Spray drying

Introduction

Spray drying is a simple and quick method in which the material in a liquid state (solution, suspension, emulsion) is converted into a dry solid form by spraying it into a hot drying medium (air, inert gas). The spray drying product is a powder, granulated or agglomerated powder.

Short drying time followed by rapid stabilization of the material at moderate temperatures allows spray drying of biological and thermolabile materials (fruit juices and pulp, milk products, herbal extracts, essential oils, enzymes, aromatic compounds and various pharmaceuticals), hydrophilic and hydrophobic materials, low or high molecular weight products, including a wide range of polymers.

The main aim of this method is to obtain dry particles of desired properties (particle size, particle shape, residual moisture content, bulk density). Depending on the material composition and operating conditions, spray drying provides powders consisting of nanoparticles (210 - 280 nm), microparticles (10 - 50 μm), or agglomerates (up to 3 mm). It also makes it possible to increase the dissolution rate and solubility of a given substance, to influence appearance, flow properties, dispersibility, bioavailability and stability of the formulation.

Spray drying process

The spray drying process consist of 4 basic phases:

- Atomization – the material in liquid state is sprayed into the droplets
- Contact of droplets with the drying medium (air, N_2) - drying
- Solvent evaporation, particle formation – evaporation of liquid to form particles that fall to the bottom of the drying chamber
- Regeneration – separation of solid particles from drying gas using the cyclone/filter

Atomization

It involves atomization and dispersing of the material into fine droplets while reducing the particle size. As a result, a large surface is formed which is exposed to a drying gas. The atomization is carried out by means of atomizers. The choice of atomizer depends on the nature and viscosity of the material and on the desired properties of the product. Different types of pumps allow the transport of the material to the atomizer, most often peristaltic pumps are used.

Atomizer types:

- Rotary atomizers – most efficient, centrifugal force atomization, flexibility, high feed rate, suitable for abrasive materials, low risk of clogging, easy droplet size control. They require a wider drying chamber, they cannot be used in horizontal dryers, higher risk of deposits on the walls of the chamber.
- Hydraulic nozzles – atomization by pressure, different diameters of the nozzle orifice, allows the use of narrower drying chamber, product properties can be influenced by liquid flow rate, clogging, usually not suitable for highly viscous liquids, produce particles with narrow particle size distribution
- Pneumatic nozzles – two, three or four jet, kinetic energy atomization, liquid is sprayed in a compressed gas, very fine droplets, clogging
- Ultrasonic nozzles – ultrasonic energy, the output nozzle vibrates at ultrasonic frequency, droplet size is dependent on the frequency, narrow particle size distribution, self-cleaning ability

Drying

The second step of spray drying is mixing the atomized droplets with a stream of heated gas to facilitate evaporation of the solvent and production of dry particles. Ideally, the final product should be sufficiently dry before it comes into contact with the walls of the drying chamber and thus be almost all collected in a collection container. The drying gas is predominantly atmospheric air. Nitrogen and other inert gasses can be also used as a drying gas. Drying takes place in drying chamber. According to the mutual orientation of drying air stream and drying equipment, we distinguish the dryers into co-current, counter-current and combined. According to the operating conditions we distinguish open, closed and semi-closed circulation system and aseptic drying.

- **Co-current dryers (Fig. 1)** – the drying air stream and the atomizing device are both placed in the upper part of the drying chamber, the droplets fall toward the bottom of the chamber together with the airflow, simultaneously losing their liquid, rotary atomizers and nozzle-based atomizers can be used, useful for thermal sensitive materials.

- **Counter-current dryers (Fig. 2)**– the drying air stream and the atomizing device are placed opposite (usually the material at the top of the chamber and the air at the bottom), the droplets hit the air stream, which has lost most of its heat. The final temperature of the product is higher than the outlet air temperature, drying in such systems produces porous powders with a low density and large particle diameter.

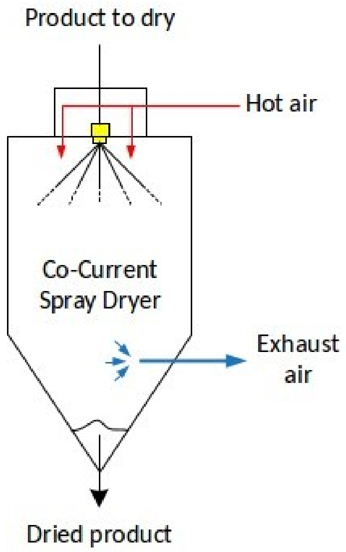

Figure 1: Co-Current spray drying

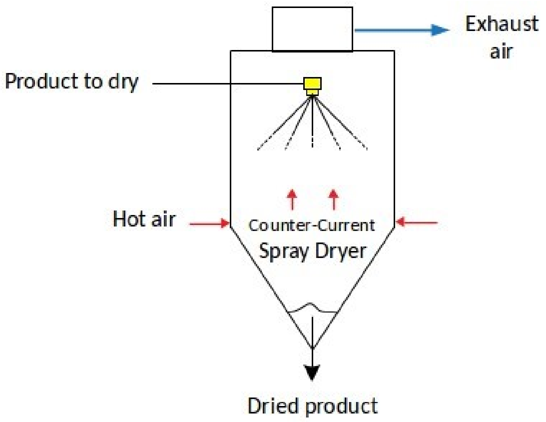

Figure 2: Counter-Current spray drying

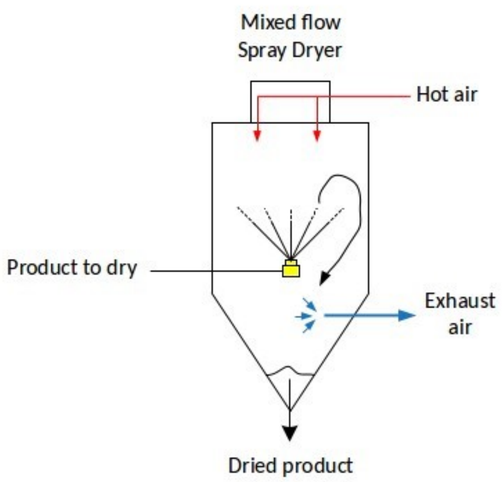

Figure 3: Mixed flow spray drying

https://powderprocess.net/Spray_Drying/Spray_Drying_Current.html

- **Combined (mixed) flow dryers –** the combination of co-current and counter-current technique – the hot air is introduced at the top of the drying chamber, but the liquid is injected on the bottom half of the chamber

- **Open circulation system** – drying of aqueous solutions; the drying gas is atmospheric air, heated directly or indirectly, passes through the chamber and then is released back into the atmosphere; the exhaust air is cleaned by means of a combination of cyclones, fabric filters, an electrostatic precipitator and humidified gas purifier

- **Closed circulation system** – for work with flammable solvents, highly toxic products, oxygen-sensitive substances, for explosion prevention, air pollution prevention; drying gas is recycled and reused; indirect gas heating

- **Semi-closed circulation system –** two basic variations – partial recycle mode (up to 60 % of the exhaust air is sucked back into the dryer) and self-inerting mode (thy drying gas is heated directly by the air-fired heater)

- **Aseptic drying –** sterile liquid is converted into a powder suitable for parenteral application without the need for terminal sterilization; drying medium passage through HEPA filters, material through sterile liquid filters; sterilization of nozzles and chamber walls, rapid product collection

Solvent evaporation, particle formation

Upon contact of the droplets with the hot drying medium, the droplets of the solution evaporate, which is driven by the difference between the vapor pressure of the solvent and its partial pressures in the gas phase. The duration varies depending on the nature of the product and the gas inlet and outlet temperature. If the gas inlet temperature is high, the material will dry faster. Evaporation and particle formation will proceed faster. The drying rate also depends on the ratio between the particle surface area of the particles and the amount of atomized droplets. Smaller droplets have a larger surface and will dry more quickly.

Product recovery

The final stage of spray drying. It involves the separation of the dry product from the drying medium by means of a cyclone and a fabric filter located outside the drying chamber. The difficulty of separating dry particles from the drying medium depends on the density, particle size, and settling rate in the cyclone. During drying, the product particles sink towards the bottom of the drying chamber. They can then leave the drying chamber together with the outlet gas and the product is separated from the gas by a cyclone (separates solid particles from the drying medium by centrifugal force) or a fabric filter. The particles may also settle at the bottom of the chamber and be separated by wiping device.

Additional processes

In some cases, the desired product cannot be obtained in a one-stage process. Then spray drying is combined with additional processes, that are applied before, during or after spray drying. The most common treatment of the solution before drying is the suspension or colloid preparation. In the modification of spray drying, additional steps may be added during atomization or drying. An example is the mixing of liquids immediately before or during atomization using atomization nozzles or the use of multi-zone drying chambers. Spray drying may be followed by other processes such as secondary drying to adjust powder moisture and more complex processes such as microencapsulation.

Parameters affecting spray drying

Inlet temperature – temperature of the drying medium at the first contact with the material; is measured before the drying medium enters the chamber; is a critical factor affecting the properties of dry product

Drying medium (air) flow rate – volume of the drying medium fed to the dryer per time unit; affects the separation of the product in cyclone and how well the product is dried; at lower medium flow rate the particles move slowly through the equipment and the drying medium act on them longer

Pressure/volume of atomized gas - the pressure under which the drying medium is fed in; with increasing atomization pressure, the bulk density of the product increases due to the decreasing droplet size and faster moisture evaporation; the formation of smaller droplets reduces the particle size of the product and increases the bulk density

Feed rate and solid concentration in feed – depends on the material properties, pumping equipment and tubing; as the feed rate increases, coarser particles are formed and drying can be inefficient; the same is true for the solid concentration in feed. However, as the temperature of the material increases, its viscosity decreases thereby reducing the size of the droplets

Selection of solvents – high solubility of the substance in the solvent reduces the drying time and energy required to evaporate the solvent; for homogeneous spraying, the viscosity is of great importance – should be relatively low; solvents used in the pharmaceutical and food industry must be approved by the competent control authorities; water, ethanol, methanol, isopropyl alcohol, acetone, methylene chloride, ethyl acetate and their mixtures can be used as solvent

Outlet temperature – the result of the heat exchange between the droplets and the drying gas; the highest temperature to which the product can be heated; measured before the drying medium enters the separation equipment; increasing the feed rate through the pump leads to greater solvent evaporation and decreasing the outlet temperature; other parameters affecting the outlet temperature are the inlet temperature and the aspirator capacity – as they are increased, outlet temperature increases; higher outlet temperature results in a lower residual content of the solvent

Spray drying applications

Increasing the aqueous solubility and bioavailability of APIs

The most common method used to increase the water solubility of API is to reduce the particle size – one way to reduce the particle size is by spray drying. Water solubility can be also increased by simultaneous drying of the water-insoluble drug with the water-soluble substance. To increase the dissolution rate, it is possible to precipitate the API together with the polymer into a stable amorphous solid dispersion using spray drying. Another possibility to accelerate the dissolution rate is the preparation of nanoparticles by spray drying.

Modified release of API

Spray drying can be used for encapsulation, which is associated with several commercial and health benefits – prolonged drug release and the associated reduction in the number of doses

Direct compression – powders prepared by spray drying are intended for direct compression without the need of further treatment. Spray dried materials show better flow properties, there is a possibility of combining more excipients by means of co-processig. This is beneficial both economically and to improve process performance

Aseptic drying – API is mixed with one or more excipients and dried in the form of sterile solution to sterile particles of desired properties without the risk of contamination

Inhalation products – powder intended for inhalation must retain its activity and aerodynamic properties even during storage; spray drying gives homogeneous dispersions with suitable aerodynamic properties that allow particles to penetrate deep into the respiratory tract

Vaccines – must be active and physically-chemically stabile; the addition of suitable stabilizers will allow us to produce vaccines suitable for mass vaccination; bacterial powders can also be used as immunizing agents; a tuberculosis vaccine was prepared using laboratory spray dryer

Viable organisms – viable organisms are used to produce biologically active substances or intermediate compounds used to make active substances; Yeasts are examples of such organisms – their powder form facilitates their application, storage and prolongs their viability. Knowledge about the behaviour of bacteria during spray drying is important due to the possibility of contamination of the material with pathogenic microorganisms and the growing interest in probiotics

Dry plant extracts – plant extracts are commonly obtained by spray drying; spray dried particles are characterized by high hygroscopicity and viscosity and poor rheological properties; for compression it is necessary to prepare the granular powder (wet or dry granulation)