



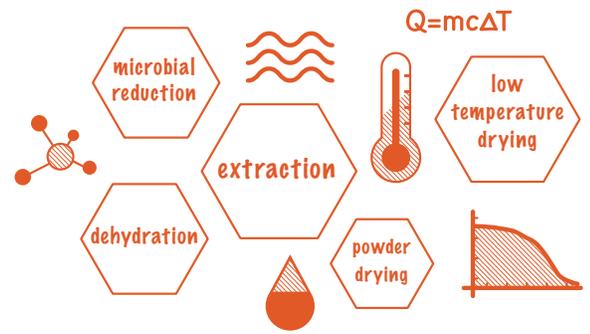
Thermal Processing Handbook

Drying Technologies
for Material Processing



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Thermal Processing Overview

Thermal processing equipment is vital technology in the manufacturing process of food, pharmaceutical, chemicals and numerous other types of applications. Thermal processing refers to changing the temperature of a material with the intention of changing its state in some way. This handbook focuses on various examples of direct and indirect thermal processing techniques. Direct methods are based on generating heat/energy within the material itself, where indirect methods rely on transfer heat generated from another source and applied to the material either through conduction or convection.

Different approaches for temperature modifications are appropriate depending on the application. Materials are thermally processed during production for a variety of reasons including, but not limited to:

- Activating chemical processes for mixes and combinations of materials
- Drying of materials
- Cooking or other types of alterations available through thermal reactions
- Sterilization or removal of microbes or other bacteria
- Crystallization and degassing

In many types of applications, thermal processing must be extremely precise, and the energy applied should be uniform. Inconsistent temperatures can cause poor material results including overheating, burning, sticking, case hardening and other quality problems within the final products.

Indirect heating is a traditional form of thermal processing. By utilizing steam or hot air, these methods heat material from the outside or indirectly. Indirect heating can be particularly effective in ovens, conveyer belts, jacketed cookers or thermal screws. These types of technologies are utilized in continuous applications where the materials are exposed to the heating element for a fixed amount of time while they are in motion through their processing. In batch applications, materials can be placed in ovens or industrial heating drums, mixers and kettles, which also agitate the materials. Batch processing allows for varying heating times, measurement of the material during heating and mixing for a more uniform material temperature.

Direct heating technology refers to methods like industrial microwave. Microwaves generate heat directly at the molecular level, thereby heating the entire material, rather than traditional methods that work from the outside in. Similar to indirect heating, microwaves can be applied in continuous or batch processes, but a key point of differentiation is microwave's ability to immediately provide precise temperature control.

APPLICATIONS

Every day, thousands of industrial applications require thermal processing of some sort. This handbook will focus on drying, as it represents a large segment of thermal processing common to food, chemical, pharmaceutical/nutraceutical and biomass.

Many of today's powdered products, highly nutritional processed foods, pharmaceutical and some organic products would not be possible without advances in thermal processing precision. As the quality of drying and processing advances, flavor, quality, density and form of these products can all be improved.

Sample applications include:

- Cannabis
- Carbon products
- Consumables that require elimination of bacteria
- Crystalized materials
- Dried fruits, meats and other types of dried foods
- Drying of moist products with low thermal conductivity
- High precision/specialty chemicals
- Nanocrystal and Nanomaterials
- Organic solvents
- Pasteurization
- Pharmaceutical API's: Active Pharmaceutical Ingredients
- Powders for pharmaceutical and food products
- Roasting
- Stationary drying of thick layers



THERMAL PROCESSING OPTIONS

Drying technologies fall into the following categories:

- Fluid Bed
- Spray
- Freeze
- Microwave
- Rotary
- Tunnel
- Flash

Each of these options has advantages and disadvantages, outlined below..

Fluid Bed

Fluid bed dryers work by allowing heated, high-pressure air or process gas to flow through a bed of material in an upward direction at a velocity greater than the settling rate of the particles. At this state, the bed is fluidized and the particles begin to dry. While fluid bed processing is an indirect heating method, it is effective for drying granular solids because each particle is completely surrounded by the drying gas, giving a consistent result. However, the volume of air in the fluidizer must be kept constant, so it may be inefficient for smaller batches. Vibration may be added to assist with the fluidization of more difficult materials. To improve energy efficiency in fluid bed dryers, exit air is sometimes recycled and re-used for heating.



Advantages of Fluid Bed Dryers:

- Shorter drying times than static bed convection
- Reduced contact time for drying
- High rates of moisture removal due to excellent gas-particle constants, resulting in high heat and mass transfer rates
- Ability to control the exposure time of the materials to heat
- Ease of control
- Lower capital and maintenance cost
- For light materials, the air flow may raise them above the bed for even heating
- Continuous and batch models available for different applications



Disadvantages of Fluid Bed Dryers:

- The air temperature range is limited for drying
- Significant effort and expense involved in commissioning and parameter optimization
- High energy consumption
- Potential for product attrition and agglomeration
- Not appropriate for materials that are liquid, too wet, sticky or adhesive
- Many models cannot dry fine powders
- Many models are difficult to clean
- Unsafe for flammable or toxic materials
- Not always effective for removing organic solvents
- The vigorous movement of the particles in the hot drying air may lead to the generation of electrostatic charge

Rotary/Drum Dryers

Rotary drum dryers use rotational cylinders that allow materials to cascade inside the drum while heat is applied in order to extract moisture resulting in a dry product. Drums can produce sheets, powders and flakes from the materials being handled.

Drum dryers are differentiated from rotary kilns by the temperatures at which they heat materials. Generally, drum dryers operate at temperatures of 600°-1400°F where rotary kilns are typically refractory lined with a brick or other lining and operate from 1000°-3000°F in order to create a chemical reaction.



Advantages of Drum Dryers:

- Low maintenance costs
- Simple installation and fast commissioning
- Low wear and low replacement part requirements
- Minimal cost and effort for the supplied air equipment with direct installation of the burner at the dryer casing
- Low specific electrical energy requirement
- Ability to compress product for sheet applications
- Appropriate for drying liquids without loss of materials
- Ability to handle viscous materials
- Insensitive to changes in the particle size
- Convenient powder and flake sizes
- Ability to handle variations in the moisture content and throughput
- Easy to operate
- Single dryer can be used for different mixes



Disadvantages of Drum Dryers:

- Long heating times
- Safety distance required for high-temperature equipment
- Large physical footprint
- Low thermal efficiency resulting in high heat loss
- Potential for material attrition
- Unable to process salty or corrosive materials.
- Counter-flow applications are limited to coarse-grained materials
- Some products are difficult to scrape from the drum (high sugar content)
- Solid materials are only partially de-dusted in drum dryer
- Significant cool-down period required in order to clean or maintenance



Spray Dryer

Spray drying uses an atomizer or spray nozzle to distribute a stream of hot air to produce dry powders, granules or agglomerates from a liquid or slurry. Rotary disk and single-fluid high pressure nozzles are the most common types of equipment used for spray dryers.

Single effect spray dryers use a spray source of drying air at the top of the chamber, blowing air in the same direction of the liquid being dried. Multiple-effect spray dryers have been developed to improve on the issues of single-effect dryers, which produce a lot of dust and can result in a poor flow of powder. Multiple-effect spray dryers have atomizers or spray nozzles at the bottom as well as the top of the chamber.



Advantages of Spray Drying:

- High heat-transfer coefficients at high temperature differences
- Rapid drying times
- Highly reproducible process and easy to automate
- Good powder quality
- Ability to handle very viscous liquids
- Enables control of particle size, bulk density, degree of crystallinity, organic volatile impurities and residual solvent levels
- Most spray-dried particles are spherical, which makes downstream operations, like packaging and filtering, easier and less costly
- The solids mixed are more homogenous than those in air drying solution
- Spray drying amorphous formulations can increase both solubility and bioavailability for pharmaceuticals
- Useful for both heat-resistant and heat-sensitive products
- Easy to descale



Disadvantages of Spray Drying:

- Low overall thermal efficiency
- High capital and overhead costs associated with operation
- Rotary disc atomizers can suffer from internal corrosion
- Abrasion damage to nozzles requires frequent replacement
- Maintenance issues with nozzles clogging
- Sticking to internal chamber walls can lead to reduced profits due to product loss and increased cleaning costs
- Equipment requires a large amount of floor space and is heavy
- Not relevant for processing that can't be atomized during drying
- Difficult to use with highly viscous materials



Tunnel Dryer

Tunnel dryers are a type of air and oven dryer, typically used in continuous configurations. Tunnel dryers can provide large scale heating and drying and are available in a variety of sizes for different applications. Continuous tunnel dryers can provide varying heat levels at different zones of the conveyer area.



Advantages of Continuous Tunnel Dryers:

- Ability to reach very high temperatures
- In some cases, ovens can be the most efficient systems for heating
- Continuous ovens can process large amounts of material without the need for loading and unloading (required in technologies that process in a batch formation)



Disadvantages of Continuous Tunnel Dryers:

- Limited control of temperature (low precision)
- Slow adjustment of temperature: ovens need appropriate time to heat and cool
- Thermolabile products can't be processed in this technology
- Inability to dry liquids
- Potential danger to people in the vicinity because of the high temperature
- Potential to burn or overheat materials
- Inconsistent heating or need to carefully arrange materials. If material on a conveyor is thicker in some places, the heating quality may be inconsistent.
- Not suitable for small scale production
- Non-agitated process doesn't allow for even application of heat
- Yield losses associated with start-up and shutdown.
- Higher labor costs incurred due to loading and unloading
- Case hardening may occur



Freeze Dryer

Freeze drying, also known as lyophilization, is a water-removal process that involves three stages. In the first stage of freeze drying, materials are placed in a freezer, chilled bath or on a shelf in the freeze dryer. Depending on the type of material, rapid or slower freezing may be applied at this stage. The second phase, known as primary drying or sublimation, involves lowering the pressure in the chamber, and applying heat and vacuum to remove the water that has crystallized in the freezing process. The final phase, called secondary drying or absorption, removes more of the water through breaking the bond between the water molecules and the dried materials.



Advantages of Freeze Drying:

- Low processing temperature
- Product uniformity
- Appropriate for temperature-sensitive materials and materials that are damaged by heat
- Crisp texture is appealing for certain types of foods
- Preserves nutritional value and flavor of foods



Disadvantages of Freeze Drying:

- Longer processing times than comparative technologies
- Some water content is retained, so freeze drying is not appropriate for all applications.
- Expensive and labor-intensive
- Difficult to integrate into production lines that require further processing because materials are processed in containers or trays
- Storage of freeze-dried materials can be challenging
- Batch processing only



Flash Dryer

Flash dryers combine mechanical agitation, hot gasses and forced air to separate moisture from solid materials. Flash dryers are similar in design to spray or fluidized bed dryers. They operate at very high temperatures for a short time, while agitating the materials. Flash dryers are an efficient method of drying products such as slurries, pastes and sludge (most with back mixing), friable filter cakes, powders and granules. Flash drying is generally used for high-moisture materials with a constant rate drying zone.



Advantages of Flash Drying:

- High heat transfer rates due to good contact between particles and gas
- Rapid heat and mass exchange, avoiding overheating of sensitive products
- Rapid processing speeds
- Homogenous moisture content and product quality
- Simple equipment with few moving parts
- Cost effective and easy to clean
- High capacity



Disadvantages of Flash Drying:

- Suspension and entrainment control problems
- High energy costs
- Susceptible to overloading
- Possible abrasion or dust formation due to high gas velocity
- Particle size limited to fine powders



Microwave Dryer

Microwave is a method of direct heating, where the materials being processed heat at the molecular level, rather than by being in contact with heat from the outside. Microwave has been gaining popularity in many industrial applications because of its versatility and precise heating capabilities. Microwave energy can be applied within mixers, kettles, conveyors or ovens.



Advantages of Microwave Processing:

- Combined with pressure/vacuum, can heat at specific temperatures lower than the boiling point of the liquid being processed
- Precise temperature control
- Rapid drying times compared to ovens and drum drying
- Energy efficient
- Achieves highly consistent volumetric heating
- Ability to adjust temperature according to the materials, with immediate response
- Extremely safe—hot surfaces are greatly reduced
- Retains taste, smell and other innate characteristics of materials
- Effective for microbial reduction or change of state applications
- Usable for materials that have poor thermal conductivity
- Ability to dry stationary materials with thick layers, without frictional losses
- In addition to drying, microwave provides the flexibility to accommodate a variety of other thermal processes including, melting, drying, extraction and roasting
- Able to combine with other processing methods, such as vacuum, pressure and mixing capabilities



Disadvantages of Microwave Processing:

- Limited capacity compared to high-volume conveyor ovens
- Materials must be able to interact with microwave energy
- Necessity to learn a new processing technique



Combining Vacuum and Thermal Processing

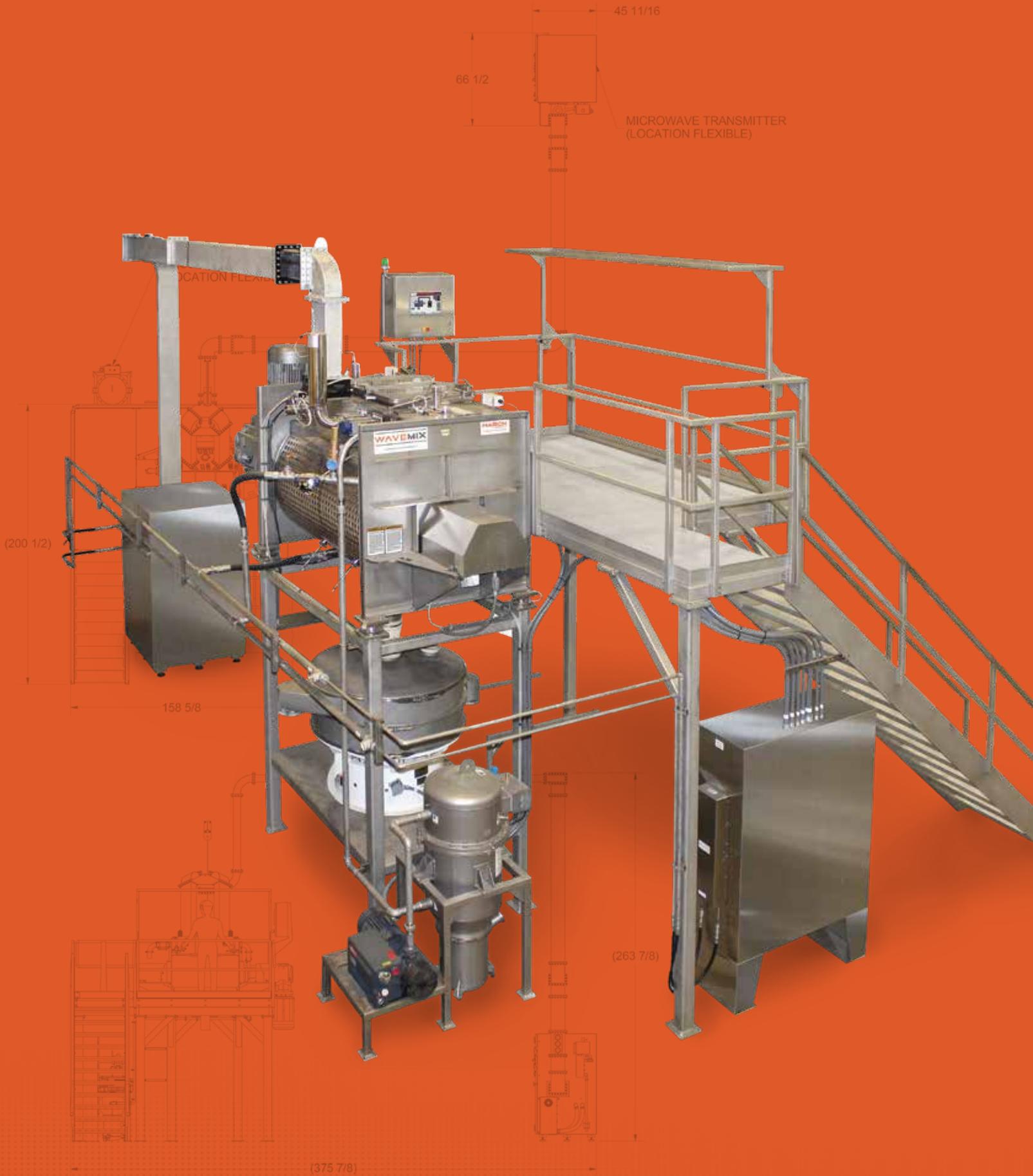
The Benefits

The addition of vacuum in thermal applications has allowed some manufacturers to achieve breakthrough results by processing at lower temperatures. The main benefits of incorporating vacuum and simultaneously using it to apply pressure to the materials being heated are the reduction in boiling points while increasing the speed and improving the uniformity of the drying process.

Using vacuum pressure of 200 Torr, it's possible to reduce the boiling point of water from 212°F to 154°F. This can be hugely important when working with temperature sensitive processes such as the drying of fruits, where heating to 212°F can be detrimental to the finished product. The combination of heat and vacuum can greatly reduce the temperature required, which allows for more of the flavor, aroma, color and nutritional value to be retained.

Other sample applications where adding vacuum to thermal processing is known to improve outcomes include:

- Conversion of bulk frozen materials to powders
- Drying for biomass materials
- Drying pastes
- Food dehydration
- Puffing to expand and retain structure of a material
- Wet granulation



MICROWAVE TRANSMITTER
(LOCATION FLEXIBLE)

WAVEMIX

MARION

WAVE MIX™

Technological Breakthrough: Microwave, Mixing and Vacuum

Presented with challenges from a number of customers originally in the food and chemical industries, Marion Process Solutions set out to find solutions for low temperature and low moisture drying, finish drying, microbial reduction and change of state. Marion's goal was to provide a direct heating solution that was precise and extremely repeatable for high-value thermal processing.

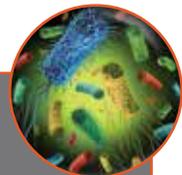
The result is WaveMix™, an innovative combination of three time-tested technologies into one machine incorporating:

- Industrial microwave
- Vacuum
- Mixing

WaveMix creates a consistent, highly controlled environment for materials to be processed. Since 2014, this technology has been used in a variety of industrial applications with impressive results, allowing customers to create a competitive advantage in their respective industries by developing products and/or processes that previously were simply not possible to produce.

At Marion's state-of-the-art laboratory, clients can test at both the R&D and pilot scale levels to see first-hand the superior benefits of the WaveMix product line. The results have been game-changing. WaveMix can deliver safe processing for a variety of materials in ways that were previously subject to inconsistent quality or small batches.

Microbial Reduction in Food Ingredients



As food manufacturers look to reduce the microbial load within their products, they require precise thermal processing equipment to help them accomplish this task. Consumers are increasingly searching for alternative foods for special diets, which requires manufacturers to find new ways to process new varieties of food ingredients in specific conditions. WaveMix™ has proven to be the ideal solution for companies tackling food safety challenges.



The Benefits of Using WaveMix™ Technology

Compared to Alternative Drying Technologies



Time Savings

WaveMix reduces the drying times compared to other thermal processing methods.

Repeatable Results

By creating a fluidized bed through mechanical agitation, the materials are exposed to consistent heat distribution.

Unmatched Versatility

With the ability to control the boiling point of materials, and heat at a moment-by-moment basis, WaveMix places the operator in full control of the application.



Precise Control

Temperature is measured at multiple locations in the vessel, allowing for real-time adjustment through the process.

Energy Optimization

Compared to other methods, WaveMix reduces energy loss during heat transfer.

No Case Hardening

While indirect heating methods can cause the outer surface of a particle to be harder than the internal consistency, microwave processing removes this problem.



Quality Results

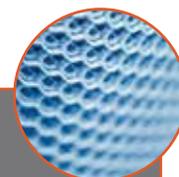
WaveMix maintains flavor, color and other desirable characteristics of the materials being processed.

Gentle Processing

Being able to precisely control temperature and agitation allows the handling of delicate, thermolabile, crystallized, nano and other types of sensitive materials.

Eliminate Material Loss

Tight control removes the opportunity for batches to be ruined due to burning, overcooking or undercooking.



Nanomaterials

Nanomaterials are produced from various sources and used as strengtheners to increase chemical reactivity or conductivity. Nanomaterials are extremely difficult to dry due to the complex molecular structures, and moisture from manufacturing processes tends to be exceptionally bonded. In addition, exposing nanomaterials to high temperatures can cause material degradation and material loss. WaveMix™ technology can provide results at low temperatures with minimal material loss.



Vegetable Drying for Packaged Foods



For today's food products, the color, flavor and nutritional value is top of mind for manufacturers and consumers alike. While in the past it might have been common practice to add artificial ingredients and colorings to make a product look more appealing, increased scrutiny is now being placed on these additives. Companies want to provide, and consumers demand, healthier products. WaveMix™ can dry vegetables with outstanding color, scent and flavor retention. By completing multiple trials in our Test Center, customers can dial in the time, temperature, and pressure to produce the optimal result for new product lines.



Quiet and Easily Placed

WaveMix's quiet compact footprint is ideal for the processing plant or laboratory.



Safety

Due to the low external temperature and numerous safeguards in place, operators work in a lower risk environment.

Flexibility

WaveMix technology is appropriate for materials that are neither perfect electrical conductors nor perfect electrical insulators.

Scalability

Equipment allows for future growth or expansion into new materials.

Small and Trial Batches

WaveMix Mini can be utilized for laboratory experimentation, R&D and small batch processing.



Simple ROI Calculation

WaveMix is a predictable, repeatable system that allows for maximization of profitability and efficiency.

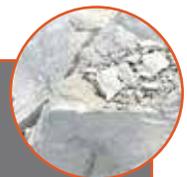


Extra Safety

WaveMix's ability to run under nitrogen purge creates an additional layer of security in even the toughest of applications.

Moisture Content Management

By managing the heating profile, the moisture content can be effectively controlled.



Calcium Carbonate

Calcium carbonate is an important industrial compound in commercial applications, including use as a filler in paper and plastics, as an extender in paints and as an additive to sealants, adhesives and ceramics. Controlling or reducing residual moisture levels is critical for many applications, especially those involving air or water-cured products. In under an hour, WaveMix™ was able to reduce the moisture content to 0.05% at a temperature below 171°F, compared to drying without agitation, which took approximately 4 hours at 400°F.

Applications

BIOMASS:

- Low-temperature drying of cannabis, hops and other agricultural products

MINERALS:

- Low-moisture drying of carbon black, calcium carbonate, titanium dioxide
- Coating and drying of ceramics

FOOD:

- Drying of powders or slurries
- Dehydration of fruits, vegetables and meats
- Microbial reduction in food powders
- Extraction
- Pasteurization
- Roasting
- Thawing of IQF products

PHARMACEUTICALS:

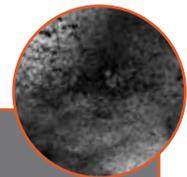
- Drying of powders including active pharmaceutical ingredients

CHEMICAL:

- Change of state
- Solvent removal

SPECIALTY APPLICATIONS:

- Nanocrystal and nanomaterial processing



Carbon Black

Carbon black is an industrial compound used as a pigment and reinforcement in plastic and rubber goods, as an antistatic agent in plastics and electronics, and as a filler in paints, films, and adhesives. Reducing moisture levels is important in applications such as water-cured polymers and processes involving heat (such as extrusion), where steam emitted from moisture content may damage the product. One of the main issues with carbon black drying has been the high temperature required in conventional (indirect) heating methods. WaveMix™ reduced the moisture content from 0.486% (4860 ppm) to 0.049% (490 ppm) after 80 minutes of drying time at a temperature of 325.4°F.

WAVEMIX™ Production Configurations

MINI SPECIFICATIONS

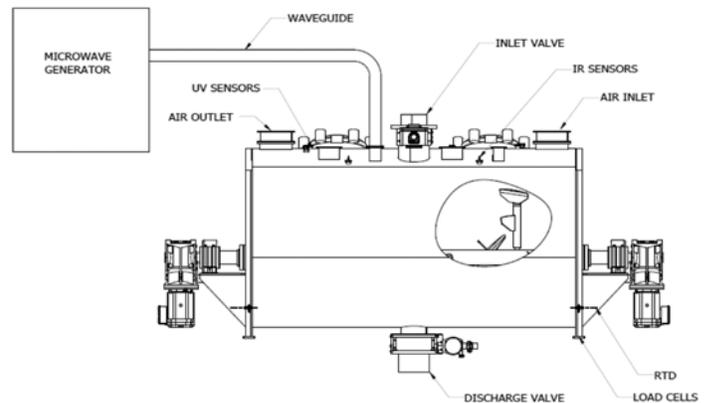
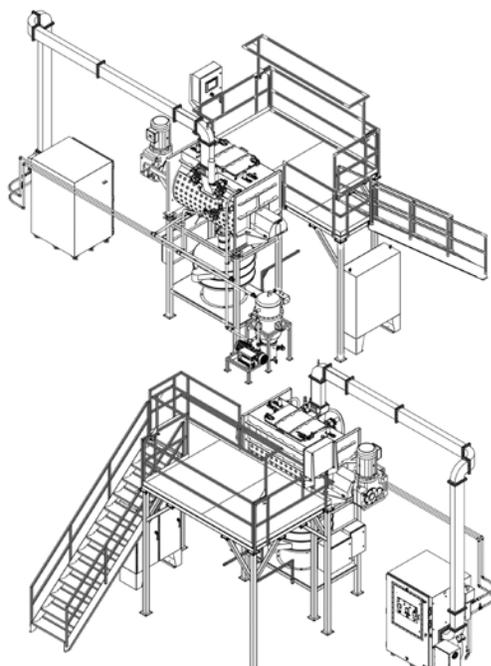
Capacity	0.6 cuft / 4.5 Gal / 17 liter
Microwave Generator Output	300-3000 Watts
Auxiliary Mode of Heating or Cooling	ASME Rated Dimpled Jacket
Material Temperature	<400 F / 204 C
Temperature Sensor	Infrared and RTD measurement
Maximum Vacuum Level	Atmosphere - 100 Torr
Mixer Materials	Stainless Steel
Product Contact Surfaces	32RA / Food Grade FKM / Food Grade PTFE
Electrical Requirements	3 PH / 50/60 Hz
Vacuum Pump Type	Liquid Ring

FULL SIZE SPECIFICATIONS

Capacity	Pilot Scale to Production 10 cuft / 283.1 liters to 400cuft / 11.3 m3
Microwave Generator Output	10kW-400kW
Auxiliary Mode of Heating or Cooling	ASME Rated Dimpled Jacket
Material Temperature	<400 F / 204 C
Temperature Sensor	Infrared and RTD measurement
Maximum Vacuum Level	Atmosphere - 200 Torr
Mixer Materials	Stainless Steel
Product Contact Surfaces	32RA / Food Grade FKM / Food Grade PTFE
Electrical Requirements	3 PH / 50/60 Hz
Vacuum Pump Type	Liquid Ring

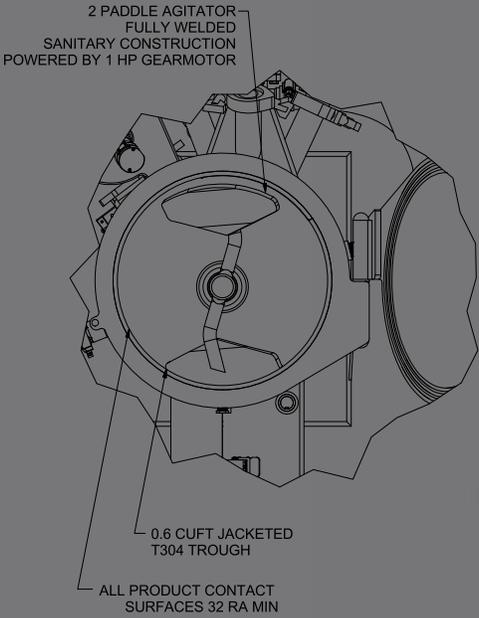
Sample Lab Reports

Through the Marion Test Center, it's possible to run a variety trials on both small batch and pilot scale WaveMix equipment. The extensive testing process supplies clients with comprehensive images, videos, tables and machine data logs allowing them to discover the predictable results of processing prior to scaling up to production levels.

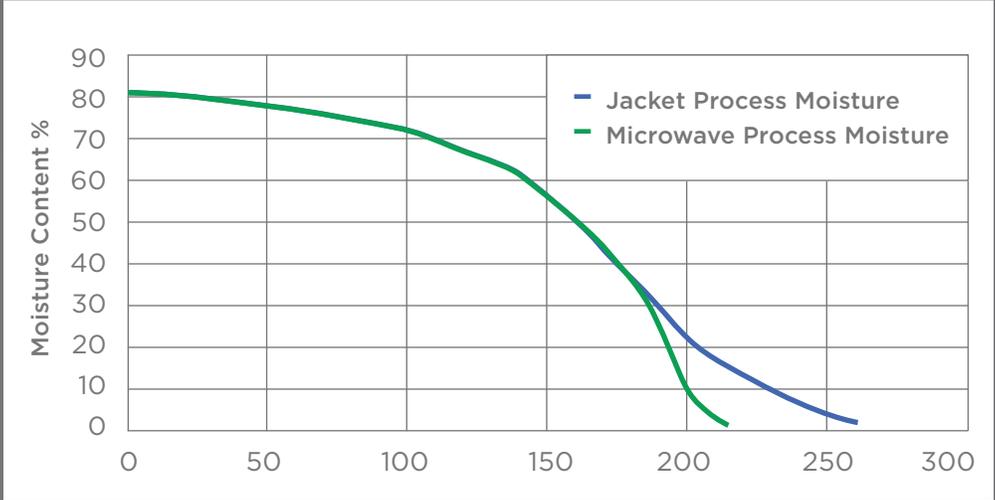


WAVEMIX™

By the Numbers

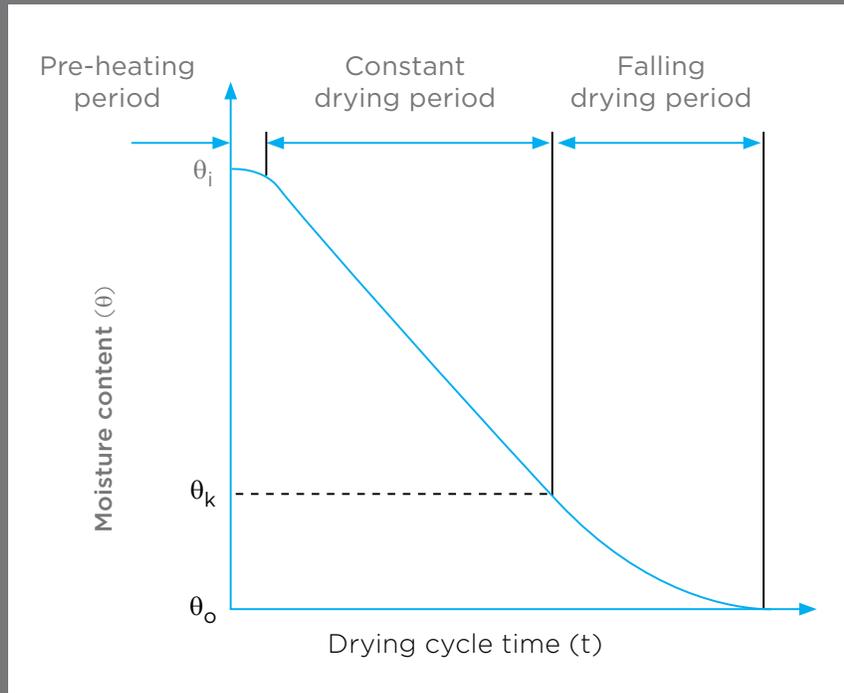


Heat range and falling rate comparison for different methods

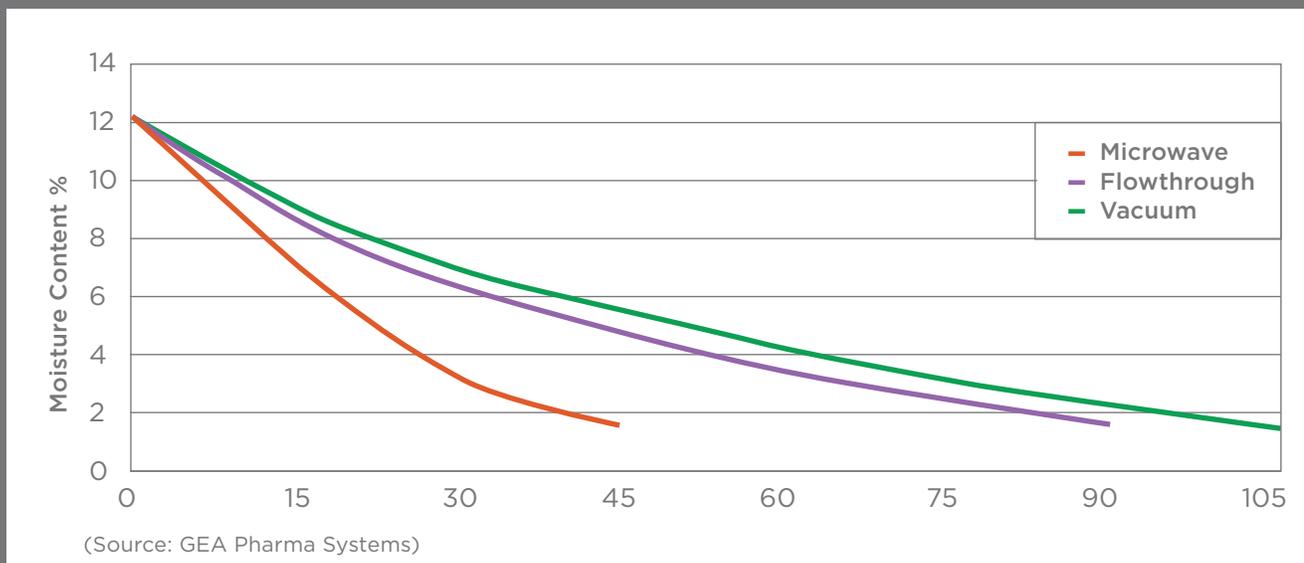




Drying Curve



Microwave-assisted vacuum dryers can achieve faster drying times compared to vacuum alone



Marion Process Solutions Overview

Since 1938, the commitment to excellence has been the hallmark of the Marion brand. We deliver process solutions designed to fit the specific requirements of one type of application—yours. When you partner with Marion Process Solutions you choose craftsmanship at its finest.

More than a manufacturer, Marion serves as problem solvers for clients in over 75 countries on 6 continents in the food, plastic, chemical, mineral and biomass markets. Year after year, through the continued development of mixing, blending and microwave processing equipment, we deliver the insight needed to meet even the toughest of challenges.

The team at Marion Process Solutions is 100% dedicated to pre-sale engineering, testing and customization to ensure that every piece of equipment we sell is tailored for your specific needs. Of course, no one understands your need for accuracy, flexibility, consistency and reliability better than you—so we listen first, then craft your solution that sits in the sweet spot of cost and performance.

Our services include:

- **Onsite discovery**
- **Dedicated project team from concept to delivery**
- **Full-scale acceptance testing**
- **Setup and commissioning supervision**
- **Ongoing life-cycle maintenance and support**

Leveraging our experience ensures you'll receive far more than a solid return on your investment...you will create a competitive advantage in your industry. It's simple really: when you're proud of your work, you sign your name to it. You'll find it on everything we build.



MARION TEST CENTER

Need to test first? Our industry-leading lab is at-the-ready to help you define or refine your process. With decades of experience in mixtures and materials, we're your expert resource when considering new equipment for your operation. For thermal processing our lab offers:

- WaveMix™ Mini: 0.5 Cubic foot
- WaveMix™ 10 cubic foot, non-vacuum
- WaveMix™ 30 cubic with full vacuum

In addition, we provide various sizes and configurations of mixers and other associated process equipment for testing at our facility or yours. Our test engineers will guide you through the process and deliver detailed results upon the completion of testing.



MARION PERFORMANCE GROUP

Marion Performance Group (MPG) provides the aftermarket services that give our clients the best performance over the lifetime of the equipment. It's the peace-of-mind to know that your relationship with Marion doesn't end when we ship your mixer or thermal processing equipment, that's when our relationship begins—helping to ensure optimal performance for the life of your investment.

Among the services we provide:

- On-site installation and configuration
- Routine maintenance and replacement parts
- Monthly or quarterly site visits to assess and optimize performance
- Equipment refurbishment
- Engineering support for any issues that arise with your process equipment
- Needs assessments to support growth, diversification or new product development
- Suggestions and updates, based on industry trends, laboratory tests and knowledge from processing expertise in similar fields and industry best practices.

Each client is different, so MPG creates a customized plan designed to fit you perfectly.

CONNECT WITH US

Think of the last time you were delighted by a company. They asked the right questions, listened with eyes and ears, stayed engaged throughout the process, applied their unique expertise, provided you with a spot-on recommendation, and then delivered more than they promised—right? We call this experience “Full Engagement” and it’s common practice at Marion Process Solutions.

So let’s engage, start the dialogue, and see where this goes.

Call: 800.397.6371

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