Downstream-process: Drying

A literature review written by

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Table of content

Background and scope of Drying ........................................................................................................ 2
I. Vacuum tray dryer .......................................................................................................................... 3
II. Freeze drying .................................................................................................................................. 4
   1. Pretreatment ........................................................................................................................... 4
   2. Freezing .................................................................................................................................... 4
   3. Primary Drying ........................................................................................................................ 4
   4. Secondary Drying ..................................................................................................................... 4
III. Rotary Drum Dryer ...................................................................................................................... 5
IV. Spray dryers .................................................................................................................................. 6
V. Pneumatic Conveyor Dryers ......................................................................................................... 6
Conclusion .......................................................................................................................................... 8
Outlook/ Integration .......................................................................................................................... 9
List of figures ..................................................................................................................................... 10
Background and scope of Drying

The drying process is typically the last stage of most manufacturing processes, which involves the removal of water as well as other solvents while ensuring a minimum loss in the viability of the product. There are numerous benefits of utilizing drying. For example, the cost of transport is lowered as redundant weight like water and solvent weight is removed, the handling and packaging of the material is simpler and storage is also more convenient in a dry state. In this report, a few methods of drying will be outlined, and they are:

1. Vacuum Tray Dryer
2. Freeze Drying
3. Rotary-Drum Dryers
4. Spray Dryers
5. Pneumatic Conveyor Dryers

In general, the methods utilized in drying involves removing as much water as possible in the initial stage, either by centrifugation or via a filter press. This reduces the heating costs incurred by the drying process as less water is required to be evaporated. [1]

In the context of Bioprocesses, Drying is a process that is useful in the manufacture of products like pharmaceuticals like antibiotics, hormones, flavors and fragrances. It has also been utilized in the production of food, with the advent of products like freeze-dried food which has been used for production of ‘space food’ – food brought to outer space for astronauts to snacks consumed by the average consumer.
Downstream-process: Drying

I. Vacuum tray dryer

Vacuum tray dryer works by removing moisture through a vacuum created [2]. A vacuum oven is a typical form of equipment used in this process, as iron is able to withstand the vacuum pressure without deforming. An air tight environment is then created, with the oven connected to a vacuum pump for the creation of a pressure free environment. The product to be dried is kept in a tray, which is then put in the oven for the drying process. The water vapor that is produced from the drying process is sent into the condenser of the vacuum oven and the dried product is then removed from the trays. This method of drying is particularly useful for products that are sensitive to heating so in the context of Bioprocesses, the drying of enzymes could be dried via this method as heating could cause the denaturing of the enzymes, rendering the product useless. Heating of the product is around 25-30 °C due to the low pressure inside the vacuum oven.

Figure 1.: Schematic of a vacuum oven dryer, with the condenser to remove water vapors, and heat pumps to provide heating for the removal of water. [2]
II. Freeze drying

Freeze drying typically involves four stages [3]:

1. Pretreatment
Pretreatment includes any process that is required to treat the product prior to the primary freezing and drying process. Some processes that may be utilized in this stage could be concentrating of the product, surface area increasing, composition or formulation revisions. For most of the pretreatment processes, the steps taken are established based on theoretical knowledge, or production requirements such as quality or quantity requirements.

2. Freezing
In an industrial sized freezing facility, a freeze drying machine is used. The product is typically cooled to a temperature below its triple point; thereafter, sublimation occurs in place of melting, which is useful for the steps to follow in the freeze drying process.

3. Primary Drying
In this part of the process, the pressure is lowered in the system to a range of a few millibars. Then, just enough heat is supplied to the system just for the sublimation of ice. This is done by calculating the latent heat of sublimation for the process and the amount of heat can thus be determined. There is typically a condenser in the freeze drying machine for the water vapor to condense and solidify on, as a place to remove the water.

4. Secondary Drying
In the primary drying phase, around 95% of the water will be removed. The remaining unfrozen water molecules will then be removed in this phase. In the secondary drying phase, the system is heated to a temperature where the physical-chemical interactions between the water molecules and the frozen material can be broken. In this stage, the pressure is lowered even further, to a factor of a few microbars.

For the final product from freeze drying, the residual water composition is anywhere from the range of 1%-4%.
III. Rotary Drum Dryer

Rotary Drum Dryers are made up of large rotating cylindrical tube with a slight slope using the gravity force for material transfer. [4] The water is being removed by the steam-heated surface of the rotating drum. [5] The inner wall of the dryer is usually equipped with a series of internal fins lining. A dryer can also consist of multiple shells to be utilized in a more compact space. [4] Rotary Drum dryers can be used for temperature stable bioproducts. The material is in contact with the heating surface for 6-15 seconds, with a general heat transfer coefficient of 1 to 2 kW m$^{-2}$K$^{-1}$. [6]
IV. Spray dryers

A very economical and widely used option is the spray dryer. Herefore the starting material has to be a liquid or a paste so that it can be atomized through a nozzle. The small droplets are sprayed into a heated chamber and fall into a spiral stream of hot gas, usually 150-250°C. The small droplets have a relative high sourface and so the drying rate is relativly high and in direct corealtion to the droplet size. The material can so be dried compeltly in seconds and the cooling effect from evaporation prevents the material from overheating. Spray dryers are expensive to purchase but econocmical to operate and are very good for heat sensitive materials. [5] [6]

![Spray dryer diagram](image)

Figure 4.: Spray dryer. [5]

V. Pneumatic Conveyor Dryers

As in any other kind of drying process the goal is to remove as much water from the product as is needed to be removed. The idea of pneumatic drying is dry reasonably solid feed (moisture level below 35-40 %) even further. Pneumatic conveying dryers are those in which powders or granular materials are dried while suspended in a stream of heated air. That makes it as extension of the drying process and the total drying requires multiple different steps beforehand. [7] Pneumatic drying requires reasonable solid feed as particles. Heated air conveys particles and removes moisture. You can see form the Figure 5 that the blower blows the air which transports fed particles into the silo. Temperature is adjusted by heaters along the conveying duct or belts or by adjusting blower air temperature.
The process of a pneumatic conveying system is simple and basically consists of a pressure vessel that pumps the materials (powders, granules or other dry bulk materials in this case cell based biomass) via enclosed horizontal or vertical pipelines (conveying lines or ducts) by using compressed air. The key factor is to achieve it in the most efficient and reliable way. A sales pitch from [8] pneumatic drying requires conveying that is easily achieved by pneumatic conveyors. Lines, shaft or ducts that utilize air to move feed particles around. The size of the particles matters and usually the smaller particles are easier to convey.

The advantages of pneumatic drying are that it is mechanically strong, reasonably fast process and the end content of water is low. Disadvantages are that is requires somewhat low moisture content to start with and is usable for relatively solid materials. [9]
Conclusion

The drying is a process where excess water is removed from the product of the process. Depending on the goal water content, initial water content, physical stress sensibility, heat resistance, particle size and goal purity of the product, a correct drying sequence is needed. Usually drying starts with mechanical drying with press dryers or centrifugal dryers to remove the initial amount of water. Drying processes can be categorized according to the physical conditions used to add heat and remove water vapor:

1. In heat exchange drying, heat is added by direct contact with heated air at atmospheric pressure and the water vapor formed is removed by the air.
2. In vacuum drying, the evaporation of water proceeds more rapidly at low pressures, and the heat is added indirectly by contact with a metal wall or by radiation (low temperatures can also be used under vacuum for certain materials that may discolor or decompose at higher temperatures).
3. In freeze drying, water is sublimed from the frozen material. Dryers expose the solids to a hot surface with which the solid is in contact.

Different drying methods are useful for different products. The following table shows the rough comparison of the usage for each drying method described in this review.

<table>
<thead>
<tr>
<th>Method</th>
<th>Water-% range</th>
<th>Temperature</th>
<th>Usable for liquids/solids</th>
<th>Pressure</th>
<th>Damage to cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum drying</td>
<td>high</td>
<td>low</td>
<td>Liquids and solids</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Freeze drying</td>
<td>medium</td>
<td>Very low</td>
<td>Solids (liquids with pretreatment)</td>
<td>Low</td>
<td>high</td>
</tr>
<tr>
<td>Rotary drum drying</td>
<td>high</td>
<td>medium</td>
<td>solids</td>
<td>Low/medium</td>
<td>low</td>
</tr>
<tr>
<td>Spray dryers</td>
<td>high</td>
<td>hot</td>
<td>liquids</td>
<td>Medium</td>
<td>low</td>
</tr>
<tr>
<td>Pneumatic dryers</td>
<td>low</td>
<td>medium</td>
<td>solids</td>
<td>Medium/high</td>
<td>low</td>
</tr>
</tbody>
</table>

Table 1 Comparison of presented methods

In short: the choice of drying method is based on several factors:

- Water content, initial and goal
- Product’s tolerance to heat, pressure, physical stress
- Size and phase of the processed product
Outlook/ Integration

As stated in this document drying is an important part of the fermentation process to generate marketable biomass. But to optimize the drying process by itself may not lead to optimal results. It is recommended to try to couple some aspects of the purification with the reactor. This requires the work of both engineers and biologist to build a better process than sequential optimization could achieve. Small changes in the upstream process can lead to great changes in the downstream process and strongly simplify it or complicate it. [5] For example, dextran sulfate reduces cell clumping in the bioprocess but can lead to changes in the structure of product proteins, reduce their shelf life and complicating the downstream process. [10]

Another target of integration is to reduce the energy consumption. For this target it is sometimes possible to use sometimes low temperature steam and water as energy supply for drying. Figure 1 shows how the steam of a combustion boiler in a bioenergy plant can be used to generate energy. Subsequently the hot, condensated water can be used to power the dryer reducing the energy cost heavily. [11]

Figure 5.: Integration of a dryer and energy production. [11]
Bibliography


List of figures

Figure 1.: Schematic of a vacuum oven dryer, with the condenser to remove water vapors, and heat pumps to provide heating for the removal of water. [2].................................................................3

Figure 2.: Diagram of the freeze-drying steps on a Pressure – Temperature graph of H2O. [3] ...............5

Figure 3.: Rotary Drum Dryer. [7] ........................................................................................................5

Figure 4.: Spray dryer. [5] ................................................................................................................6

Figure 5.: Integration of a dryer and energy production. [9].................................................................9