38 to 56°C.
3. Exhaust air relative humidity = 0.095 or 9.5%
4. Heat loss is 730.0 kW, which is 35.1% (730.0/2079.2) of the total heat to satisfy the 147°C exhaust air outlet temperature.

It is obvious that the heat loss of the dryer (more accurately, of the drying process) is excessive. This is also reflected in the high value of the specific heat consumption at 4,422.7 kJ/kg water removed. However, the exhaust air relative humidity appears to be very low, at only 9.5%.

In the following sections, parametric studies will be carried out to see whether some energy savings can be achieved by changing only the current operating conditions without changing the existing equipment. Then we will investigate all possible potentials for energy efficiency improvements of not only the dryer but the drying system as a whole.

EFFECTS OF OPERATING PARAMETERS

On the basis of current operating conditions, parametric studies were carried out to see how some major operating parameters such as the dryer heat input and fresh air inflow affect the energy consumption.

Effect of Heat Input

As is seen from above, the relative humidity of the exhaust air is only 9.5%, which seems to be very low. One might think that it is possible for the dryer to perform its required task with a reduced heat input.

To investigate this possibility, we keep all operating conditions the same but reduce the dryer heat input to see how the exhaust air temperature and relative humidity change.

Figures 4a and 4b display the simulation results with two assumed dryer heat input values. Table 1 is a summary of the simulation results for Figs. 3, 4a, and 4b.

From Table 1 we can see that with a decrease of the dryer heat input, the exhaust air temperature drops but relative humidity rises sharply. A sharp rise in relative humidity can lead to a significant decrease in drying rate, which will result in unfulfilled drying duty of the dryer.

Thus, the conclusion can be reached that there is not much room to reduce the dryer heat input.

Effect of Fresh Air Inflow

To investigate the effects of fresh air inflow, we keep all operating conditions the same but increase the fresh air inflow (the volume flow rate of Gas 1 in Fig. 2) to see how the exhaust air temperature and relative humidity change.

Figures 5a and 5b display the simulation results with two assumed fresh air inflow values. Table 2 is a summary of the simulation results for Figs. 3, 5a, and 5b.

From Table 2 we can see that with an increase of the fresh air inflow, the exhaust air temperature drops, but the exhaust relative humidity rises slightly.

From the heat and mass balance point of view, an increased fresh air inflow has almost no effect on the energy balance of the dryer. However, it can impact the drying kinetics, which will be further discussed in the following sections.

It should be noted that, from Fig. 5a, under the specified fresh air inflow the net heat recovered from exhaust air by heating fresh air from 38 to 56°C is 27.1 kW. The heat duty needed to heat fresh air from 56 to 122°C is 99.8 kW. The heat input to the dryer in addition to the fresh air is 2,079.2 − 99.8 = 1,979.8.

Note that, in Fig. 5b, under the specified fresh air inflow the net heat recovered from the exhaust air by heating fresh air from 38 to 56°C is 32.9 kW. The heat duty to heat fresh air from 56 to 122°C is 121.0 kW. The heat input to the dryer in addition to the fresh air is 2,079.2 − 121.0 = 1,958.2.

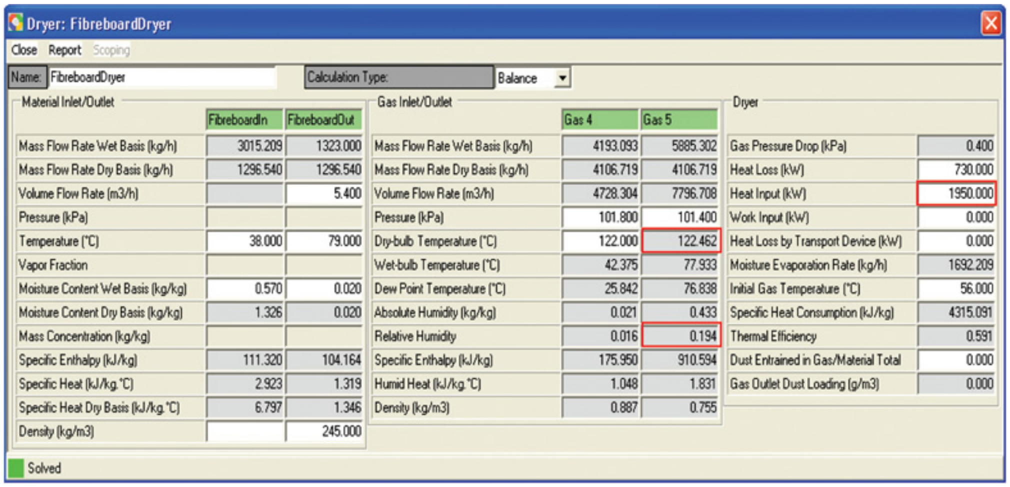
POSSIBLE WAYS TO IMPROVE ENERGY EFFICIENCY

Based on measured process data and the heat and mass balance analysis results from Simprosys, we find that there are three possible ways to improve the dryer energy efficiency. They are as follows:

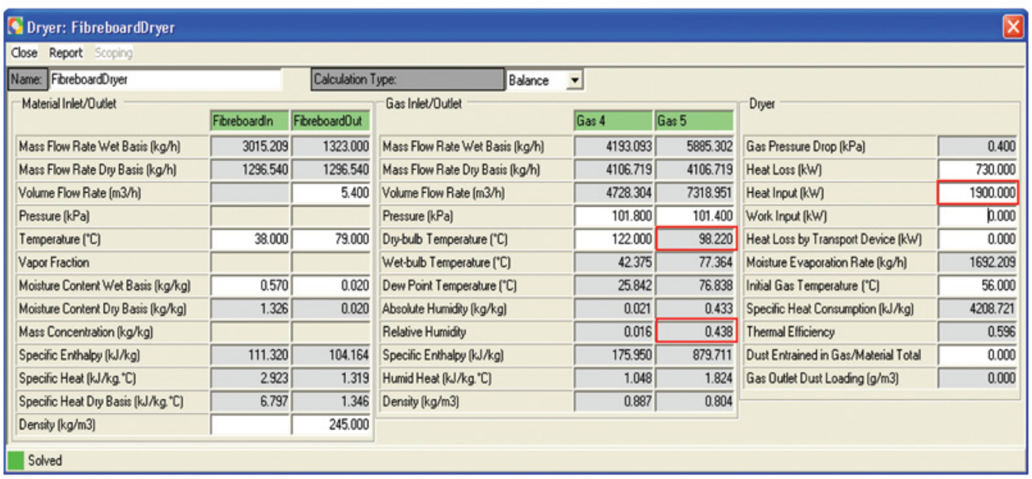
1. Decrease heat loss by improving insulation of the dryer and the hot water transport lines.
2. Effectively recover the waste heat from the exhaust air.
3. Shorten the drying time by increasing air flow in the dryer or by increasing hot water temperature or by doing both, which might be the most feasible way without significantly upgrading current equipment.

To investigate the possible improvements, a drying flow sheet as displayed in Fig. 6 was created using Simprosys 2.1 for the necessary parametric studies of the dryer and drying system. This flow sheet is an extension of the simple flow sheet in Fig. 2.

Fresh air (Gas 1) goes into the drying system through Fan 1. It is then preheated by a portion of the dryer exhaust (Gas 7) in Exch 1. The other portion of the dryer exhaust (Gas 8) goes through Fan 2 and is recycled back



(a)



(b)

FIG. 4. Dryer heat input at 1,950 kW (a) and at 1900 kW (b).

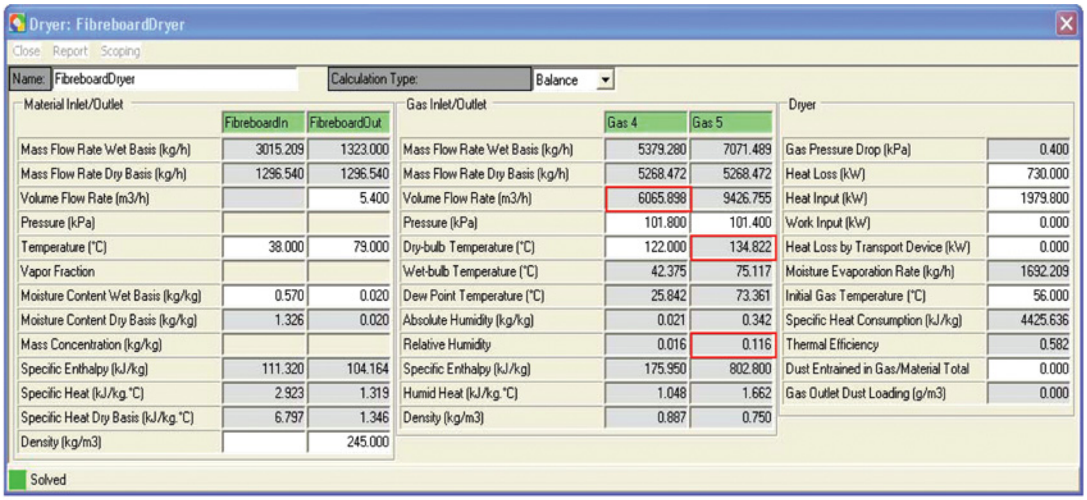
into the drying system. Then fresh air (Gas 3) is further heated by hot water in Exch 2 to 122°C before it is mixed with the recyled dryer exhaust (Gas 10) in Mixer 1. The mixed drying air (Gas 5) is introduced into the dryer. Exch 3 is used to calculate the heat loss of the hot water, which is taken as the heat input of the dryer. Exch 4 is used to calculate the possible sensible heat recovery above the dew point of the dryer exhaust. A scrubber/condenser (ScrbCond 1) is used to calculate possible heat recovery below the dew point of the dryer exhaust air.

TABLE 1
Effects of dryer heat input

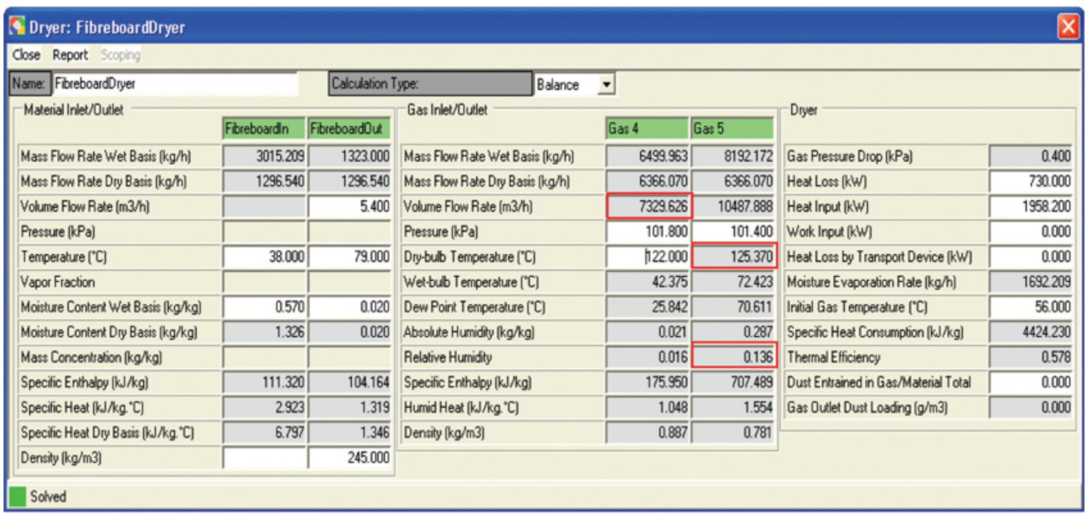
Dryer heat input (kW)	Exhaust temperature (°C)	Exhaust relative humidity (%)
2,000.6	147.0	9.5
1,950.0	122.5	19.4
1,900.0	98.2	43.8

Decreasing Heat Loss

Heat loss of the current drying process is approximately 35% of the total required heat for this specific drying product. Improving dryer isolation and eliminating hot air leaks are two possible ways to decrease heat loss. To achieve such goals an enclosed dryer or drying production line like the well-insulated dryer hood of a paper machine may be required. However, the cost for such an equipment upgrade is not minor. It needs to be carefully designed and a feasibility study of the equipment cost and operating benefit is necessary.



(a)



(b)

FIG. 5. Fresh air inflow at 4,800 m^3/h (a) and at 5800 m^3/h (b).

Exhaust Air Heat Recovery

Because the exhaust air is discharged at such a high temperature (147°C), it contains quite an amount of sensible and latent heat that can be recovered. Currently only a very small portion (about 21.4 kW) of the exhaust heat is recovered.

TABLE 2
Effects of fresh air inflow

Fresh air inflow (m^3/h)	Fresh air at dyer inlet (m^3/h)	Exhaust temperature (°C)	Exhaust relative humidity (%)
3,742	4,728	147.0	9.5
4,800	6,066	134.8	11.6
5,800	7,330	125.4	13.6

To investigate the potential of heat recovery, three assumed exhaust air discharge temperatures are simulated. The simulation results are summarized in Table 3.

It is calculated by Exch 4 that 127 kW of sensible heat can be recovered from 137.7°C (the temperature of Gas 11, the exhaust after preheating the fresh air) to the dew point of the exhaust air at 76.7°C in addition to the 21.4 kW currently recovered. Further possible recovery below the dew point is simulated as displayed in Figs. 7a through 7c. Simulation results are summarized in Table 3.

The recoverable sensible heat can be easily used to heat the fresh air if the exhaust air discharge system is well

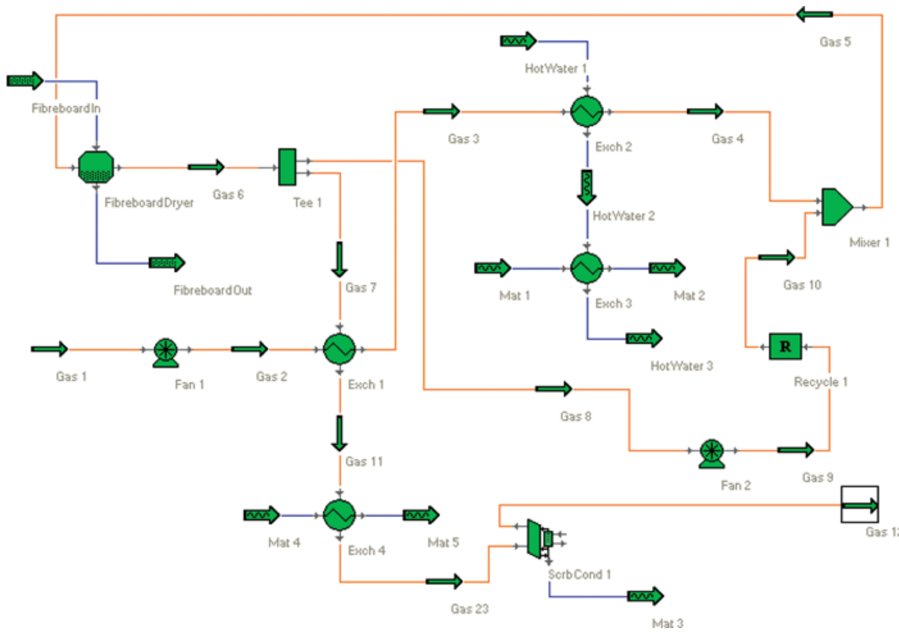


FIG. 6. Fiberboard drying flow sheet with recycled exhaust and heat recovery.

controlled. The recoverable latent heat can be used in other processes of the plant such as the pulping process.

It is obvious that the lower the discharge temperature of the exhaust air, the more heat that can be recovered. However, with a decreased discharge temperature, the heat recovery cost will increase. Therefore, when the discharge temperature is decided on, a trade-off must be carefully balanced for the equipment cost and operating benefit.

It is always a good idea to put the exhaust air heat recovery into the energy picture of the whole plant to see whether the recoverable heat can be effectively used in other processes such as the pulping process.

Simulation results (not shown here) also indicate that with an increased fresh air inflow, possible heat recovery will decrease slightly because increased fresh air means increased heat carried away by the exhaust at the same discharge temperature. Also, possible heat recovery will be different when the exhaust air outlet temperature changes.

TABLE 3
Possible heat recovery

Exhaust discharge temperature (°C)	Sensible heat recovery above dew point (kW)	Heat recovery below dew point (kW)	Possible total heat recovery (kW)
70	127	480	607
60	127	869	996
50	127	1,080	1,307

Increasing Air Flow

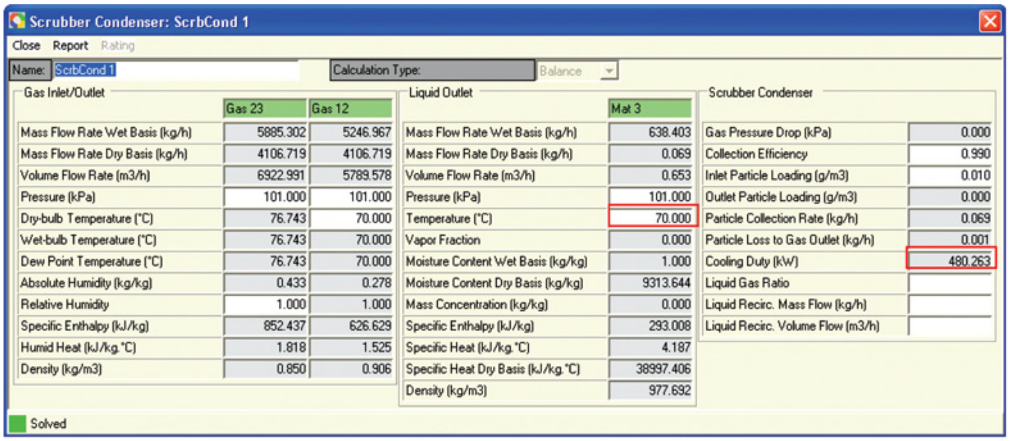
An increased air flow in the dryer will enhance the heat transfer from the air to the fiberboard, which leads to an increased drying rate for not only the constant drying period but also the falling rate drying period, which will result in a decreased drying time.

If the drying time could be shortened by 20% for the drying product analyzed, there would be about 20% less heat loss, which is equivalent to about 146 kW (20% of the 730 kW) of energy savings, in addition to the benefit of a shortened production cycle.

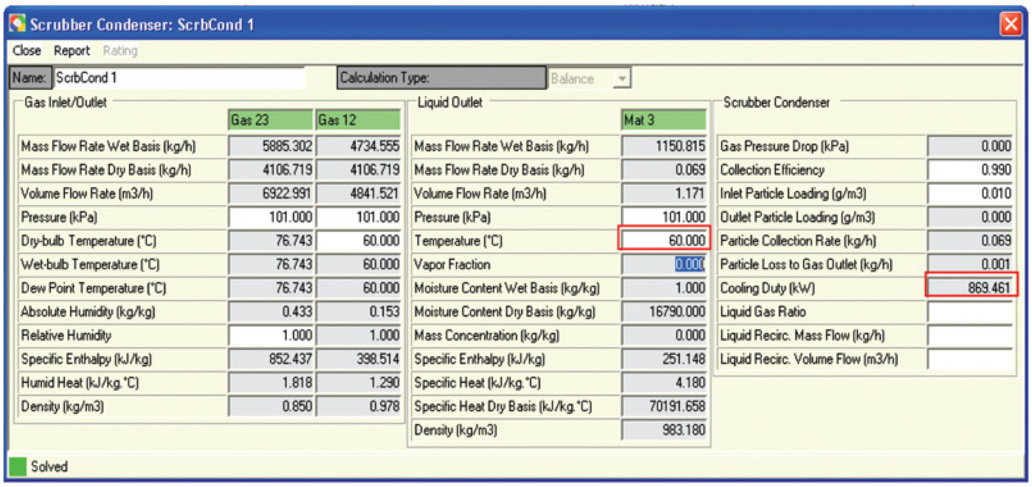
Increasing exhaust recycle ratio and/or increasing fresh air inflow are possible ways to increase the air flow of the dryer.

To investigate the effects of exhaust air recycle ratio on the mixed air inlet temperature and relative humidity (so that we can gain some sense of the drying kinetics), we can keep all operating conditions the same but change the exhaust air recycle ratio. Figures 8a through 8c display the simulation results with three assumed exhaust recycle ratios. Table 4 is a summary of the simulation results for Figs. 3 and 8a–8c.

From Table 4 it is seen that with an increase of the exhaust air recycle ratio, both the mixed air inlet temperature and relative humidity are increased. An increased mixed air inlet temperature will result in an enhanced heat transfer from the air to the fiberboard, which leads to an increased drying rate. An increased mixed air inlet relative humidity may lead to a decreased mass transfer rate of the water vapor into air. However, even in the case of 70% of recycle ratio, the inlet relative humidity of the mixed air is



(a)



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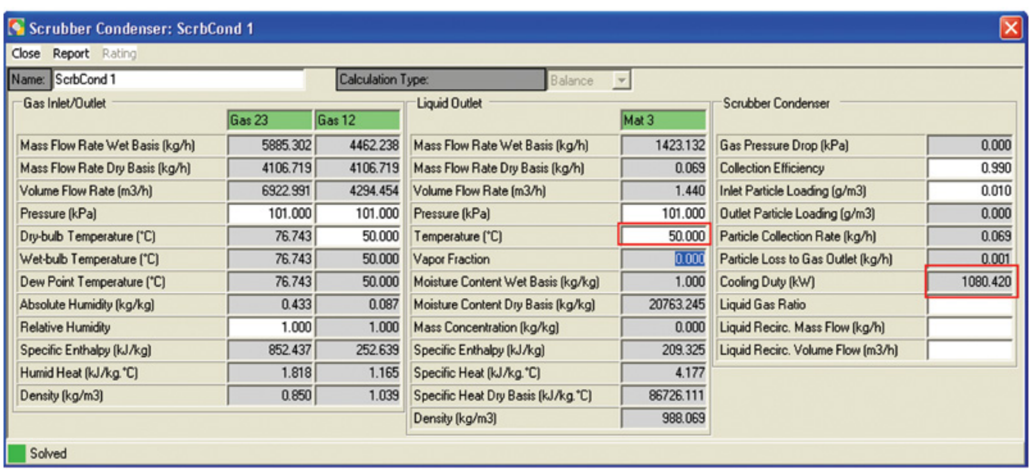
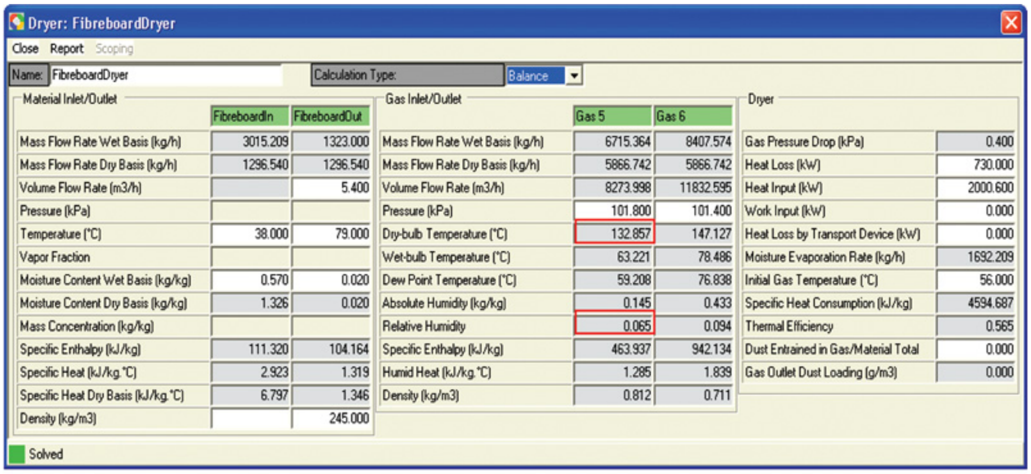
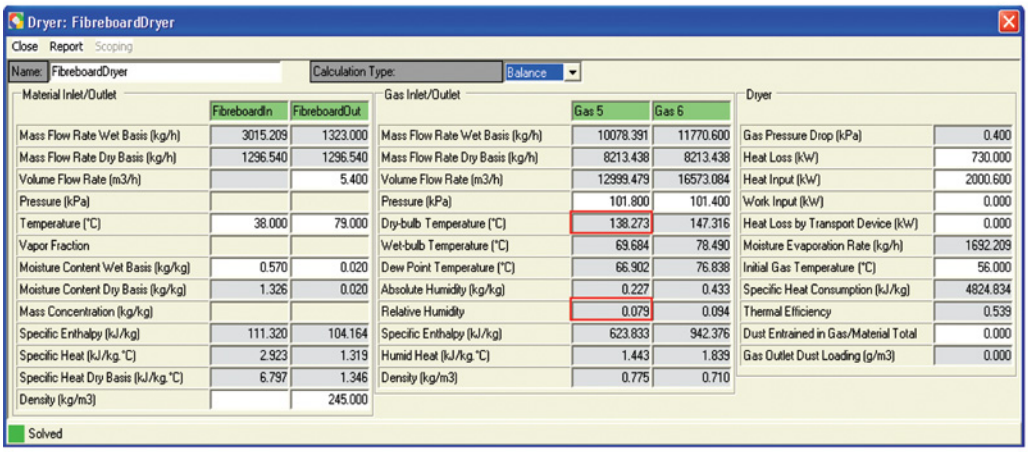


(c)

FIG. 7. Possible heat recovery at discharge temperature of 70°C (a), 60°C (b), and 50°C (c).



(a)



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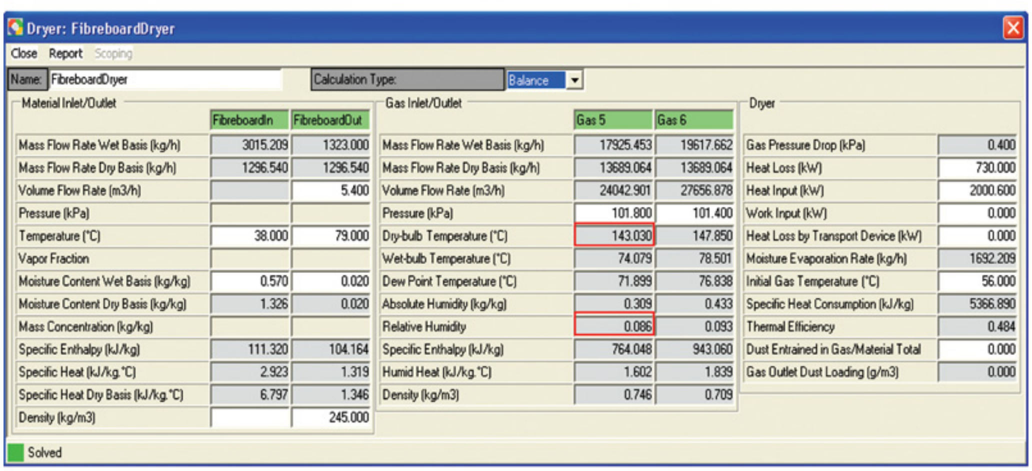

(c)

FIG. 8. Exhaust air recycle ratio at 30% (a), 50% (b), and 70% (c).

TABLE 4
Effects of exhaust air recycle ratio

Exhaust air recycle ratio (%)	Mixed air inlet temperature (°C)	Mixed air inlet relative humidity (%)
0	122	1.6
30	132	6.5
50	138	7.9
70	143	8.6

only 8.6%, which is very low and should not decrease the drying rate.

When air flow is increased in the dryer, the volume flow rate of the hot water needs to be increased accordingly to make up for the increased heat input to the dryer.

Note that with Simprosys it is easy to include the power of the added fans due to recycling the exhaust air in the parametric studies if practical pressure drop data is available.

In its current version 2.1, Simprosys does not have drying kinetics calculations. Extension to such calculations is planned and will be available in future versions.

Increasing Hot Water Temperature

An increased hot water temperature will result in increased heat transfer. However, it may also lead to increased heat loss of the hot water pipelines. Therefore, increasing hot water temperature should be used as a secondary tool for shortening drying time.

However, if the targeted drying time cannot be reached by only increasing air flow in the dryer, increasing hot water temperature can be used in combination with increasing air flow to reach the final target.

To determine the drying time for targeted air flow and hot water temperature, a drying curve is needed to determine the constant rate and falling rate drying periods of the fiberboard. Then heat and mass transfer thermal dynamics calculations, in addition to heat and mass balance, are needed for each drying period to optimize the drying process from the energy point of view. At the same time, product quality should be considered for the optimized design and operating conditions.

CLOSING REMARKS

An energy audit of the production line determined that excessive heat loss and lack of feasible heat recovery are two major factors that contribute to the low energy efficiency of the drying system. Heat loss of the drying process is about 35% of the total heat required. Improving dryer insulation and eliminating hot air leaks are two possible ways to decrease heat loss.

There is a significant potential for heat recovery from the exhaust. However, this will require extra equipment to make it more effective. To make more efficient use of the recovered heat it is necessary to put the heat recovery strategy into the energy picture of the whole plant.

Increasing the air flow of the dryer is a feasible way to shorten the drying time in order to reduce the heat loss without significantly upgrading/modifying the current process equipment from the drying kinetics point of view.

To further scrutinize the drying process in detail and design more feasible ways to improve the energy efficiency, splitting the production line into a two-stage drying process is necessary, with one stage for the wet and the other for the dry sections. With such a two-stage drying process we can study the effects of balancing the heat input of the two stages, recycling the exhaust air from one stage to another, and different heat recovery strategies for each stage. However, this will require more detailed process data. Evaluation of parameter effects on drying kinetics and product quality should be examined concurrently with thermodynamic studies of heat and mass balances.

Interested readers are invited to visit http://www.simprotek.com to download a free trial version to explore the capability of Simprosys 2.1 for their own applications. The example provided here is just one relatively straightforward option for use of this software to improve the efficiency of an existing drying plant.

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