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HOW TO CHOOSE A VACUUM DRYER

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Vacuum drying can be applied in a range of processes in several industries, including chemical, pharmaceutical, food, plastics, and metal powders. This article first discusses vacuum drying benefits and limitations and dryer components and operation, then explains the differences between tumble and agitated vacuum dryers and how you can select one for your application.

Vacuum drying equipment typically removes water or removes and recovers solvents from a moist material - hence; the equipment is called a dryer. The equipment is also sometimes used to change a material's molecular and physical chemistry (called a phase change) in specialized operations such as chemical reactions and polymer solid stating. Vacuum drying is typically a batch operation.

The following information discusses available batch vacuum dryers and how to select one for your application.

Vacuum Drying Benefits and Limitations

A vacuum dryer is typically used for separating a volatile liquid by vaporization from a powder, cake, slurry, or other moist material. This process is fundamentally thermal and doesn't involve mechanically separating the liquid from the material, such as in filtration or centrifugation.

Unlike a direct-heat dryer, in which the material is immersed directly into the heating media (usually a hot gas stream) and is dried by convection, a vacuum dryer is an indirect-heat dryer. That is, the heat is transferred to the material as it contacts the dryer's heated surface, drying the material by conduction. Understanding this distinction is essential for grasping the advantages and limitations of vacuum drying, as well as for selecting a vacuum dryer that efficiently and economically achieves your process goals.

To understand how vacuum operation aids drying, let's look at a simplified drying theory, beginning with this equation:

$$Q = U A \Delta T$$

Where Q is the total heat (in British thermal units [BTU]), U is the overall heat transfer coefficient (in BTU/[ft²0F]), A is the effective heat transfer surface area (in square feet), and ΔT is the temperature difference between the liquid's boiling point (that is, vaporization temperature) and the heating media's temperature (in degrees Fahrenheit).

The process goal is to achieve an effective heat transfer (Q) to the material so that its liquid content is vaporized.

Most often, the material's properties and the dryer type effectively establish the U and A values for the process.² So when using a dryer, your focus turns to maximizing the ΔT value to increase the Q value.

Here vacuum drying provides a unique advantage. By controlling atmospheric pressure, the vacuum dryer increases the effective ΔT for a given process. That is, vacuum drying simple reduces the boiling point - or vaporization temperature - required for removing the liquid.

By controlling pressure and the heat introduced to the dryer, you can significantly increase the effective ΔT and thus dry the material faster than at normal atmosphere. For this reason, a vacuum dryer is especially suited to drying a heat-sensitive material that degrades above a given temperature and would otherwise require a lengthy drying cycle. Examples of such materials are vitamins, antibiotics, and many fine chemicals.

The closed-system design required for achieving and maintaining the low-pressure atmosphere inside the dryer also provides advantages for processing a hazardous material. Examples include toxic chemicals or solvents and explosive materials. The vacuum dryer safely contains and condenses the hazardous vapors from such substances without any threat to your workplace environment or outside atmosphere. With some hazardous materials, you can provide further protection by using inert gas to

Vacuum Drying Facts

When sizing and specifying the correct vacuum and solvent recovery systems for your vacuum drying equipment, components must be sized for the peak vapor load, not for the average or total moisture to be removed.

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limit the oxygen level in the vacuum dryer.

When comparing a vacuum dryer with a direct-heat dryer, such as a direct-heat rotary dryer or fluid bed dryer, keep some limitations in mind. The vacuum dryer almost inherently operates in batch mode because of the dryer's sealing requirements. But depending on your industry's practices, this may not be a problem. For example, if you need to identify and trace individual lots of your products, batch operation is probably preferable. Batch drying also permits greater process versatility and can be more easily adapted to changing manufacturing practices. But if your vacuum dryer is part of a continuous process, you'll need to install surge hoppers and other material handling equipment before the dryer to create a hybrid batch-continuous operation.

Another vacuum dryer limitation is related to the equipment's heat transfer mode. A vacuum dryer's upper temperature limit (typically about 600° F) is lower than that of a direct-heat dryer. The rate at which material temperature can be raised in a vacuum dryer is also limited. This is because the indirect-heat vacuum dryer is limited by the surface area available for heat transfer, unlike a direct-heat dryer, which is limited only by the hot gas volume in the drying chamber.

Dryer Components and Operation

The vacuum dryer is the centerpiece of a vacuum drying system that also incorporates media heating and circulating, vacuum, and solvent-recovery components. The dryer consists of an enclosed, thermal-jacketed vessel that serves as the drying chamber. The vessel is usually constructed from stainless steel or special alloys to match your requirements, and the vessel capacity is typically from 1 to 500 cubic feet.

Media heating and circulating components. You can use any of several heat sources to supply hot media to the thermal jacket, depending on your temperature and resulting BTU requirements. You can pipe plant steam to the jacket or, to avoid condensate problems, use heating elements and a heat exchanger to heat a fluid (usually water or oil) for the jacket. The hot media flows through the dryer's thermal jacket to transfer heat to the drying chamber.

Correctly specifying the thermal jacket and media heating and circulating components and ensuring that the media flowrates and pressure are compatible with your jacket are important to successful vacuum drying. Be aware that using steam or pressurized hot water or oil in the jacket often requires a high-pressure jacket design (to handle a positive pressure higher than 1 atmosphere). The high-pressure jacket allows better media flowrates and heat transfer through the jacket to the dryer wall, but the jacket design will need to meet the rigorous requirements of the ASME Code for unfired pressure vessels.

Vacuum and solvent-recovery components. A vacuum line runs from the dryer to the vacuum source, usually a vacuum pump, which reduces the atmospheric pressure in the dryer. The vacuum pump is primarily responsible for the vacuum level in the dryer, as long as the vessel is properly welded and the vacuum line is effectively sealed to the vessel. The most common type is a liquid ring vacuum pump. The sealing liquid in this pump can be water, oil, or a compatible solvent. The pump typically produces a vacuum in the range of 100 torr. For an application requiring a very high vacuum (atmosphere as low 0.1 torr), you can use a rotary blower and air injectors to boost the liquid ring pump's capability.

The vacuum line pulls off the vapors that exit the dryer as the wet material dries. The vapors are captured by a condensing system located between the vacuum pump and the dryer. The system typically includes a precondenser and a condensate receiver tank. The precondenser is chilled to condense the vapor, and the condensed water or solvent is captured in the condensate receiver tank. A condensate pump removes the condensate from the tank.

In some cases - such as when the solvent is toxic or hazardous and would pose an environmental hazard if discarded without special treatment - the solvent can also be used for the sealant in the liquid ring vacuum pump. This requires equipping the vacuum with a condensing system that has a closed-loop sealant arrangement.

Dryer types. Most vacuum dryers are adapted from solids blenders. The two principal types of vacuum dryers are tumble and agitated.

Tumble and Agitated Vacuum Dryers

Determining which vacuum dryer is best for your application depends in part on knowing your material's moisture content. But you also need to understand the material's particle characteristics because these characteristics at different moisture levels can vary in unexpected ways. For instance, a filter cake containing 40 percent moisture can flow better than one with 15

percent moisture. For this reason, expect the dryer manufacturer to test your material before determining which dryer will best handle it.

Tumble vacuum dryers. The tumble vacuum dryer consists of a rotating or tumbling vessel, most commonly in a double-cone shape.

By controlling atmospheric pressure, the vacuum dryer increases the effective ΔT for a given process.

A thermal jacket encloses the entire vessel; the vessel is supported by two trunnions. A small, stationary vacuum line in one trunnion extends into the vessel; a small vacuum filter is located at the line's inlet. A delumping bar can be mounted on one trunnion and extend into the drying chamber.

In operation, the vessel rotates about the trunnions' axis. The integrity of the seal around the stationary vacuum line - which extends through the trunnion and is angled upward into the drying chamber's top, above the material in the rotating vessel - is critical for maintaining the dryer's vacuum. During rotation, the material cascades inside the chamber, gently tumbling and folding to bring the material into contact with the heated walls. This action makes the dryer especially suitable for handling friable and fragile materials that can't withstand shear from agitation, such as polyethylene terephthalate pellets. The delumping bar can be operated intermittently to break up undesired agglomerates.

Agitated vacuum dryer. The agitated vacuum dryer consists of a stationary cylindrical or trough-shaped vessel that has a rotating shaft mounted with agitators of various configurations. The dryer can handle wetter materials and less free-flowing materials than the tumble dryer.

The dryer's agitator configurations are based on various blender designs, including ribbon, paddle, and plow mixers. In some models, the rotating shaft and agitators can also be heated with hot media. A large vacuum line is connected to a large jacketed vacuum filter housing at the dryer vessel's top.

Your material's particle characteristics at different moisture levels can vary in unexpected ways.

In operation, the material is blended as the shaft-mounted agitators rotate and move the material into contact with the dryer's heated walls (and, in some cases, the heated shaft and agitators). The agitation permits the dryer to handle materials approaching slurry consistency or sticky materials with high viscosity. Examples include various clays, aluminum pastes, and other metal pastes.

How they compare. Both tumble and agitated dryers are easy to load. However, discharge and cleaning are much easier in the tumble dryer because it has no internal shaft or agitators. The tumble dryer also has a significantly lower capital cost than the agitated dryer.

On the other hand, the agitated dryer provides greater efficiency than the tumble dryer by providing a higher overall heat transfer coefficient (U), allowing better heat transfer to the material. The agitated unit also provides greater effective heat transfer surface area (A) than the tumble dryer, resulting in a better heated-surface-to-volume ratio for drying.

The agitated unit's larger vacuum line and larger filter area (in the jacketed vacuum filter housing) also provide a vapor-flow advantage for an application where the vaporization of unbound moisture is especially fast during constant-rate drying. Removed moisture in such a case can sometimes bottleneck in the tumble dryer's smaller through-the-trunnion vacuum line and smaller filter area.

The agitated dryer's stationary vessel also allows hard piping and fixed connections that aren't possible with the tumble dryer, which simplifies installation and maintenance.

How to Select a Tumble or Agitated Vacuum Dryer

The first step in choosing a vacuum dryer is to determine what size batch you will process. Once you've established the batch size, consider which dryer type will drive up the temperature difference between your material and the heating media (ΔT) by controlling temperature and vacuum with an appropriate heating system and vacuum and solvent-recovery system. The greater the ΔT , the shorter your drying cycle will be.

Selecting components in the dryer's vacuum and solvent-recovery system requires considering your material's moisture content, because the ease and rate of vaporization in your application will depend on your material and the liquid in it. Key variables to consider are the amount of liquid in the material and the nature of that liquid. Ask, "How much liquid must be removed? Is the moisture bound to the particles, in pores or capillaries or through molecular absorption? Or is it unbound moisture that will vaporize quickly?" Be aware that different liquids have different vapor pressure profiles at different temperatures. You need to specify a vacuum and solvent-recovery system that can handle peak loading, not just the average vaporization rate for your drying cycle. Engineering the right system with the right components will ensure the dryer achieves the temperature, pressure, and solvent-recovery capacity you need.

For help selecting the dryer, consult a vacuum dryer manufacturer. Typically, the manufacturer will ask you to provide information about your application on a dryer selection questionnaire. The information includes your material characteristics, characteristics of the liquid to be removed, and drying requirements. You'll also need to explain what resources, such as electric power, heating, and cooling, are available at your plant; whether your process requires solvent recovery; and whether you need associated material handling equipment such as loading or conveying equipment.

After you've filled out the questionnaire, the dryer manufacturer will typically test your material using a lab-scale dryer in the manufacturer's testing facility. For the test, the manufacturer will request that you ship a sample of your material to the facility along with a Material Safety Data Sheet A 1-to 2-cubic-foot sample of your material is typically enough for a single test of a dryer's feasibility; a larger sample is

required to run a series of tests, such as for fine-tuning your drying process.

Testing will confirm your material's flowability in the chosen dryer as well as the dryer's approximate overall heat transfer coefficient (U value). From such test results, the dryer manufacturer can accurately scale up a dryer to forecast the process requirements and cycle times for drying your production-size batch.

References

1. David Cox, "Using a batch vacuum dryer to protect workers, the environment, and heat-sensitive materials." Powder and Bulk Engineering, April 1991, pages 40-46.
2. The U factor is more complex than this equation shows. Resistance impedes the heat transfer from the heating media to the dryer's hot surface as well as from this surface to the material and liquid. The overall U value represents the heat transfer from the dryer surface to a particle or liquid, from particle to particle, and so on. The range of U values are unique to each application, depending on the properties of the material and the nature of its liquid content (for instance, whether the moisture is bound to particles or unbound). The U value can't be varied for a given drying application unless the material's formulation is changed.

The A value is fixed for any dryer and is always lower than the total surface area because not all surfaces continuously contact the material.