Ways to reduce energy for spray drying

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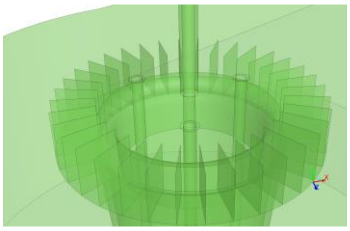
Inside the tower



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1.0 Introduction

Spray drying is one of the type of driers which is most commonly used in all kind of industries worldwide. It enables the industry turning liquids, emulsions, slurries and solutions into dry powder, on a very nice way. This drying technique itself makes small droplets which are exposed to hot air stream, evaporating the water out of the liquids at high rates. It is a mild and fast drying technique. The product temperature is never high thanks to the wet bulb protection. It enables the industry not only to dry but also to agglomerate, or co-spray and is in a way a product differentiating technique. It is one of the processes in industry where multiple disciplines are working together. Process engineers, technologists, civil, electrical, safety experts, quality staff, energy specialists, formulation experts, flavourists, mechanical engineers and operating staff. In dairy and baby food industry is the leading technology for making well agglomerated low density functional powders. Spray drying is the way to produce for examples colorants, pigments, malto dextrines, functional proteins from agricultural source. In The Netherlands it is estimated that more than 200 units are in operations. From small to big sizes, varying in capacity from few kg water evaporations per hour to 10 ton. In 2022, spray dryers are still being built in

The Netherlands for goat milk products, lacto ferrines and special ingredients for the pharma industry.

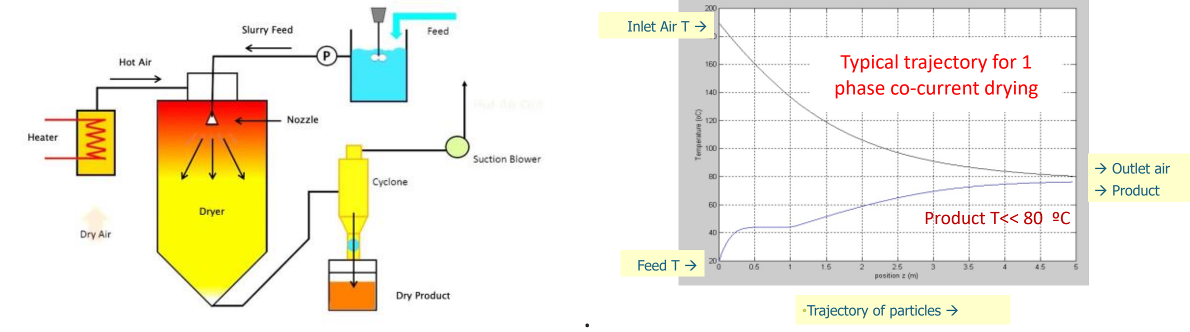

Figure 1; most simple execution of 1 step spraydrying unit and its temperature profile of product and drying air

There are also quite some **disadvantages** on spraying; high investment costs, dealing with potential explosion risks while drying are major draw backs of this technique. The topic of this article is another disadvantage namely its **high energy consumption** involved in spray drying.

These days, more than ever, there is an urgent need to reduce its high energy consumptions. Electrification is already introduced in this industry as well as alternative to gas as heating source.

There are quite some other possibilities to reduce the energy bill considerably. Not only looking at the energy source but more important to understand the spray drier and your product drying behaviour in first place. It all starts with knowing the actual product properties and drier configuration and operation as it is today.

A list of proven possibilities is written down in this article and hopefully inspires the reader to start saving energy. The list is not complete but at least a few should be working for your unit as well.

Figure 2; spray pattern in normal dairy agglomeration spray dryer. DW-1000 spray drier for small productions (SDW). Typical agglomerated powder

2.0 Spray dryer thermal efficiencies

A normal production train of concentration techniques consist of a number of steps; membranes, evaporation and spray drying as last step. Underneath table shows some typical energy consumption for each of the techniques (see figure 3)

Heat consumption to evaporate 1 kg water (kJ) - typicals	
membrane	140
1stage evaporator	2600
2 stage evaporator	1300
6 stage evaporator	430
Idem + thermo compression	370
Idem + mechanical vapor recompresion	400
Spray drying process	Upto 6000

Figure 3; heat consumptions of various concentration techniques

Secondly, Mujundar c.s. showed clearly in 1980 already what the effect is of drier inlet temperature and drying outlet temperature on the efficiency of drying for an ordinary milk spray drier. The bigger the difference between temperature the better the energy is used. For a typical drier at 200C inlet and 85 C outlet temperature the efficiency is about 65% only. Nowadays efficiencies can be much higher potentially.

Further it is obvious that starting with more concentrated feeds for the spray dryer, the overall energy consumption of the concentration train drops tremendously. For example, boosting up 30 % dry solids containing watery feed spray drying to a 40% one liquid feed reduces the energy consumption with roughly a third (see figure 4).

Higher concentration fluids are in general more viscous, generating larger droplets and somewhat larger particle size distribution of the powder produced. Technically a small increase in dry solids should be possible by increasing the liquid feeding temperature somewhat. The optimization work has to start here.

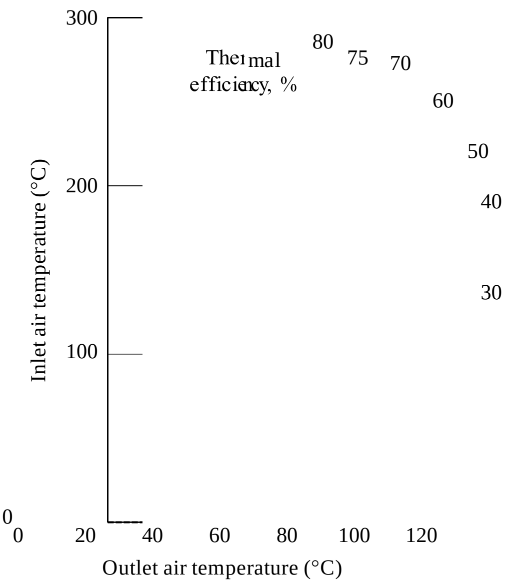

FIGURE 9.42 The effect of both inlet and outlet air temperature on thermal efficiency. (From Kessler, H.G., Heat conservation in concentration and spray drying of milk products, *Drying’80*, Vol. 1, A.S. Mujumdar, ed., Hemisphere, New York, 1980, pp. 339–342.)

Energy Consumption as function of Feed Concentrations

Feed Solids (%DS)	est energy (kJ/kg Powder)
10	23.65×10^3
20	10.46×10^3
30	6.17×10^3
40	3.97×10^3
50	2.68×10^3

Figure 4; impact on energy consumption for a spray drier for the different concentrations

3.0 First steps to save energy

3.1 STEP 1: Know your product and drying process in the first place

Before you can start your 'energy scan', quite some data and information is needed. Collect the following product/process data as a start.

Product data

- What are the main quality parameters for your product? If you need a high-density product the set-up of a spray drier is quite different than low density product. In case agglomeration can be avoided this helps to a large-scale saving energy. Low density products are in general agglomerated products with interstitial air and air inclusion.
- What is the solubility index since most of the powders being produced are solved by its end users. The degree of solubility is made to large extent in your drier
- What is the degree of inactivation for pro-biotics, enzymes and other products? Some products are shear and temperature sensitive. This limits the energy saving in total.
- What is the degree of oxidation of your product?
- What is the specification on residual moisture in your product really? If some more allowed less energy is needed. However, the use of higher residual moisture levels is to be checked with the growth of bacteria by shelf-life trials
- Measure in the laboratory the dynamic viscosity of your fluid using Brooksfield apparatus. May be higher the dry solids to your drier can be increased saving energy at the end.

Process scan

- Collect data on your drying process. Measure drying air flows, energy consumption, product residual moisture, air humidity, air inlet and outlet temperatures, under-pressure, nozzle cooling amongst other. Assess the rate of fouling if possible. Preferably measure the in- and outlet relative humidity and temperature.
- Collect data on drier run lengths and your variety of product port folio
- Collect downtime data and the time involved in Cleaning. Cleaning is a major energy consumer and a costly exercise. The best is going for longest production runs possible.
- Type of atomisation. High pressure atomisation is the standard. Rotary wheel atomisation is seen often for old drier. Two phase atomisation using pressurised air are for tangible products and small driers
- Collect major data on your drier dimensions. What is the drier type being used (single stage drier, multi stage, tall form, counter-current), What drier body volume is available for the air to dry and separate from powder/used air, type of air distributor and type of heater (direct or indirect)

Minimum number of instruments/analysers needed

In practice spray dryers are missing some key measurements, needed to be able to optimise the spray drier constantly. As a minimum the following inline measurements are needed

- gas meter dedicated for the spray drier plant

- air intake humidity and temperature
- double temperature sensors at the inlet of the spray drier
- same at the outlet before and after the cyclone/filter
- preferably an air humidity measurement at the cyclone/filter outlet
- pressure sensors in drier
- Pitot measurements
- proper feedback control liquid and outlet temperature

In addition, some instrument holes for the process engineer to be used for field instrumentation measurement, e.g. Kimo measurements

Product/process data

- Stickyness is a phenomenon which is limiting the maximum energy saving possible for your drier. It is known for instance that sugary products tend more to stick at higher inlet temperature of the drier. By lowering this temperature, the whole run length of the drier will increase avoiding early cleaning. At the end approach of drying at low temperature is more energy efficient than going for high inlet temperatures.
- Drying curves. In general, the residence time of the drier is not the limiting factor for optimisations. It is good to know by measuring from laboratory measurements about the minimum residence time needed.

Product safety data

- Is your product potentially explosive? If yes, what is the explosion class (ST-1, 2 or higher)
- What is the maximum allowable temperature before your product starts smouldering? This sets the maximum inlet temperature of your drier.
- What is the minimum ignition energy MIE of your product?

3.2 STEP 2; Simple calculation tool and Mollier diagram

Now you have collected quite some information, a simple calculation model in excel can be made to know and calculate heat and material balance.

Try also to fill in these data on a Mollier diagram (see attached). Its summaries the air/product data of your system is working in.

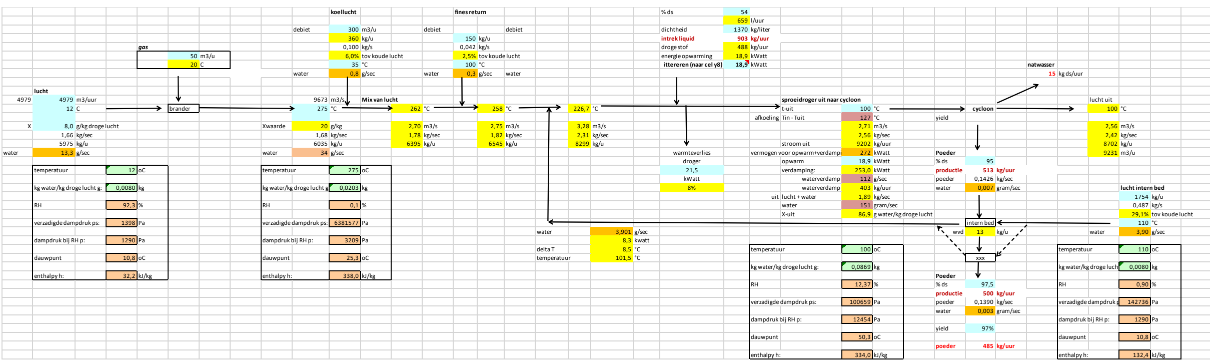

Figure 5; simple drier calculation tool in excel (example)

4. Step 3; Energy saving possibilities

4.1 Use of air dehumification system

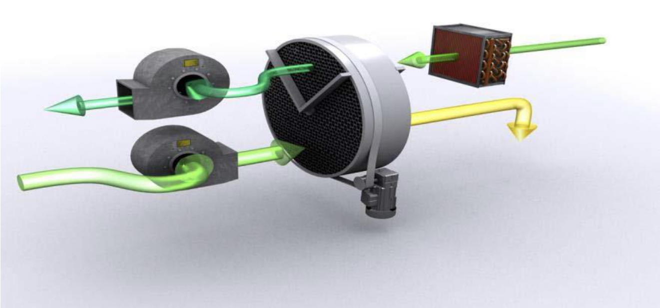

Figure 6; schematic of silica gel for de-humification of drying air

Air from the environment is used for the majority of the ST-1 qualified spray driers. Fresh air is being routed via a series of intake filters to assure hygiene, a heat exchanger and a push ventilator which leads the air finally to the top entrance of the spray drier. The impact of the weather conditions has a major impact on the drier operations. At high air humidity more moisture is taken into the drier limiting the capacity of the drier and hence boosting up energy consumption. Since the variance of weather conditions are quite large, air DE-humifications using silica gel wheels are the way to go. It is an efficient tool sending constant air humidity of typical 6 g/kg moisture to your drier.

Silica gel driers are the standard for spray drying nowadays. In addition, operation in food and dairy a dehumifier enables the drier at constant conditions, lower outlet relative humidities and enables to dry sticky materials all year round. A yearly ball parc figure energy saving of 14% can be achieved by using them.

Installing a silica gel drier for your drier is the standard not only for your drier air, but also for packaging, fluid bed air and other users. Underneath a schematic how this silica gel drier impacts your way of drier operation.

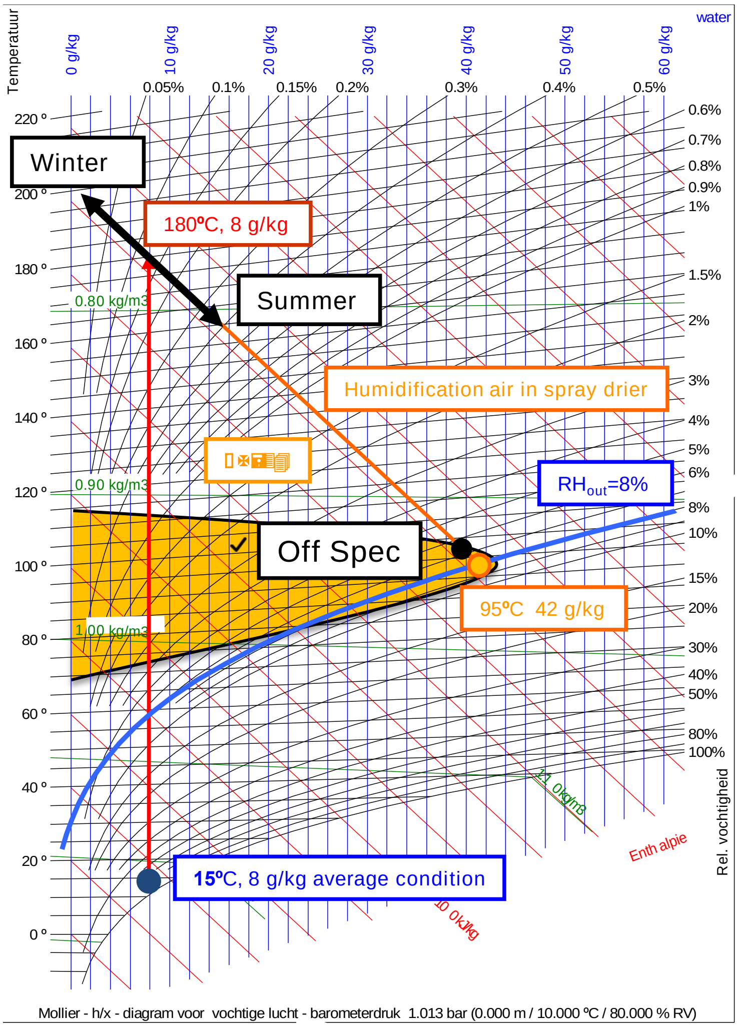

Figure 7; impact of silica wheel on the performance of your drier and sticky product in winter and summer

4.2 Heat exchange of air (pre-heater)

On average the outlet temperature of a spray drier is some 90-95C degrees. The majority of the product residual moistures varies between 1 -4% which is sufficient for long shelf life. The dew point of the air stream is some 30-35C range. In other words, this 90-95 temperature can be used for quite a range, efficiently by closed water loop and heat exchanger: to pre-heat the air for example. In general, a pre-heater is saving 4-5% on the energy bill.

4.3 Air heating

Direct gas heaters versus Indirect gas heaters

Old spray driers are using direct gas heaters. The burning CH4 methane gas is directly mixed with the drying air. While gas burning releases quite some water vapours, these water vapours are introduced extra into your drier. This is a major drawback. In addition, potentially carbon monoxide traces can be come in direct contact with your dry product. For reasons of safety, hygienic and energy costs this direct heater are not the standard. Direct heater produces flames which are a potential safety hazard too.

Since the industry has developed highly efficient IN-DIRECT gas heater years ago, this is the standard now. Although this consensus is changing slightly into completely electrical air heater types.

Changing a direct gas heater into a IN-Direct gas saves <5% energy

Indirect gas heater + electrical heater in series!
Although development towards large multiple Mega-watt electrical heaters are going fast, it is good compromise to consider installation of a small type after or before your indirect gas heater. In such a way you have dual sourcing of energy for your drier.

Electrical heaters only!
In The Netherlands there are examples popping up of using up to 10 MW electrical air heaters without the need for burning gas on the factory at all. These developments are going very fast. In case this set-up of electrical heaters proves 99,999% reliability on operating time this will be the new standard for spray driers.

4.4 Increase the difference between air inlet and air outlet temperature

The bigger the difference between drier in and outlet temperature the higher the efficiency. Tin is the drier inlet temperature. Tout is the outlet drier temperature. Two examples one for dairy, one for minerals. Comparing the conditions Tin/Tout 200/90 C/C with 200/80 C/C saves already some 9% on energy. Comparing 300/90 with 300/80 saves some 5%

Important to know: how about your sticky zones? What temperature/humidity combinations are the danger zones? For long spray drier runs it is key to know this region and keep out of it. For optimisations know first the relative humidity at the outlet first and start moving slowly from there.

4.5 Use of high-pressure nozzle atomisation

The standard in spray drier is high pressure nozzle atomisation. They are able to make small defined droplets of your fluid, spraying in a nice way the direction you want. In that way you can position the high-pressure nozzles nicely in whatever position you like in the top region of your spray drier. When the drier is designed properly, the majority of the droplets are moving downwards immediately, with minimum fouling to the upper deck. Fouling deposits to the top deck are to be avoiding as this is safety hazard.

Computational fluid dynamics (CFD) simulations show clearly: the more your position the nozzle spray closer to the top deck of the spray drier, the higher inlet temperature these droplets are 'seeing' actually, the higher the efficiency. If possible, put the nozzles close to the upper deck reducing the energy consumption with few % instantly.

This is something you only must consider after collecting all necessary data mentioned in section 3.

4.5.2 Rotary atomisers versus high pressure nozzle atomisation

Rotary atomisers are still used for older types of driers. By high rotating wheels with gaps liquids are breaking up in a quite uncontrolled way. These wheels are located near the roof of the drier. The range of liquid particles produced out of the wheel are quite broad compared to nozzles. Fines droplets are immediately attracted to the inner roof of the drier increasing the risk of (heavy) fouling and safety issues over there.

In comparison high pressure nozzles are located somewhat lower to the upperdeck and spraying downwards. Less material is flown upwards to the upper deck. In general nozzle towers are less fouling than rotary wheel towers. If this results in more frequent cleaning a big energy saving potential is there by changing the way atomisation for high pressure type.

Inside the tower

Figure 8; fouling at upperdeck for rotary wheel drier

4.6 Preferably dry clean only, avoiding CIP

Most spray driers are multi-functional enabling producing various batches. In between cleaning is often necessary, often done using Cleaning in Place devices. After normal shut down of the tower, cooling down, cleaning can start using Cleaning in Place system. The tower will be wetted for longer times. After CIP the unit is to be dried and gradually re-started again for the next batch of powder production. This time-consuming exercise costs a lot of time, energy and capacity. The main driver for that is hygiene, avoiding mixing any residual material traces of various batches with another. Change over material is now often re-processed too or send an outlet in feed industry.

Ideally optimum logistic planning makes fewer CIP runs possible. For sure it can be done for quite some markets.

4.7 Reduce air nozzle/lance cooling

For nozzle type spray driers, an amount of cold air is to be introduced around the lance while spray drying. This is a safety item avoiding high temperature in the lance. It is obligatory to use this nozzle cooling. However, the rate of cooling air being used provides room for improvement and energy saving. Typical 2-4% nozzle cooling is sufficient. Higher rates make energy use unnecessary high. Total energy saving potential is smaller than 1 % for most driers. If an air dehumifier unit is installed use this quality air.

4.8 Increase liquid inlet temperature to 5C lower than drier outlet temperature

The more the liquid is pre-heated the less energy in total is being used. Heating by a pre-heater outside the spray drier itself is way more efficient than being done in the dryer itself.

If possibly try to heat-up as close to the drier outlet temperature minus 5C safety margin. Typically, energy saving in total is 2-5% as ball park.

4.9 thermal isolation

Make sure the total drier is foreseen with thermal isolation. It is to be closed configuration for hygienic purposes. Check by IR inspection the quality of isolation.

Some drier installations do not have a thermal isolation for the bottom conus leaking deliberately some heat to the environment as cooling is the next step in the drying process.

Attachment: mollier diagram