IMPROVING ENERGY EFFICIENCY AND SUSTAINABILITY OF INDUSTRIAL THERMAL DRYING SYSTEMS USING SIMPROSYS SOFTWARE

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ABSTRACT

Industrial thermal drying plays a major role in many industries such as the food, pharmaceutical, chemical and mineral processing. Thermal drying process is highly energy intensive. In developed countries, up to one fifth of the rational industrial energy consumption goes into thermal drying operations. With industrial drying efficiencies ranging only from 30 to 60 percent, there is great potential for improvement. The aim of this work is to present different options for improving dryer energy efficiency for two cases, viz., coal drying and spray drying of sodium palconate using a new software package entitled "Simprosys" (http://www.simprotek.com). This is accomplished by recovering heat from exhaust streams from the dryer. Through Simprosys simulation, the use of recycling exhaust air from dryer or recycling a part of dried material back into the dryer enables one to improve the energy efficiency of a drying system. However, recovering heat from exhaust air to preheat the fresh air results in significant increase in the energy efficiency in case of a coal drying system. Another way of improving sustainability is the use of renewable sources of energy for air heating which is also analyzed using Simprosys. The analysis of spray drying flow sheet was carried out in the same fashion with similar conclusions. The main advantage of Simprosys is that it allows rapid evaluation of alternate flowsheets to evaluate and optimize overall energy efficiency and sustainability.

Keywords: Simprosys, energy efficiency, sustainability, energy recovery, renewable energy

1. INTRODUCTION

Thermal drying is highly energy intensive and competes with distillation as the most energy intensive unit operation due to the high latent heat of vaporization of water and the inherent inefficiency of using hot air as the most common drying medium [1-2]. Drying operation is common in many industries from food, pharmaceutical to special chemicals, mineral processing and bio-products. Various studies report national energy consumption for industrial drying operations ranging from 10-25% for developed countries [2]. The thermal efficiency of industrial dryers varies from 30-60% which opens opportunity for increasing the efficiency [3]. Baker [4] reported that a typical convective dryer consumes five times its capital cost in energy in its lifetime and most of this energy is wasted. The common reason for this is the improper monitoring of a dryer. Due to the increasing cost of fuel and limited resources (mainly natural gas and oil), lots of efforts have been attempted to improve the efficiency of such energy intensive processes without exception to drying. As it is a well-known fact that the energy cost will be increasing, energy sector has become an important part of innovations in drying. Emission of green house gases due to use of fossil fuel as energy source is also another important global concern and should be taken into account while developing any industrial process. Almost in all engineering sectors researchers are trying to develop sustainable processes with minimal carbon footprint rather than being just cost-effective.

To enhance the efficiency of an existing drying system it is necessary to have appropriate measured data. Then, the mass and energy balances should be carried out carefully not just for the dryer but the drying system as a whole. With these preliminary data in hand, one can try to enhance the efficiency of a dryer/drying system using different combinations. To make the dryer thermally more efficient, it is necessary to make innovative changes in the dryer design itself, reduce air leaks, and improve dryer insulation [4]. This may include for example, improving the air distribution system in fluidized bed dryer, conduction heat transfer in fluidized bed or use of hybrid drying techniques to enhance the drying rate during final stages of drying. However, the overall energy efficiency of the drying system can be improved by different ways. This may involve selecting the right pre-drying process which can reduce the load on dryer, recovering heat from the exhaust drying gas and dried product, using non-conventional sources of energy, using innovative drying techniques and better control and monitoring of drying equipment. Baker [4] has reported that if these schemes are used the energy savings can be as high as 60% or more.

It is very difficult to evaluate different options for improving energy efficiency only by experiments. The thermal calculations involved in drying are monotonous and complex. However, recent efforts in development of different software, such as Simprosys developed by Simprotek Corporation, have made it easier to evaluate the thermal performance of even complicated drying flow process. Simprosys not only takes in-to account the process parameters for dryer but for the drying system as a whole including filters, fans, heaters, cyclones, etc. This article focuses on the use of this software for evaluation of thermal performance of two systems, coal drying and spray drying of a sodium palconate, which are illustrations of applications of this software.

2. BACKGROUND AND ABOUT SIMPROSYS

As discussed earlier, there have been a few attempts on the development of commercial software packages specifically for drying, dryers and drying systems, although the number is limited. Kemp [5] provided the overview of different software available in the field of drying. He also has provided general guidelines for the development of the drying software.

The commonly used software packages are DrySel, is a expert system marketed by Aspen Technology which is used for the selection of the dryers, dryPak is a DOS based software used for dryer design calculations including heat and mass balances and drying kinetics calculations for various gas-solvent systems. DRYSPECC2 and DrySim are two other software packages used for modeling and simulation of spray dryers. Recently, Kudra et al. [6] have developed a simple excel based tool for the analysis of energy performance of convective dryers. Simprosys is a software developed by Simprotek Corporation (http://www.simprotek.com) and is based on simple mass and energy balances of the dryer and the other necessary equipment used [3, 7]. Simprosys is a Windows-based process simulator which can be used for flowsheet design and simulation of drying and evaporation systems. It can also be used for the design of dryers. Simprosys can use various unit operations in addition to a solid and liquid dryer. The dryer model and other unit operations' models of Simprosys are based on the most authoritative handbooks [1, 8-9]. Simprosys can deal with not only the most common Air-Water system, but also eleven additional other non-aqueous drying systems as well.

Following are key terms used in the present work:

$$\text{Dryer Thermal Efficiency} = \frac{\text{Amount of energy use for water evaporation}}{\text{Amount of total energy input to drying air}}$$

$$\text{Specific energy consumption } \left(\frac{\text{kJ}}{\text{kg}}\right) = \frac{\text{Amount of energy given in heater (kJ)}}{\text{Aount of water evaporated (kg)}}$$

3. COAL DRYING

Coal is the world's most important source of energy fueling around 40% of the power stations around the world beside its use as a starting material for many chemical syntheses [10-11]. The major part of the global coal reserves, about 45%, consist of Low Rank Coal (LRC, also known as Brown coal, mainly Lignite), it is not exploited much because of its inherent poor properties such as higher moisture content and hence low calorific value, high ash content and low carbon content. But the high amount of moisture in LRC leads to higher energy requirements during combustion, high amount of stack gas flow, lower plant efficiency, high transportation cost and potential safety hazards during transportation and storage etc. All applications of lignite require drying as a pre-processing step [10].

Keeping in mind the fact that the low rank coal is not a high value product and hence the cost involved in drying of such coal should be minimal. It is known that coal companies are reluctant to use thermal drying for low rank coal as there is hardly any value addition using existing drying systems. Hence, it is necessary to use very energy-efficient drying systems to make it cost-effective. Generally coal is dried either at mine site to reduce the transportation cost or at plant site before it is used for its final application. In former case use of renewable sources of energy such as solar energy for heating and wind energy to supply power for gas pumping as well as heating can be an efficient way to improve the sustainability of a drying process with reduced carbon footprint. However, in later case the use of waste heat from the plant can result in improved overall efficiency of the coal drying process. If the cost of drying is more than the value addition to the coal then it is difficult prove the benefit of thermal drying for this particular application.

In the present study, simple drying flowsheets (fig. 1) are simulated initially for drying of coal based on the assumed parameters. Most of the parameters such as initial moisture content, final expected moisture content, drying temperature are selected based on reported values; however, the throughput is authors' choice for comparison amongbetween different flowsheets.

Coal:

Initial moisture content: 50% (w/w on wet basis)

Temperature at dryer inlet: 30˚C
Final moisture content: 8% (w/w on wet basis)
Temperature at dryer outlet: varied according to the requirements

Wet solid mass flow: 2 tons per hour
Specific heat capacity of dry coal: 1.38 kJ kg^{-1} K^{-1}

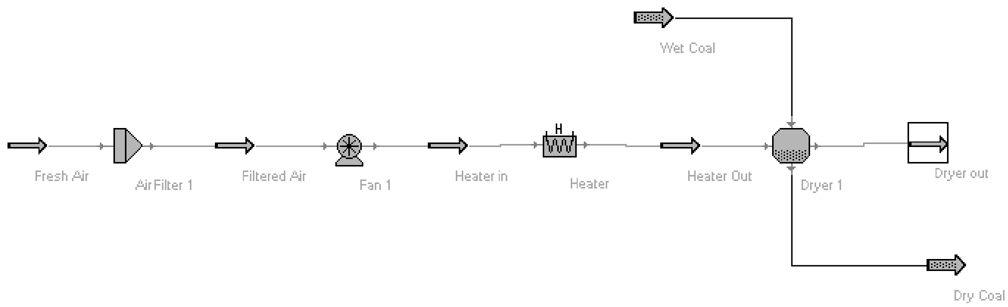
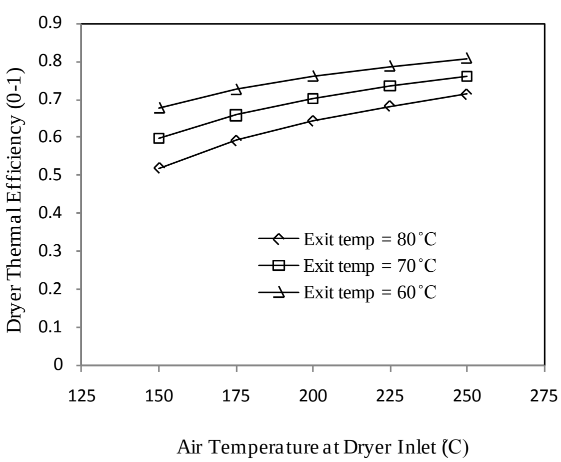


Fig. 1. Flow-sheet for a simple coal drying system

Drying Air:

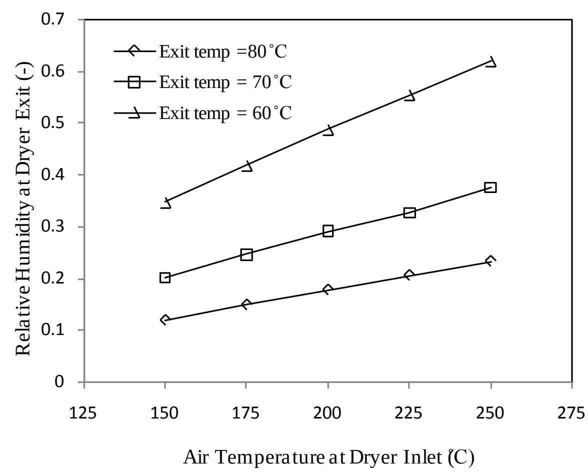
Fresh air temperature: 30˚C
Ambient humidity: 0.09 kg/kg of dry air
Temperature at dryer inlet: 200˚C
Air properties: Simprosys uses correlation from standard handbooks

First, the air temperature at the dryer exit was set to determine the minimum air flow which can be used for the set conditions. Although the dryer exit temperature will depend on numerous factors such as the drying kinetics, the residence time of solids in a dryer, Simprosys does not take in-to account these parameters. This is the reason why simulations were carried out for pre-defined exit air conditions to compare different options.

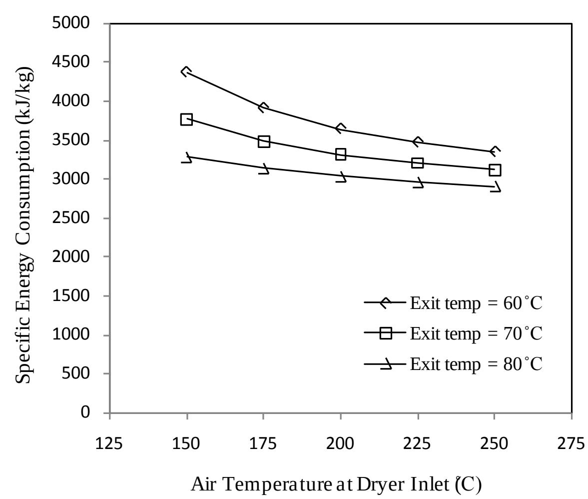


(a)

Fig. 2 shows the dryer thermal efficiency, outlet relative humidity and the specific energy consumption as a function of varying air inlet temperatures for different air exit temperatures. It can be seen that for lower dryer exit temperature the exit humidity is sufficiently high hence most of the energy is utilized in a dryer, which also reflects from the specific energy consumption.



(b)



(c)

Fig. 2. Effect of air temperature on dryer thermal efficiency, exit relative humidity and specific energy consumption

These results mean that the residence time is sufficiently high with a bigger drying unit and hence the higher capital cost. However for higher exit temperature (80°C), high amount of energy is lost and hence there is a scope to recover this energy to make the system more efficient. It can be seen from fig. 2. (b) that the exit humidity is around 17% for air exit temperature of 80°C. The comparison of different ways to recover heat will be carried out based on this base case.

3.1. Different ways to improve energy efficiency

As noted by [3, 4, 12], there are different ways to improve the energy efficiency of the drying system. As discussed previously the thermal efficiency of a dryer cannot be improved much unless its design is modified. However the energy efficiency of the drying system can be enhanced by different ways as follows

1. Minimize heat losses - this can be achieved by proper insulation of a drying system as well as the air ducting.
2. Heat recovery from the exhaust gas stream - this can be done either by recycling the exhaust air again for drying as the exit humidity is not high, or recycling the exhaust air to preheat the drying air.
3. Indirect heat transfer - use of indirect heating can also result in reduced air flow requirement and hence lower specific energy consumption.

Bahu et al. [12], have experimentally proven that proper insulation of drying system and reducing the air leakages from the system can result in 26% reduction in energy consumption over existing drying system under study. However, in the present study the Simprosys software was used to analyze the effect of recycle air and the indirect heating on the specific energy consumption.

3.2. Use of recycle air

The recovery of heat from exhaust air can be done either be recycling it back to the dryer or by using it to pre-heat the drying air. The recycle of air to the dryer can be done in two ways; either by mixing it with the heated fresh air at the dryer inlet or by mixing it with the fresh air before heater. From the initial simulations it was found that the latter case is more beneficial hence the results are reported only for the recycle of exhaust air before the heater. Fig. 3 shows the flowsheet which uses the dryer exhaust air for pre-heating of the drying air.

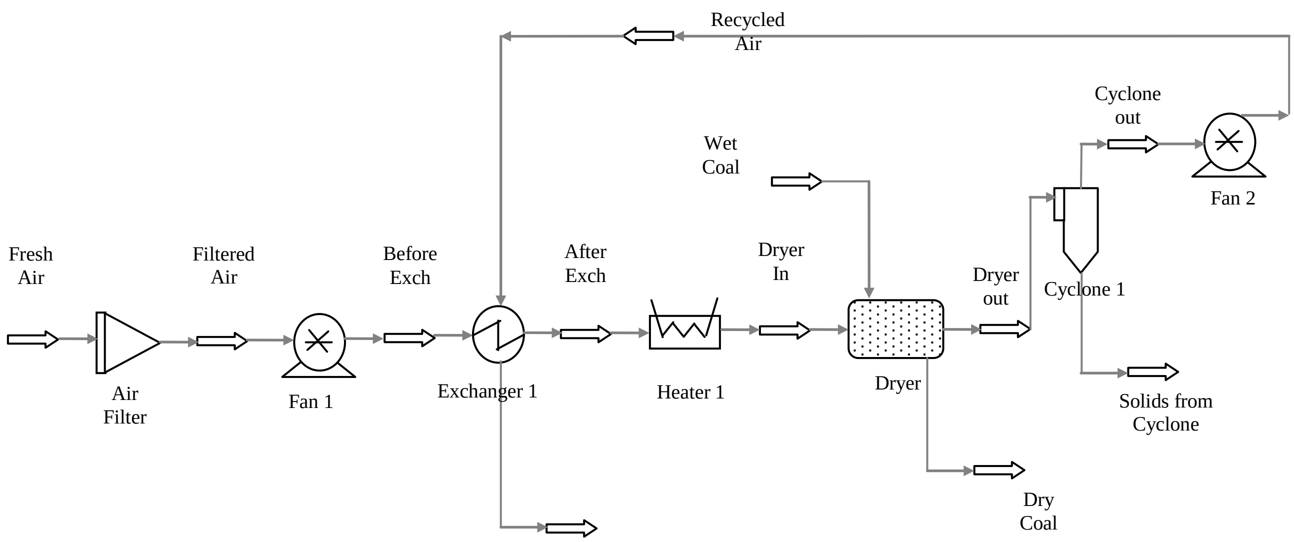


Fig. 3. Preheating of drying air using recylce air

To study the effect of preheating of the ambient air, the total volume of exhaust air is recycled and the temperature of the purged air from the pre-heater was varied to study effect on the specific energy consumption. It can be seen from fig. 4 that the effect of preheating of fresh air is more prominent at lower drying air temperatures however, as the temperature of the purged air from pre-heater is lowered, the effect on specific energy consumption reduces. Fig. 5 shows the flowsheet used to study the effect of recycle of dryer exhaust air back to the dryer but before the air heater. It is explained previously that the recycle of dryer exhaust air back to the dryer inlet does not help to improve the efficiency; the remaining volume of air is purged to atmosphere. It should be noted from the figure that entire volume of exhaust drying air can be recycled, however, the cost air pumping and air ducting should be taken into account while selecting the recycle ratio. Fig. 6 shows the effect of the recycle ratio of the dryer exhaust air on the specific energy consumption and the exhaust air relative humidity. It can be seen that the relative humidity of the exhaust air increases as the recycle ratio is increased, which means the drying air is used more efficiently. This can also be seen from the graph of the specific energy consumption values. The SEC decreases as the recycle ratio is increased. It is also possible to study if the part of the air is recycled for drying and a part is used for the preheating of ambient air. This probability was also simulated using Simprosys. For this case for example, a recycle ratio of 0.7 means 70% air is recycled to dryer and 30% is used for preheating. These simulations were carried out for the same dryer exit conditions. Fig. 7 shows the effect of recycle ratio on the specific energy consumption for both cases, recycle for only ~~for~~ drying and recycle for drying and pre-heating.

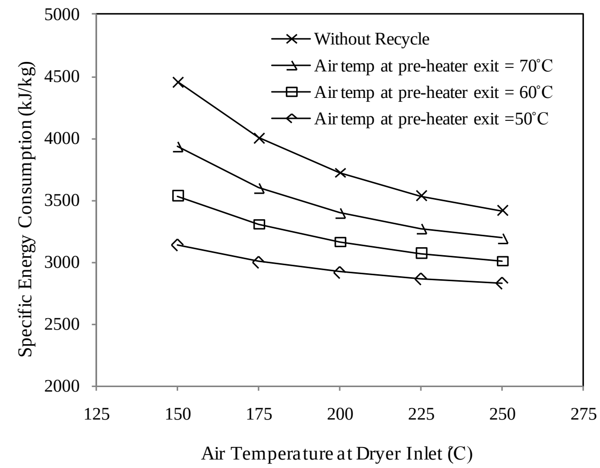


Fig. 4. Effect of pre-heating of fresh air on specific energy consumption

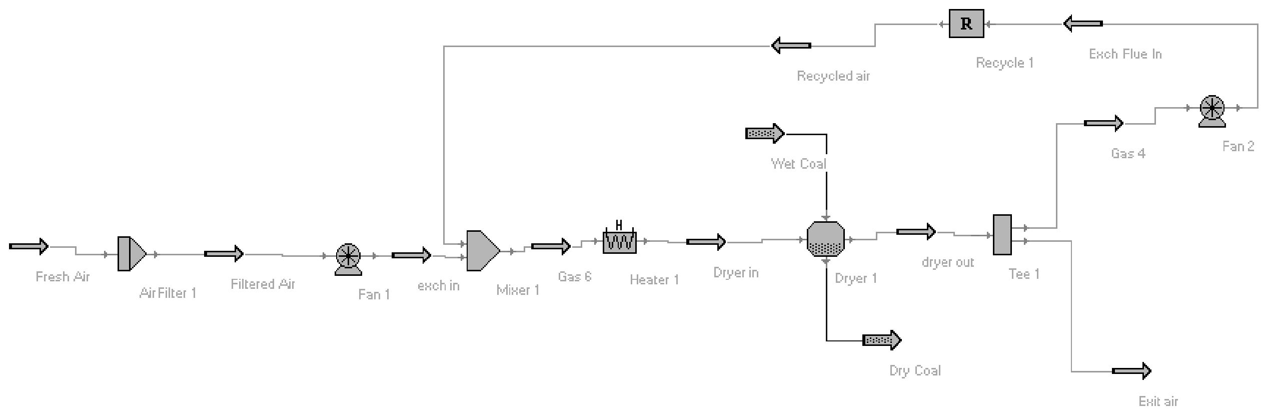


Fig. 5. Flowsheet for recycle of air to dryer

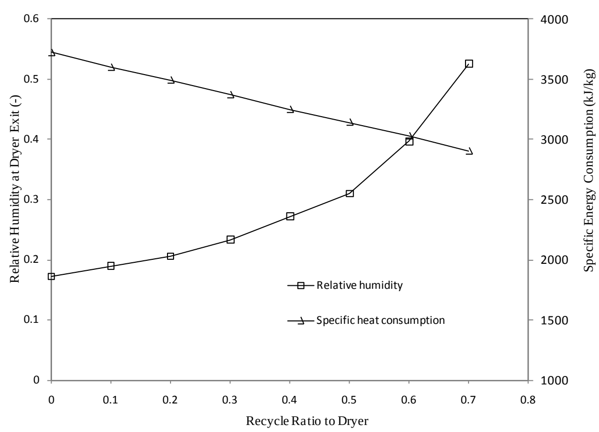


Fig. 6. Effect of recycle ratio on exhaust air humidity and specific energy consumption

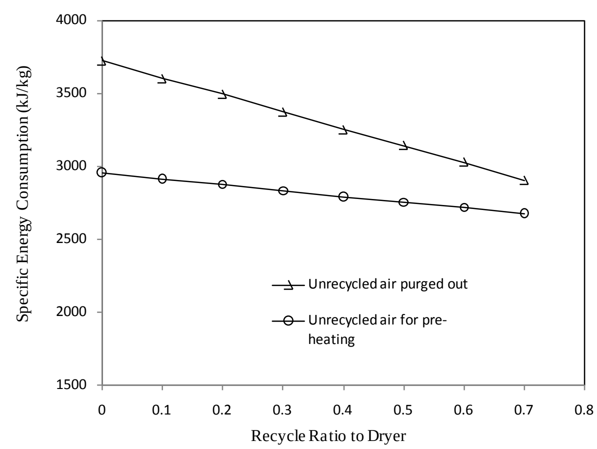


Fig. 7. Effect of recycle and pre-heating on specific energy consumption

3.3. Effect of indirect heating

Coal, especially low rank coal is highly susceptible to spontaneous combustion hence using high temperature air can result in increase of fire hazard. Use of indirect heat can reduce the hazard as less air at lower temperatures can be used [11]. The use of indirect heating can result in lower required air volume for drying. This can result in lower specific energy consumption, lower air pumping cost as well as smaller ducting for drying air. Thus, efficient indirect heating offers a number of advantages. Simprosys offers the advantage of easily incorporating indirect heat for drying. This possibility was simulated for drying of low rank coals with the existing case. Fig. 8 shows the effect of percentage of total required heat supplied by indirect heating. It can be seen that the increase in the indirect heat results in higher dryer exit humidity and lower specific energy consumption, this is because of the lower quantity of required drying air. This indicates that the air is used more effectively. However, the extent of indirect heating will be limited by the dew point of the drying air.

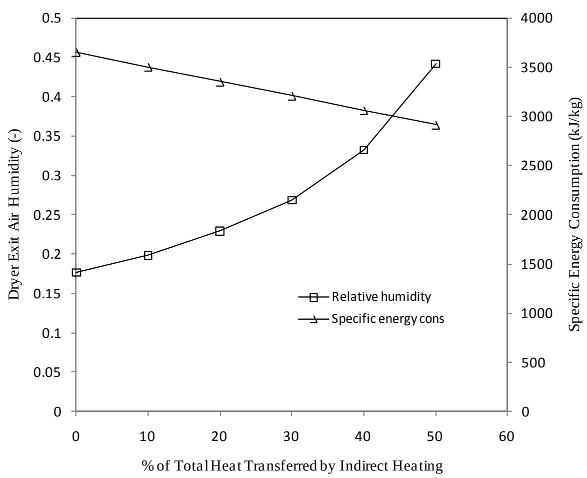


Fig. 8. Effect of indirect heating on exit humidity and specific energy consumption

4. SPRAY DRYING OF SODIUM PALCONATE:

To study the use of Simprosys for drying of liquid, it was decided to use the reported experimental data for the pilot plant drying of sodium palconate [13]. Spray dryers also have very low energy efficiency, hence tremendous scope for improvement [8, 14]. In this study, authors used an evaporator which removes most of the water, followed by the spray dryer which gives particles with moisture content of 9% (w/w on wet basis). Fig. 9 shows the system in detail. Steam is used in evaporator for heating of the feed liquid. However the condensate coming out of the evaporator drained out.

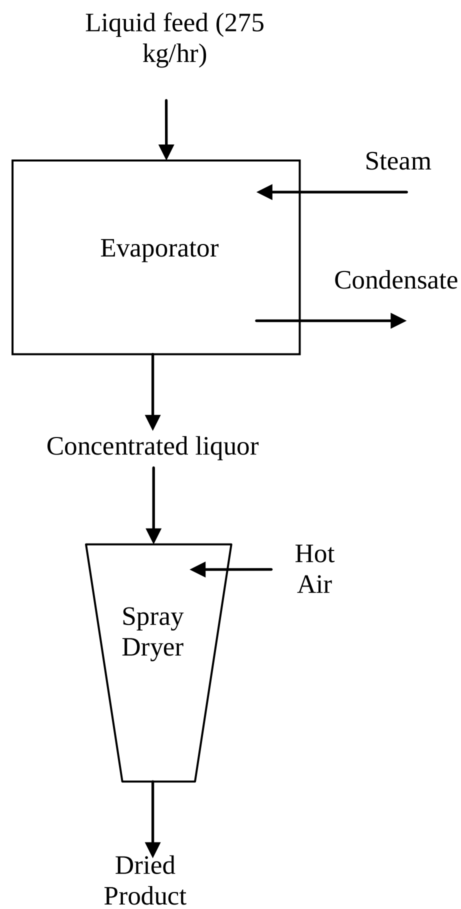


Fig. 9. Spray drying system used for study

The operating conditions are reported as follows.

Evaporator

Feed flow: 257 kg/h
Inlet temperature of liquid: 20˚C
Water: 96% (w/w)
Exit temperature: 98˚C
Exit moisture in liquor: 74.14%
Steam pressure: 265 kPa
Steam temperature: 130˚C
Steam flow rate: 250 kg/h
Condensate temperature: 130˚C

Spray dryer

Feed flow: 75 kg/h
Inlet air temperature: 230˚C
Outlet air temperature: 110˚C
Exit solid temperature: 60˚C
Final moisture content: 9% (w/w on wet basis)

For the initial simulation of the reported system using Simprosys, the flowsheet shown in fig. 10 was used.

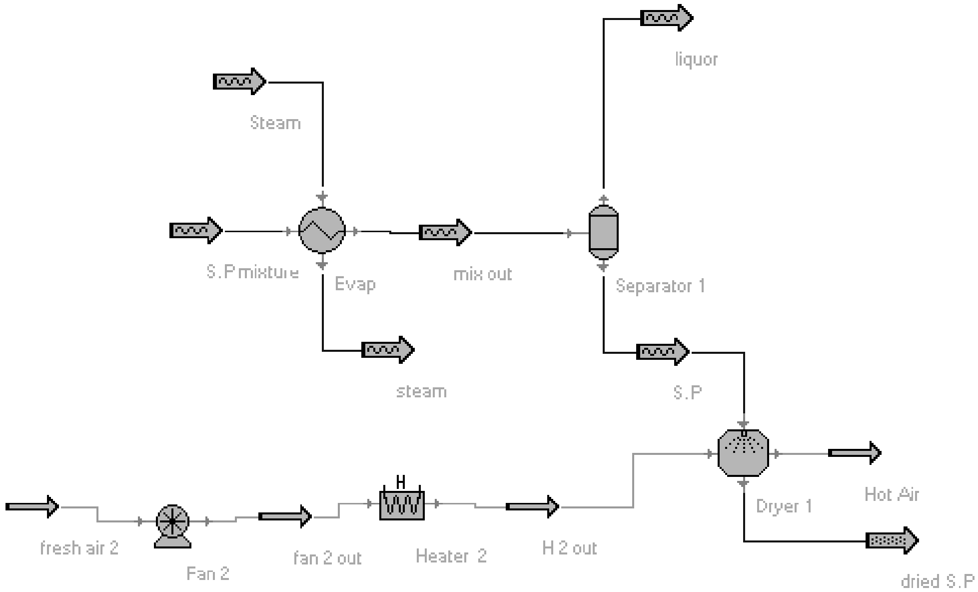


Fig. 10. Basic spray drying flowsheet used

It was found that for the existing flowsheet the specific energy consumption was 4610 kJ per kg of total water evaporated, which is high. It was also found from the reported data that there was substantial loss of heat from the spray dryer, 32 kW. This value is quite high for a pilot scale dryer. Hence it was decided to study the effect of reducing the heat losses. Table 1 shows that the specific energy consumption can be reduced considerably by reducing the heat losses.

Use of condensate/exhaust air for pre-heating

Fig. 11 shows the flowsheet used to simulate the use of condensate from the evaporator and the dryer exhaust air to pre-heat the drying air. Initially only the condensate was used to preheat the air.

Table 1. Effect of reduced heat losses from spray dryer

Heat loss (kW)	Specific energy consumption (kJ/kg)	Thermal efficiency
32 (existing)	4610 (Existing)	0.31
24	4357	0.36
16	4138	0.40
10	3936	0.46
0	3835	0.51

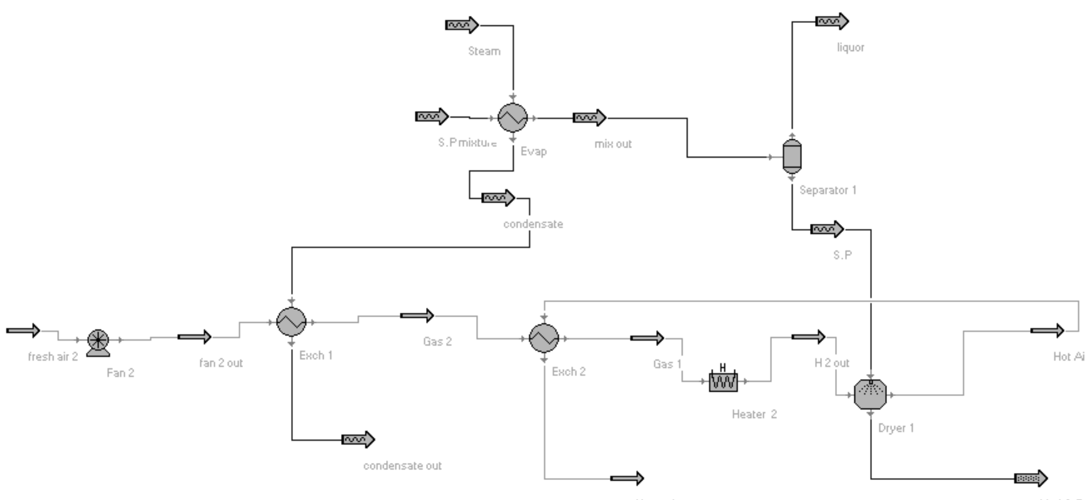


Fig. 11. Recovery if heat from condensate and dryer exhaust air

Table 2 shows the effect of condensate outlet temperature on SEC. It can be seen that heat extracted from the condensate reduces the specific energy consumption.

Table 2. Effect of condensate outlet temperature

Condensate outlet temperature (°C)	Specific energy consumption (kJ/kg)
Without preheating	4610
100	4466
80	4373
60	4272

Further, simulations were carried out for a condensate temperature of 60°C along with use of the dryer exhaust for preheating. In the existing system, air is discharged at 160°C. Hence huge amount of energy is lost which decreases the efficiency. Table 3 shows our simulation results. It can be seen that ~~the~~ using exhaust air for pre-heating significantly reduces the net energy consumption.

Table 3. Effect of dryer exhaust air for pre-heating

Air exhaust temperature after pre-heating (°C)	Specific energy consumption (kJ/kg)
Without preheating	4610
130	3928
120	3820
110	3713
100	3608

5. CONCLUSIONS

Excessive heat losses, and lack of heat recovery are the two important factors responsible for lower energy efficiency of the driying systems. Most of the existing drying processes have potential to improve their energy efficiency. This is very important for drying of products such coal, for which~~where~~, it is very necessary to develop cost-effective and sustainable drying system. Although it is difficult to experimentaly study the use of recycle and heat recovery, software such as Simprosys is very handy in determining feasibility of alternative approaches to improve the energy efficiency.

In the present work, two systems were simulated using Simprosys, coal drying and spray drying of sodium perconate. For~~,~~ coal drying, it was found that the reycle of dryer exhaust air, recovery of heat from dryer exhaust air and use of indirect heating can significantly improve the efficiency of the drying system. Simillar finidings were obtained for spray drying of sodium perconate from the reported experimental data.

It is noted that Simprosys has great potential to carry out useful heat and mass balances on complicated flowsheets to study the possibility for improvements in the existing drying systems. Interested readers can visit www.simprotek.com for more details. It is an easy-to-use tool for designers and ~~as well as~~ students of heat and mass transfer as well as engineering thermodynamics.

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