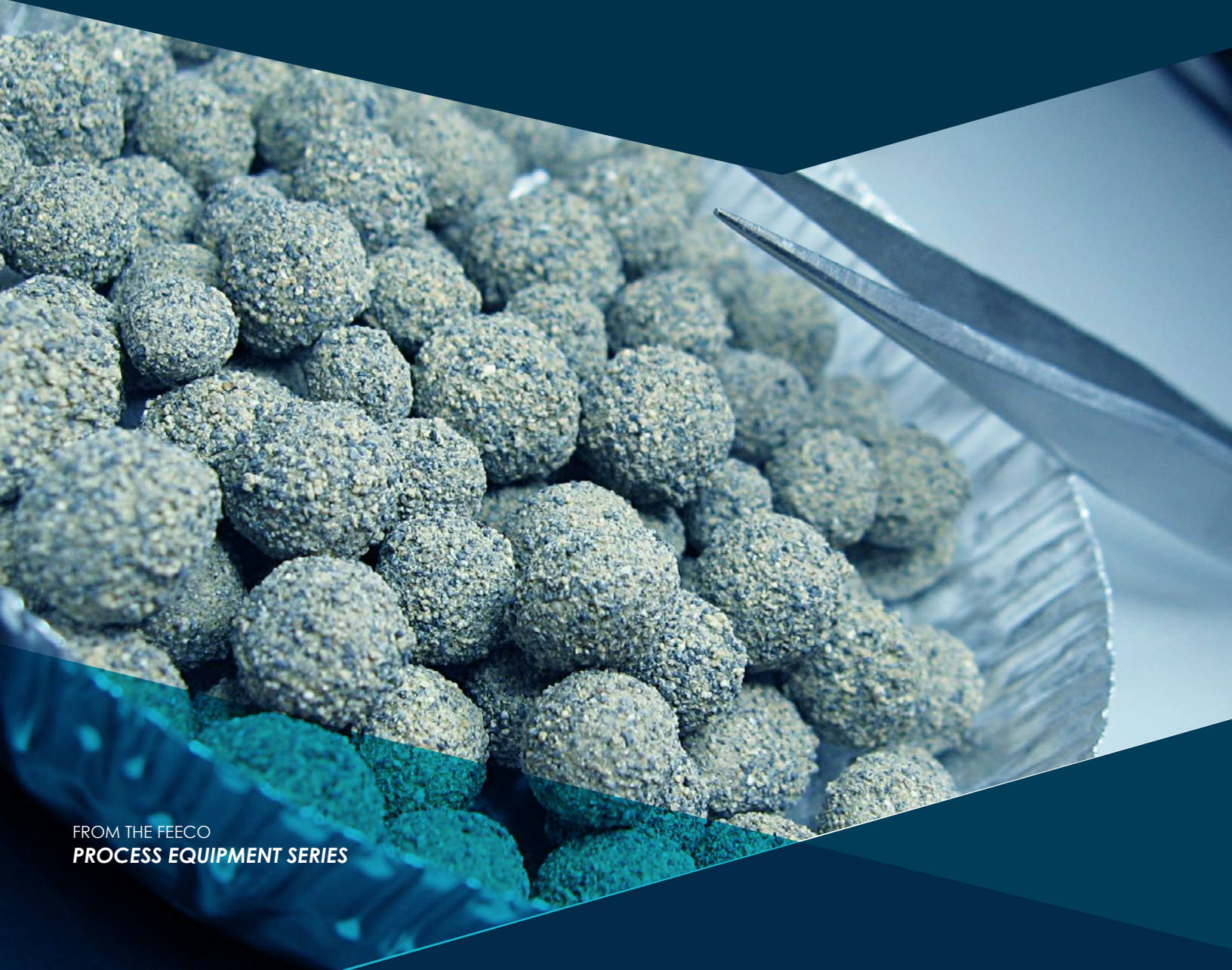


THE **AGGLOMERATION**

HANDBOOK



FROM THE FEECO
PROCESS EQUIPMENT SERIES

FEECO
INTERNATIONAL

TOMORROW'S PROCESSES, **TODAY.**

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CONTENTS

INTRO

Introduction 1

An Intro to Agglomeration 3

Benefits of Agglomeration 4

EQUIPMENT & PROCESSING

Agglomeration Equipment Basics.....7

Pelletizing10

Pelletizing Vs. Compaction Granulation 12

A Look at Micro Pelletizing13

CONSIDERATIONS IN AGGLOMERATION

Choices in Equipment18

 Choosing an Industrial Mixer: Pin Mixer Vs. Pugmill Mixer.....18

 Drum or Disc?20

 Agglomeration or Granulation Drum - What's the Difference?.....21

The Benefits of Preconditioning Your Material23

Choosing A Binder in the Agglomeration Process24

The Role of Drying in Agglomeration25

Coating27

Size Reduction31

Testing Particle Characteristics in the FEECO Innovation Center.....33

Profile: Agglomeration Testing in the FEECO Innovation Center.....39

Advanced Particle Analysis42

Additional Resources44

About FEECO45

Introduction

FEECO International was founded in 1951 as an engineering and manufacturing company. We quickly became known as the material experts, able to solve all sorts of material processing and handling problems, and now serve nearly every industry, from energy and agriculture, to mining and minerals.

As experts in the field of particle size enlargement and tumble-growth agglomeration, FEECO has been on the forefront of the agglomeration industry since the 1950s. We've helped our customers process hundreds of materials into value-added products, eliminating handling and transportation problems, improving product characteristics, and creating marketable products.

Our Agglomeration Handbook is a comprehensive resource on tumble-growth agglomeration techniques, in which methods, processing considerations, and equipment are examined.

Many of the world's top companies have come to rely on FEECO for the best in custom process equipment and solutions. Some of these companies include:



For further information on agglomeration, [contact a FEECO expert](#) today.

FEECO US Headquarters

3913 Algoma Rd. Green Bay, WI 54311, USA

Phone: (920)468.1000

Toll Free: 1.800.373.9347

FEECO.com/contact

Find us on:



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An Overview of **AGGLOMERATION**

INTRO | TYPES OF AGGLOMERATION | WHY AGGLOMERATE?



Synthetic Gypsum pellets
created in the FEECO
Innovation Center

AN INTRO TO AGGLOMERATION

Agglomeration is the process of particle size enlargement and most commonly refers to the upgrading of material fines into larger particles, such as pellets or granules.

In addition to material fines, agglomeration is also useful for sludge-like materials, such as manure or FGD sludge, transforming them into more usable, more easily handled forms.

Long used throughout the iron and steel sector, agglomeration is far from a new technique. Despite this, however, it is constantly gaining popularity in an increasing number of industries, particularly in the past few decades, as the numerous benefits it has to offer become more evident.

There are many types of agglomeration, all offering their own unique advantages and disadvantages, but in general, they can all offer the following benefits:

- Significant dust reduction
- Improved handling
- More complete utilization of raw materials
- Improved product characteristics

Agglomeration continues to evolve as an industry, finding its way into an increasing number of applications. This has created a wealth of activity in the field of particle technology, with new processes being forged and old ones being improved upon.

Some of the problems to which agglomeration has been successfully applied include:

- Material entrainment in furnaces
- Product loss
- Skewed product formulations
- Ineffective metering/dosing of material
- Caking during storage or shelf life
- A hazardous work environment
- Non-user-friendly deliverable
- Unpredictable application results
- Uncontrolled product breakdown
- Flowability issues

TYPES OF AGGLOMERATION

While many agglomeration techniques exist, they typically fall under one of two main categories: pressure agglomeration, or non-pressure agglomeration.

Pressure agglomeration technologies use mechanical compression to shape a material into a desired form, with very little, if any, moisture as a binding agent.

Non-pressure agglomeration technologies use a tumbling process to “grow” material into a spherical pellet form. A liquid binder is commonly used to assist in the agglomeration process.

This handbook focuses on non-pressure agglomeration, also commonly referred to as tumble-growth agglomeration, agitation agglomeration, or wet granulation.

NON-PRESSURE AGGLOMERATION:

Many techniques exist within the category of non-pressure agglomeration. Because overlap exists



Image: Various agglomerate samples created in the FEECO Innovation Center

between these techniques, the terms used to describe them are often used interchangeably. Key techniques in non-pressure agglomeration include:

Pelletizing: A process whereby material fines are rolled into uniform pellets with the help of a binding agent.

Micro Pelletizing: A process in which material fines are mixed with a binder to form small agglomerates, or create “seed pellets” to prepare the material for pelletizing.

Conditioning: A process which often refers to the mixing of material fines with a binding agent in order to reduce dust and transform the material into a more usable form.

A variety of elements are considered when determining which technique should be used. Contributing factors include: equipment capabilities, binder properties, industry standards, desired end product characteristics, and raw material characteristics.

BENEFITS OF AGGLOMERATION

There are many reasons why it might be desirable to agglomerate a material. The choice to agglomerate often stems from a material problem, be it a dust issue, a waste problem, handling challenge, or otherwise. When a material is agglomerated, several of the following benefits are often achieved:

Product Benefits: Dust-free product handling, segregation prevention, and improved product characteristics and appearance.

Industry Example: Agglomerated agricultural wastes (such as manure or compost) are easier to transport, store, and apply than unprocessed materials. Other benefits include opportunity for custom formulations, as well as improved storage.

Raw Material Benefits: Simplified transportation, dust loss prevention, and increased porosity, density, and melting abilities.

Industry Example: Ore agglomeration creates a uniform particle size distribution, which in turn maximizes the heap leaching process, allowing a more efficient extraction of minerals from the ore.

Process Benefits: Elimination of dust and fines, enhanced process flow effectiveness, and increased process efficiency.

Industry Example: Glass powder in its raw state incurs a great deal of material loss during processing, ultimately throwing off glass formulas. Agglomerated glass powder reduces product losses, increases process efficiency, and ensures that formulas are not skewed through the loss of dust in the furnace.

Economic Benefits: Conversion of waste to a marketable product, reduced transportation costs, and reduced material handling costs.

Industry Example: After agglomeration, previously unsalable limestone fines become a marketable product (limestone soil amendment pellets).

Environmental Benefits: Potential to eliminate the need for landfill, improved cost-efficient recycling capabilities, potential for waste-to-fuel processes, and improved waste disposal cost efficiency.

Industry Example: After agglomeration, previously landfilled waste paper sludge is recycled into a usable product.

In addition to the benefits listed above, the following chart from *The Science and Engineering of Granulation Processes* identifies further reasons for which agglomeration is used in various applications.

TABLE: ADDITIONAL REASONS & APPLICATIONS FOR AGGLOMERATION

REASON	TYPICAL APPLICATION
To produce useful structural forms	Powder Metallurgy
To provide a defined quantity for dispensing and metering	Agricultural Chemical Granules, Pharmaceutical Tablets
To eliminate dust handling hazards or losses	Agglomeration of Waste Fines
To improve product appearance and/or performance	Food Products
To reduce caking and lump formation	Fertilizers
To improve flow properties for further processing	Pharmaceuticals, Ceramics
To increase bulk density for storage	Detergents
To control dispersion and solubility	Instant Food Products
To control porosity and surface-to-volume ratio	Catalyst Supports
To improve permeability for further processing	Ore Smelting
To create non-segregating blends of powder ingredients	Ore Smelting, Agricultural Chemicals, Pharmaceuticals

Source: Lister, Jim and Ennis, Bryan. *The Science and Engineering of Granulation Processes*. Boston: Kluwer Academic Publishers, 2004.

EQUIPMENT & PROCESSING

EQUIPMENT | PELLETIZING | PELLETIZATION VS. COMPACTION | MICRO PELLETIZING



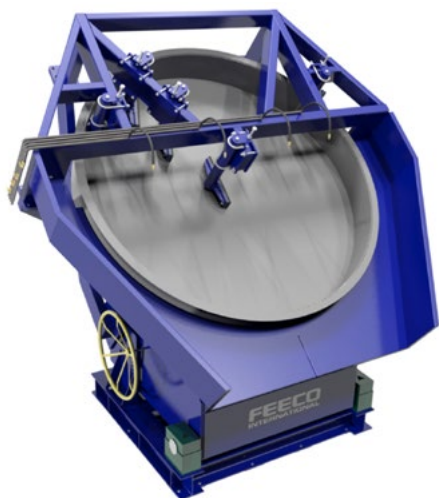
Pellet sample taken during a disc pelletizer test in the Innovation Center

AGGLOMERATION EQUIPMENT BASICS

Many choices exist on the market when it comes to agglomeration equipment. Additionally, new uses are being developed all the time, making current equipment options increasingly flexible. The following is an overview of some of the most common types of agglomeration equipment.

DISC PELLETIZERS

[Disc pelletizers](#), also commonly called pan granulators, are often chosen for their ability to fine-tune product size—the process of which is a combination of both science and art. The pelletizer offers several variables, all of which can be adjusted and work together to create the desired pellet product.



FEECO Disc Pelletizer

HOW DISC PELLETIZERS WORK

Material is fed onto the disc, where it is taken up by the rotation. Both material feedstock and a binder are continuously fed onto the disc pelletizer, making this a continuous process. The binder causes the fines to become tacky, allowing them to pick up more fines

as they tumble, resulting in an effect similar to rolling a snowball, referred to as *coalescence*.

FEECO DISC PELLETIZERS AT A GLANCE

SIZE	6' - 25' (1.8 - 7.5m)
CAPACITY	1 TPH - 100 TPH
CUSTOMIZABLE?	Yes

AGGLOMERATION DRUMS & GRANULATION DRUMS (ROTARY DRUMS)

[Agglomeration drums](#) are valued for their high throughput, and while they are used throughout a variety of industries, they are perhaps most common in the mining industry, due to their ability to accept variance in feedstock, and their heavy-duty construction, ideal for the industry's demanding process requirements. Here, they aid in the heap leaching process by promoting optimal mineral extraction through more uniform particle shape and size.



FEECO Agglomeration Drum

HOW AGGLOMERATION & GRANULATION DRUMS WORK

Similar to disc pelletizers, agglomeration drums tumble material fines in the presence of a binder to promote agglomeration.

Agglomeration drums can also be valuable when a

chemical reaction is required during agglomeration, such as in the fertilizer industry. Here, agglomeration drums, referred to as [granulation drums](#) (granulators), are used to produce a variety of fertilizer products.

FEECO AGGLOMERATION DRUMS AT A GLANCE

SIZE	Drum diameters from 36" - 15' (1 - 4.6m)
CAPACITY	500 lb/hr - 3500+ TPH
CUSTOMIZABLE?	Yes

PIN MIXERS

[Pin mixers](#) are industrial mixers used for a variety of purposes, including: micro pelletizing, conditioning, agglomerating, and mixing. These versatile mixers are particularly adept at processing ultra-fine materials, such as powders, and are optimal machines for mixing fines with a liquid binder. Pin mixers can also act as a stand-alone agglomeration unit, or as the precursor to a disc pelletizer or agglomeration drum setup.

HOW PIN MIXERS WORK

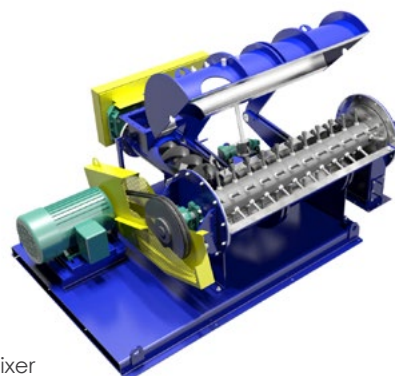
Pin mixers use a high-speed spinning action to both mix and agglomerate materials in the presence of a binder. A single shaft affixed with rods (pins) rotates at a constant speed, creating a densified product through the use of motion.

FEECO PIN MIXERS AT A GLANCE

SIZE	15" - 50" (380 - 1,270mm)
CAPACITY	500 lb/hr - 70 TPH
CUSTOMIZABLE?	Yes

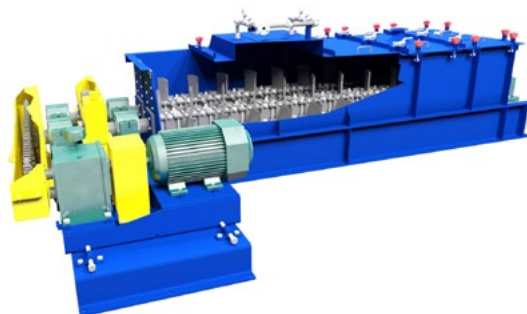
PUGMILL MIXERS / PADDLE MIXERS

Like pin mixers, [pugmill mixers](#), sometimes called paddle mixers or pug mills, are industrial mixers



FEECO Pin Mixer

capable of conditioning, mixing, and agglomerating. Pugmill mixers are also ideal solutions for processing material in the presence of a binder, though unlike pin mixers, they are more suited for heavy-duty material processing, such as that found in the mining industry.



FEECO Pugmill Mixer/Paddle Mixer

HOW PUGMILL MIXERS WORK

Pugmill mixers use dual shafts with pitched paddles to create a kneading and folding-over motion inside the mixer. This results in a thorough mixture of ingredients. Here again, pugmill mixers can be used as a stand-alone agglomeration device, or as part of a larger processing configuration.

FEECO PUGMILL MIXERS AT A GLANCE

SIZE	22" - 78" (560 - 1,981mm)
CAPACITY	2 TPH - 250 TPH
CUSTOMIZABLE?	Yes

TABLE: AGGLOMERATION EQUIPMENT SUMMARY

EQUIPMENT NAME	OTHER NAMES	PRESSURE OR NON-PRESSURE?	BINDER NORMALLY REQUIRED?	USES
Disc Pelletizers	Disc Granulators Pan Pelletizers Pan Granulators Granulators	Non-Pressure	Yes	Pelletizing
Rotary Drums	Agglomeration Drums Balling Drums Agglomerators Ore Drums Granulators Granulation Drums	Non-Pressure	Yes	Pelletizing Granulating with a Chemical Reaction Coating
Pin Mixers	Pin Agglomerators	Non-Pressure	Yes	Micro Pelletizing Mixing Conditioning Agglomerating
Pugmill Mixers	Paddle Mixers Pug Mills	Non-Pressure	Yes	Mixing Conditioning Agglomerating

Potash: Before & After Pelletizing



PELLETIZING

Pelletizing is a form of tumble-growth agglomeration, whereby material fines are “grown” through a tumbling motion and the addition of water or a binding agent.

Pelletizing is carried out using either a disc pelletizer or rotary drum, with disc pelletizers being the most common choice, and drums being more suited to specific applications such as heap leaching or fertilizer production. *The choice between a drum and a disc is discussed further on page 20.*

A typical pelletizing process looks like this:

Material fines are first conditioned in a pin mixer or pugmill mixer. While not all processes utilize a preconditioning step, those that do see many benefits as a result, such as reduced binder usage, increased production, and an improved product. *For more information on this topic, see [The Benefits of Preconditioning Your Material](#) on page 23.*

Once material has been conditioned, it moves on to pelletizing. For processes that do not use a preconditioning step, this is where the process begins.

Here, material is fed onto a disc pelletizer at a continuous rate, where binder is continually added. The material fines are tacky as a result of the binder, and as they tumble against themselves while the disc rotates, they pick up more fines, growing in similar fashion to a snowball.

Once pellets have reached the desired size, they exit the disc pelletizer, and are carried to a dryer if moisture removal is necessary.

The dryer “cures” the pellets into their final form, removing the desired amount of moisture. Drying is commonly carried out using a rotary dryer or fluid bed dryer. Rotary dryers offer the added benefit of polishing the granules as a result of the tumbling action they impart on the material bed.

The diagram shown below illustrates a simplified pelletizing setup. In situations where a rotary drum is used instead of a pelletizing disc, the process is typically the same, with only the drum replacing the disc.

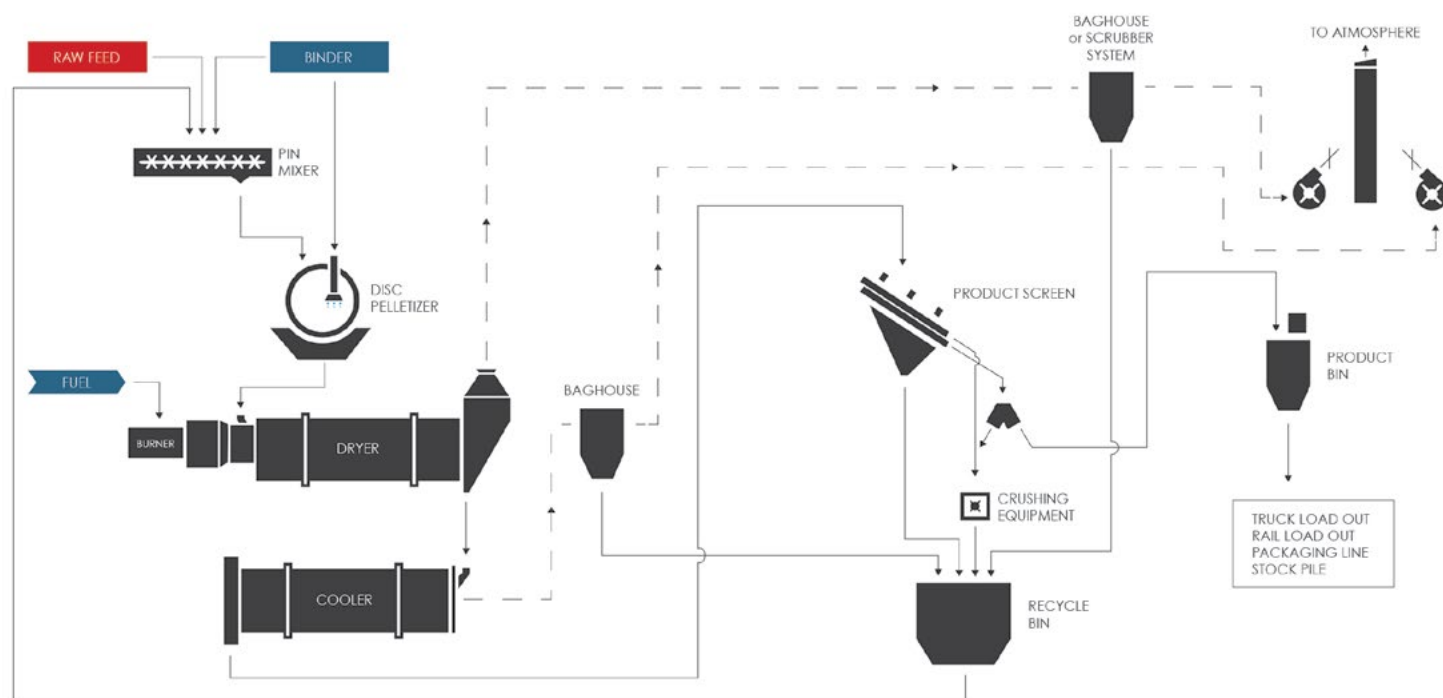
Pelletizing on a disc has been likened to an art, with many variables affecting the success of the end product. The most common variables include:

- Binder formulation
- Binder feed rate
- Material feed rate and location
- Disc/Pan speed
- Disc/Pan angle
- Liquid addition rate and location

Pelletizing is used throughout a variety of industries, with new applications developing all the time. Some of the most commonly pelletized materials include:

- EAF Dusts
- Chemical Powders
- Limestone
- Gypsum
- Coal
- Fly Ash
- Minerals and Ores
- And more...

FLOW DIAGRAM OF A TYPICAL PELLETIZING PROCESS



PELLETIZING VS. COMPACTION

Pelletizing is often investigated alongside compaction—a pressure agglomeration technique that produces jagged, irregular granules.

Both methods are an effective solution, with each offering distinct advantages and disadvantages. And while operating and capital costs are often the deciding factor between the two, there are many factors to consider when choosing which method best suits the intended application. Additionally, some materials may respond well to only one of these methods, making the choice clear, while other materials may respond well to both (such as bentonite, coal, humate, potash, urea, and others) and require further consideration.

ADVANTAGES TO PELLETIZING:

Faster nutrient delivery: Because pellets are not created through pressure, they are less dense than their compaction granule counterparts. The less dense pellets created in pelletizing can withstand handling, but are still able to break down quickly upon application, an ideal characteristic for soil amendments, fertilizers, and other applications that benefit from faster active ingredient delivery.

Less dust and fines: Compared to compaction granules, pellets produce less fines (since pellets are round, there are no rough edges to rub together, break off, and create dust).

Binders can serve as beneficial additives: The binder used in the process can also be formulated to serve as a beneficial additive.

Lower capital costs: The pelletizing method often requires a lower capital investment than compaction granulation.

A premium product is produced: The round, smooth pellets produced in the pelletizing process are considered a premium product. Additionally, the pelletizing process offers the opportunity to include additives to further customize and enhance the end product.

DISADVANTAGES TO PELLETIZING:

Higher Processing Costs: The use of a binder and subsequent drying step results in higher processing costs when compared to compaction granulation.

ADVANTAGES TO COMPACTION GRANULATION:

Lower Processing Costs: Because no binder or drying step is needed, processing costs are usually lower compared to pelletizing.

DISADVANTAGES TO COMPACTION GRANULATION:

Attrition: Attrition is the breakdown of granule edges into material fines and dust. This is common with compaction granules because of the rough, jagged edges. Methods to aid in reducing attrition exist, but may increase production costs.

Sometimes, it's also sufficient to simply condition or micro pelletize material in a pin mixer or pugmill mixer, instead of pelletizing or granulating it. This is common for applications where the material only needs to be de-dusted, such as in cases where transportation to landfill is made difficult because of a dusty product. Oftentimes, it's not clear which method of agglom-

TABLE: PELLETIZATION VS COMPACTION SUMMARY

PELLETIZATION	COMPACTION GRANULATION
Produces round, smooth pellets considered a premium product	Produces coarse granules
Relatively dust-free	Significant amount of attrition likely
Binder usually required	Typically no binder required
Drying required	Usually no drying required
Faster product breakdown	Delayed product breakdown
Lower capital investment	Reduced processing costs

eration will produce the desired results, and in these cases, testing is recommended and often required.

AGGLOMERATION TESTING

Running testing trials with representative material samples in a facility such as the [FEECO Innovation Center](#) will offer a number of benefits; it will not only reveal whether or not a material is capable of agglomerating, but it will also help to determine the best method of agglomeration to achieve the desired end product characteristics. Taking it a step further, in addition to running batch tests on a single piece of equipment, the FEECO Innovation Center can also do testing in a continuous process loop, utilizing many pieces of equipment. This is useful in determining the best equipment configuration and the process variables needed to produce desired product characteristics. *For more information on testing in the FEECO Innovation Center, see page 33.*

A LOOK AT MICRO PELLETIZING

WHAT IS MICRO PELLETIZING?

Micro pelletizing is the process of agglomerating material fines into small pellets, or “micro pellets.” Unlike traditional pelletizing, where slightly larger pellets are

produced, micro pelletizing produces pellets around 20-60 mesh.

Micro pelletizing can be carried out either in a stand-alone pin mixer (this process is sometimes referred to as “conditioning”), or with a pin mixer/disc pelletizer combination. When a full-scale pelletizing operation is not necessary, or when only smaller pellets or material conditioning is needed, the use of a pin mixer to micro pelletize material offers a cost-effective alternative to a full-scale pelletizing operation and can provide sufficient results.

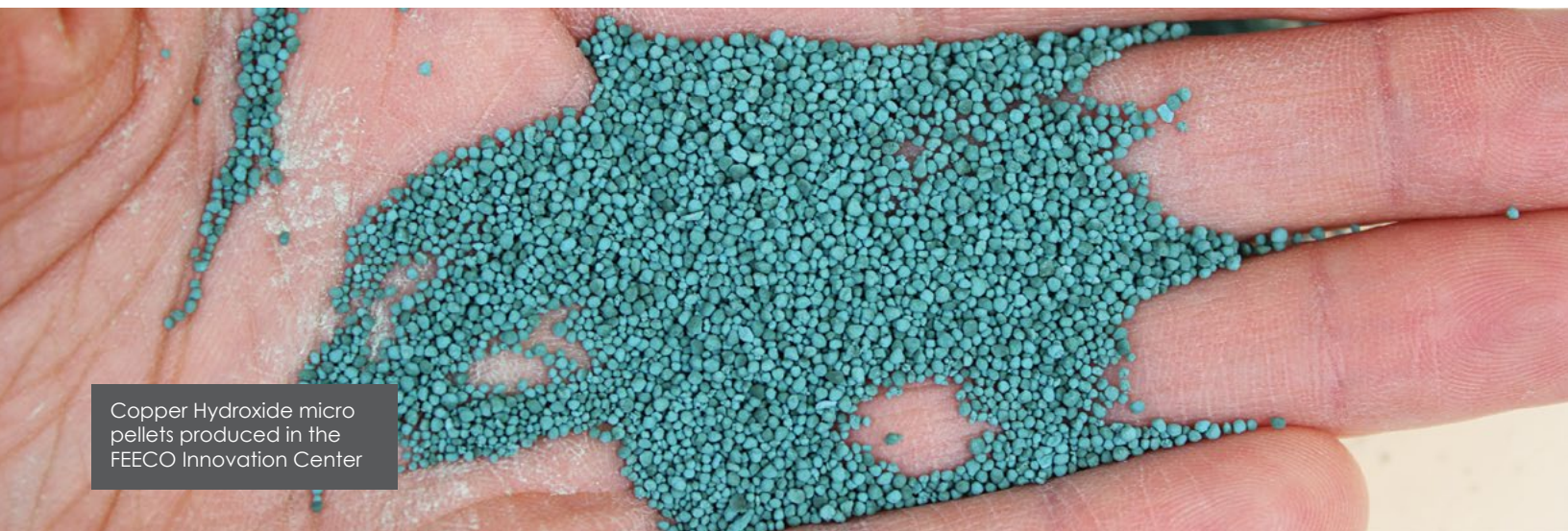
WHY MICRO PELLETIZE?

Micro pelletizing is used to process fine materials in order to make them easier to handle, transport, and use. There are several reasons why this may be desirable: to improve how a product performs, to reduce product lost to dust, to condition a material prior to landfill, or to reduce other issues associated with dust.

BENEFITS OF MICRO PELLETIZING

Like all agglomeration techniques, micro pelletizing a fine material offers a variety of benefits:

Significant Dust Reduction/Elimination – Dust reduction



Copper Hydroxide micro pellets produced in the FEECO Innovation Center

or elimination is beneficial for many reasons. Sometimes, materials are micro pelletized prior to being landfilled to avoid excessive amounts of wind-blown material. This is commonly seen with fly ash, a by-product of burning fossil fuels that comes in the form of an ultra-fine powder. While some [fly ash](#) can be recycled into other products, other fly ash is not usable, and is therefore micro pelletized, or conditioned, before it is brought to a landfill, to avoid it becoming wind blown.

Dust reduction is also beneficial during processing. If not well managed, fugitive dust can easily escape into the air, which can not only damage equipment if left unchecked, but can also be a health and safety hazard. An extreme example of this can be found at coal-fired power plants where coal fines are generated. Here, coal fines are micro pelletized because they can be combustible if sufficiently aerated.

Dust reduction or elimination is also valuable because it reduces the amount of product or raw material lost to waste as dust, a common problem among dusty materials. This results in more usable material/product, and a reduction in material waste.

Improved Handling and Transport – As one can imagine, a fine, dusty material can be difficult to move around or haul without losing a significant amount of material. Micro pelletizing allows the material to be much more easily handled and transported.

Improved Application and Use – While micro pelletizing generally focuses on making a material less dusty and easier to handle, it also allows for improved application and performance in many instances. A good example of this is in the agriculture industry, where soil amendments are sometimes micro pelletized, offering significant benefits, including:

More accurate application – micro pellets can move through spreading equipment much more efficiently than powdered materials, making application more precise and reliable.

More predictable results – Because micro pellets won't blow away like a powdered material might, applications stay where they are applied, delivering nutrients where they are needed and nowhere else.

Faster product breakdown – smaller pellets are more quickly broken down than larger ones and thus, in the case of soil amendments, nutrients reach the soil sooner.

Reduced visibility – micro pellets sink between the grass blades quickly. This is beneficial because the application does not detract from the beauty of the turf, a valuable characteristic for applications such as golf courses and lawns. This is a common reason for choosing micro pellets over larger particle sizes.

Micro pellets also offer the opportunity to serve as a “core” for applications that require the pellets to be coated, but still need the pellets to remain in the desired size range.

COMMONLY MICRO PELLETIZED MATERIALS

Because micro pelletizing can benefit nearly any material that comes in the form of a powder, the applications for micro pelletizing are innumerable (and growing!). Some of the most commonly micro pelletized materials include:

- Carbon Black
- Catalysts
- Coal Dust
- Filter Media
- Fly Ash
- Pigments and Dyestuffs
- Specialty Powders

MICRO PELLETIZING IN A PIN MIXER

While micro pelletizing can be done in a pugmill mixer, it is best carried out in a pin mixer. Pin mixers are the

industry standard for micro pelletizing, offering an ideal solution for agglomerating material fines into small pellets. For this reason, pin mixers have been used extensively for decades in both the coal and carbon black industries.

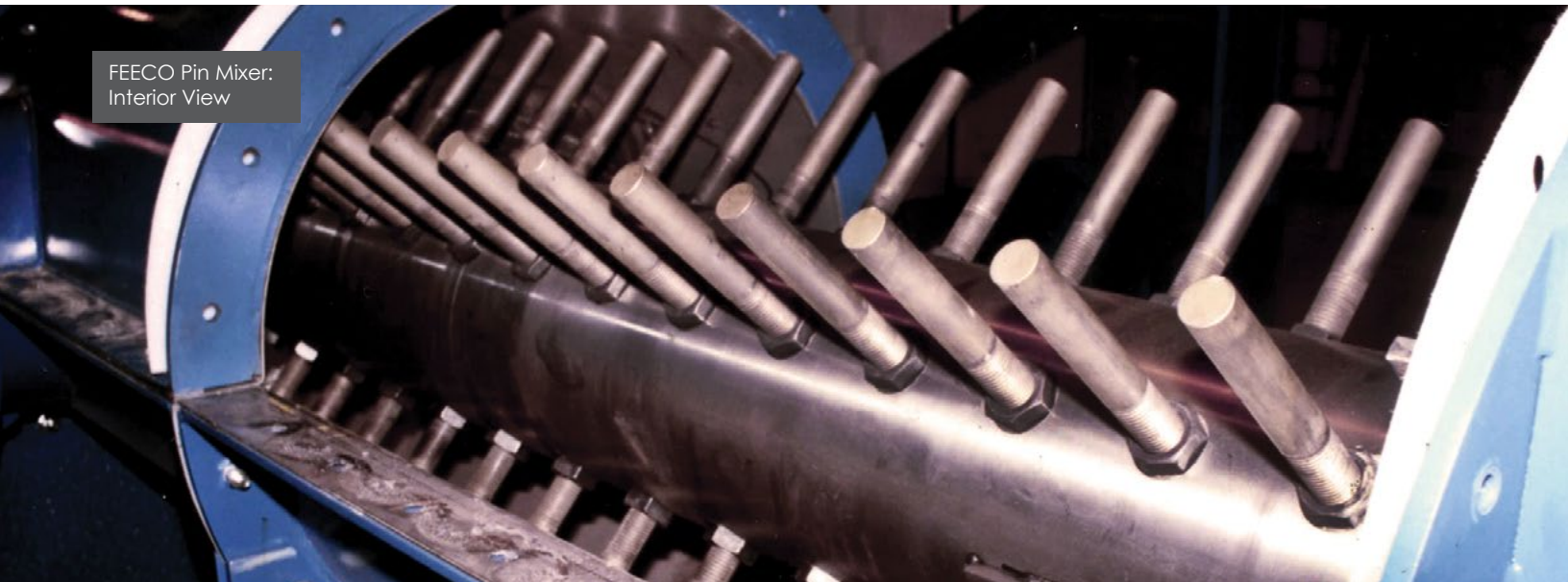
Pin mixers utilize a high-speed spinning action that not only thoroughly mixes liquid and solid feeds, but also begins to agglomerate material fines as well, resulting in small, dense pellets. Pin mixers can act as a continuous, stand-alone unit to quickly and reliably produce micro pellets in a process setting.

A typical micro pelletizing setup looks like this:

Raw feed material is fed into the pin mixer at a continuous rate. Simultaneously, a binder spray system sprays binder into the pin mixer at a continuous, specified rate. The material feedstock and binder are thoroughly mixed and begin to agglomerate, forming micro pellets as the mixture moves through the mixer. At this stage, a disc pelletizer could be utilized to further grow and/or round the pellets if desired. In this scenario, the pin mixer prepares the material for optimal pellet formation on the disc. It also allows the target moisture level to be reached prior to the disc pelletizer, which can increase production, and decrease the amount of binder required (because densification is being carried out in the pin mixer through motion, instead of on the disc pelletizer with binder).

After pellet formation is complete, micro pellets are then typically discharged from the pin mixer, and carried via a conveyor to a rotary dryer, in order to reduce the moisture content of the pellets down to the desired level. Here, pellets tumble through the rotating drum, while flights pick up the material and

FEECO Pin Mixer:
Interior View



drop it through the stream of drying air, maximizing heat transfer efficiency.

Pellets are then discharged from the dryer, and taken by conveyor to their next processing stop (screening), or to storage or bagging.

In some instances, it may also be desirable to cool the material prior to bagging or storage. Similar to drying, this is often carried out in a rotary cooler.

Considerations in **AGGLOMERATION**

CHOICES IN EQUIPMENT | PRECONDITIONING | BINDER SELECTION | DRYING | TESTING | PARTICLE CHARACTERISTICS



Agglomerated Tungsten
Oxide created in the
Innovation Center

CHOICES IN EQUIPMENT

Many choices often come up during the development of an agglomeration process. For this reason, we've provided this section to shed light on some of the common equipment comparisons faced when developing an agglomeration process that best meets the intended application.

CHOOSING AN INDUSTRIAL MIXER: PIN MIXER VS. PUGMILL MIXER

When considering the use of an industrial mixer, be it for preconditioning prior to a disc pelletizer, or as a stand-alone agglomeration unit, it is often common to run into the question of which mixer will serve the process and material best: a pin mixer or pugmill mixer. While both pieces of equipment are considered effective industrial mixers, they each have distinct benefits and capabilities. Typically, the material itself, along with processing considerations, will help in determining which piece of equipment will best fit the needs of the process and material.

THE PUGMILL MIXER

How It Works: Material undergoes tumbling, kneading, and medium-shear action, resulting in an intimate mixture of materials.

Typical Use: Mixing, conditioning, or agglomerating.

PROCESSING WITH A PUGMILL MIXER

FEECO's pugmill mixer is a U-shaped, horizontal trough. Inside the trough, a series of pitched paddles are mounted on dual counter-rotating shafts that run the length of the device. The paddles move material from the bottom of the trough, up the middle, and back

down the sides, creating a kneading and folding effect that intimately mixes the material.

The pugmill mixer is also used for conditioning or agglomerating materials. In these instances, a liquid spray system is added to dispense a binder that assists with the conditioning or agglomerating process.

PUGMILL MIXER APPLICATIONS

The kneading motion of a pugmill mixer makes this type of industrial mixer best suited for heavy-duty materials and applications. Typical applications include:

Mixing: FGD scrubber sludge, fly ash and lime for SO₂ neutralization, municipal sludge for composting facilities, and other processes combining moist and dry feed materials.

Conditioning: Fly ash, cement or lime kiln dust, foundry dust, iron oxide, friction material waste, lead fume, iron ore dust, and zinc oxide.

Agglomeration: Granulation of a variety of materials: agricultural chemicals, fertilizers, pesticides, coke fines, chemical consumer products, carbon powders, cement kiln dust, flue dust from dust collectors, pigments, and dyes.

THE PIN MIXER

How It Works: Material undergoes an intense spinning action, resulting in densification.

Typical Use: Micro pelletizing, solids mixing, densification, de-dusting, preconditioning, conditioning, and granulation.

PROCESSING WITH A PIN MIXER

The pin mixer is comprised of a stationary cylindrical shell that houses a high-velocity central rotor shaft. The rotor shaft extends the full length of the mixer, with numerous rods (or pins) that extend outward. A constant speed motor spins the rotor shaft at several hundred RPMs in order to impart agitation forces on the material. The motion and high rotational speeds produced by the pin mixer minimize air and reduce water volume between particles. This results in densification many times that of a disc pelletizer. A fluid binder material is added in order to aid in the agglomeration process.

PIN MIXER APPLICATIONS

Typical pin mixer material applications include:

- Calcium chloride
- Coal dust
- Gypsum
- Limestone
- Mine fines (such as zinc sulfate)
- Pigment
- Sodium aluminum chloride
- Other fine particle materials

As mentioned, pin mixers work well as stand-alone agglomeration units, or as a preconditioner in a two-stage agglomeration process involving a disc pelletizer. Pin mixers are also ideal components in an automated system, offering precise quality control and accurate production rates.

CHOOSING BETWEEN A PUGMILL MIXER AND A PIN MIXER

Pugmill mixers and pin mixers both provide a wide

array of benefits and processing capabilities. When choosing which industrial mixer to use, the material may help in determining which equipment should be selected. Processing system requirements and facility considerations are also used to determine the best equipment solution. However, the best way to choose between a pugmill mixer and a pin mixer is to evaluate the raw material and decide what type of outcome is preferred; the equipment's capabilities will often lead to choosing one device over the other.

For example, a pugmill mixer tends to handle sticky and/or abrasive materials a little better, because of its slower speed. It also offers a significantly higher throughput than a pin mixer, making it an attractive option for high-capacity operations. Pin mixers would likely get “bogged down” when trying to process a sticky material, and would not stand up as well to severely abrasive materials, due to the mixer's high rotational speed.

A pugmill mixer is also more forgiving than a pin mixer, an ideal characteristic when working with tougher materials, or where tramp could possibly enter the mixer. While a stray rock or tramp bolt may cause a few pins to break off in a pin mixer, the pugmill mixer would likely not see any damage. This is also true when working with large particle sizes; large particles could lodge between the pin tips and the interior wall of the mixer. In a pugmill mixer, however, the clearance between the trough and paddles is greater, decreasing opportunity for material becoming lodged. There is also typically enough torque in a pugmill mixer to dislodge particles as well, in the event that any do get stuck.

When looking to densify a material, the high-speed spinning action that occurs in a pin mixer can offer much better results than a pugmill mixer. Pin mixers also excel in working with ultra-fine materials, such as pigments and dyes (the pin mixer's ability to effectively micro pelletize a fine powder is tough to beat).

As can be seen, both pin mixers and pugmill mixers are effective industrial mixers, with each offering their own advantages and disadvantages.

DRUM OR DISC?

When it comes to agglomerating a material via tumble-growth agglomeration, a rotary drum agglomerator and disc pelletizer are often compared. Though the choice may seem overwhelming at first, there are many things to take into account that will help to make the right decision for the application.

Many times, the choice between a rotary drum and a disc pelletizer is dependent upon historical preference; throughout various industries, one or the other has been used for generations, and there is no need for change. But taking a look at the pros and cons of each can help to make an informed decision for optimal processing capabilities.

RECYCLE

There are many differences between a drum and a disc, but whether the differences are an advantage or a disadvantage is often dependent upon the material. This is clear when looking at the amount of recycle in a process.

Overall, a pelletizer results in far less recycle than a rotary drum. This is ideal in situations where the mate-



rial goes from a pelletizer to a dryer, because the less recycle that has to be dried, the more efficient the process will be (i.e. the more recycle that needs to be dried, the more energy spent on drying).

While rotary drums may result in a higher amount of recycle, this recycle can also be beneficial to a process. For example, when utilizing a rotary drum agglomerator, the higher amount of recycle can act as a buffer in the process; if there is any upset in conditions, there is enough recycle in the process to help “even things out.” However, with a pelletizer, there is such little recycle, that when there is an upset in conditions, the output is almost immediately affected.

Additionally, some material processes require a certain amount of recycle to function efficiently, and whether using a drum or disc, extra recycle is advantageous. Such is often the case when a pin mixer is introduced into the process. Some materials require a certain amount of recycle to be mixed in with the feedstock going into the pin mixer, in order for the feedstock to mix efficiently before going to the pelletizer. For this reason, it is often a requirement to have a little more recycle on hand.

SYSTEM CONSIDERATIONS

Another aspect to consider when choosing between a rotary drum agglomerator and a disc pelletizer is the throughput. When it comes to running a very high capacity, rotary drums are often the equipment of choice. Typically, a rotary drum can handle a much higher throughput than a pelletizer can; where it might take a few pelletizers to reach the desired capacity, it may only take a single drum. And while rotary drums allow for a higher throughput, pelletizers are the equipment of choice when a tight window of size range is desired for the output product.

Creating pellets on a pelletizer has been likened to a form of art, allowing for customization and fine-tuning of the end product. Pan speed, pan angle, feed location, and binder location, are all variables that can be adjusted to zero-in on the size range (among other qualities) of the end product. However, this also means a pelletizer requires a much more watchful eye than a rotary drum. Where one operator would be capable of watching several drums, one operator should only watch a few pelletizers. Rotary drums are far more “limited” in terms of customization, with fewer variables for adjusting end product, but subsequently requiring less monitoring.

Another side to consider in the choice between a rotary drum and disc pelletizer is whether or not a closed system is desired. Rotary drums are considered a “closed system,” because the agglomeration happens within the drum, meaning the vessel can be sealed to help control dust and odor. The disc pelletizer is considered an open system, meaning the operation happens in a less-sealed atmosphere than a drum.

MAINTENANCE

In terms of maintenance, pelletizers typically require less maintenance than a rotary drum. Though pelletizers do need to be properly maintained in order to function efficiently, there are fewer parts to be replaced—usually only scrapers and spray nozzles. With rotary drums, there are many parts that not only require regular maintenance, but also need replacing now and then. It is important to note that the performance of either piece of equipment is severely hindered if not properly maintained.

AGGLOMERATION OR GRANULATION DRUM: WHAT'S THE DIFFERENCE?

Rotary drums are flexible and capable of processing large throughputs, and as such, are extensively used in many different industries. Unfortunately, the pervasive use of these drums has created a multitude of naming opportunities and, along with it, the potential for confusion. Agglomeration drums, rotary granulators, and balling drums are just a few of the names used to label drum equipment. The following goes over some of the common nomenclature used to refer to agglomeration drums.

TYPICAL DRUM CHARACTERISTICS

Due to their robust design and ability to handle material fluctuation, drums are considered workhorses in many industries. They enhance product characteristics, improve material handling qualities, and reduce waste associated with dust issues. Most drums utilize:

- A tumbling, cascading motion on the intended granule.
- An inclined drum capable of handling a large capacity.

- Pre-moistened feed material or liquid spray within the drum.
- The ability to run large recycles of under-sized and crushed over-sized granules.
- The (potential) use of flights, or if necessary, scrapers, to move material through the drum.
- A rubber lining for sticky/abrasive materials.

Additionally, drums are the preferred equipment when an application combines a chemical reaction process with agglomeration, such as in the formation of many traditional fertilizer products.

DRUM APPLICATIONS AND CATEGORIES

As mentioned, the most common applications for agglomeration/granulation drums are found in the mining and fertilizer industries. Drums used for fertilizer purposes are usually referred to as granulation drums, while drums used for mining are usually referred to as agglomeration drums. Specialty applications also use rotary drums to process material into pellets, condition material, or apply a coating to a material.

Granulation Drums

Granulation drums are most often used for [fertilizer production](#) in the agriculture industry. The tumbling motion inside a granulation drum creates blended, uniform fertilizer granules that are easy to handle and apply. Granulation drums often include a lining as a protective measure against corrosive and/or sticky materials.

Other common names for drums used in this setting include:

- Granulator
- Granulation Drum (Drum Granulator, Granulator Drum, etc.)
- Rotary Granulator
- Rotary Drum Granulator

Agglomeration Drums

Agglomeration drums used in mining applications are designed to handle high capacities. Compared to other drum equipment, the size of an agglomeration drum tends to range from medium to large in order to handle the high throughputs associated with ore mining and processing. Agglomeration drums also often include a lining as a protective measure against abrasive and/or corrosive materials.

While most of the naming confusion for agglomeration drums is contextual, some of it also stems from more specialized. As such, agglomeration drums may also be referred to as:

- Agglomerator
- Agglomerator Drum (Drum Agglomerator, Agglomeration Drum, etc.)
- Drum Pelletizer
- Rotary Agglomerator
- Rotary Drum Agglomerator
- Heap Leaching Drum
- Ore Drum
- Ore Agglomerator
- Balling Drum

Specialty Drums

Some rotary drum applications merit their own category, as they process material in capacities outside typical mining and agricultural processes. In addition

Borax pellets created in the FEECO Innovation Center

to forming material into granules or pellets, specialty drums are also used to coat material and/or mix material with various components. Common specialty drums include coating and conditioning drums.

THE BENEFITS OF MATERIAL PRECONDITIONING

When considering an industrial agglomeration solution for a material, most focus is placed on what agglomeration process and equipment will yield the greatest, and most cost-effective final product. While these are vital primary considerations, an equally important concern should be how to precondition material for the desired agglomeration process.

Preconditioning not only prepares material for subsequent processing, but it also assists in creating the best final product possible.

PRECONDITIONING BENEFITS

Many different materials benefit from preconditioning, even materials that do not undergo agglomeration

(in this case, the process may be referred to as simply “conditioning”). Besides creating an optimal final product, preconditioning provides a variety of other advantages as well...

Each step in the agglomeration process works to make the next step easier. Preconditioned material provides an early advantage to the entire process, resulting in easier handling for all subsequent steps.

Preconditioned material enhances size control and the ability to create a uniform product. In fact, numerous issues can be avoided by gaining greater control of the overall size of the material. For example, size control can reduce excessive recycle of small (“unders”) or large pellets (“overs”).

By creating an easy-to-handle material, preconditioning creates a consistent feedstock that permits increased production rates versus unconditioned material. It allows for more control during agglomeration, which in turn creates a better final product.

PRECONDITIONING EQUIPMENT

Once the final product result is determined, the required level of preconditioning should be evaluated to ensure the desired results are achievable. The following list examines common methods used to precondition material.

ROTARY DRYERS

Because moisture is critical to the agglomeration process, material at or near its critical moisture requires drying before being agglomerated. As such, using a rotary dryer to reduce moisture allows for the addition of a binder and improves the desired tackiness necessary for pellet formation.

Rotary dryers use a rotating drum with customized lifting flights. As material travels through the drum, it cascades off the flights and comes in direct contact with a heated air stream, which effectively dries the material.

PUGMILL MIXERS

Pugmill mixers use paddles to create a kneading and medium shear action as material travels through the barrel-shaped trough. These mixers provide preconditioning benefits such as wetting, standard mixing, granulating, and back mixing dried material (recycle) into the process.

PIN MIXERS

Pin mixers use pins mounted on a rotor shaft to deliver preconditioning benefits such as standard mixing, granulating, and back mixing dried material into the process. As the pins rotate at a high velocity, the turbulent agitation forces imparted on the material also deliver densification. Both pin mixers and pugmill mixers are ideal for use when wet and dry feedstock

must be thoroughly mixed as part of the preconditioning process.

CHOOSING A BINDER IN THE AGGLOMERATION PROCESS

Choosing the right binder for a given application is one of the most important aspects of the agglomeration process. A binder not only aids in pellet formation, but can also be used to optimize product characteristics and performance.

WHY USE A BINDER?

There are three main reasons for using a binder in the agglomeration process:

1. TO ACHIEVE THE DESIRED FINAL DRY PELLET CRUSH STRENGTH

Achieving the appropriate dry crush strength is necessary to ensure the pellets are durable enough to survive all handling points prior to and during end product use. From screening and packaging, to shipping, distribution, and application, product breakage and dust needs to be kept to a minimum. A dry pellet crush strength that is too low will break up too easily, while a dry pellet crush strength that is too high won't break up easily enough, or will take too long to dissolve. Adjusting binder concentration, or testing different binders, can help to hit the target dry crush strength.

2. TO ACHIEVE THE DESIRED GREEN STRENGTH

Green strength refers to the strength of a pellet in its 'wet' state, prior to drying. Oftentimes, materials need to be able to hold up as they move throughout the process before they are dried. A material with a green strength that is too low has the potential to break up

as it drops off of conveyors or goes through chutes. Achieving the appropriate green strength will help the product to stay intact through the entire process.

3. TO ASSIST IN THE ACTUAL AGGLOMERATION PROCESS

A binder helps to achieve the tackiness needed for a material to stick to itself. Though some materials may agglomerate without a binder, most materials require some sort of binding agent to pull and hold particles together while forming the pellets. And while ideally water will do the job, many times it does not have the tackiness to give the pellet enough wet strength to hold up to the rolling, tumbling, and dropping that a pellet is exposed to during processing.

SELECTING A BINDER

Binders are available by the hundreds, from waxes, to starches, latexes, and even plastics. Choosing a binder can seem overwhelming with all of the choices available, but oftentimes, industry and end use will help to decide which binder offers the best solution.

One example of how industry and end use can quickly narrow down the choice between binders is in the fertilizer industry; though coal tar might function as a perfect binder for other industries, it contains toxins that could be passed to the soil and plants, and therefore would be unacceptable to use in a fertilizer product. The same holds true for a cement binder. A cement binder may work well during the agglomeration process and achieve desired strength characteristics, but would not break down, and would leave cement in soil. Molasses, starches, and other organic binders, however, not only function well as binders for fertilizer products, but also allow the product to break

down quickly and can even add micro nutrients.

Some industries, such as the steel industry, may require that the binder be able to withstand high amounts of heat in order to hold up in rotary kilns or other thermal processing equipment.

Another important factor in binder selection is choosing a binder that is cost-effective. Binders vary greatly in price, with water typically being the least costly. Additionally, not all binders are available in all areas. One may find that a binder works well, but the cost of getting it to the site is prohibitive.

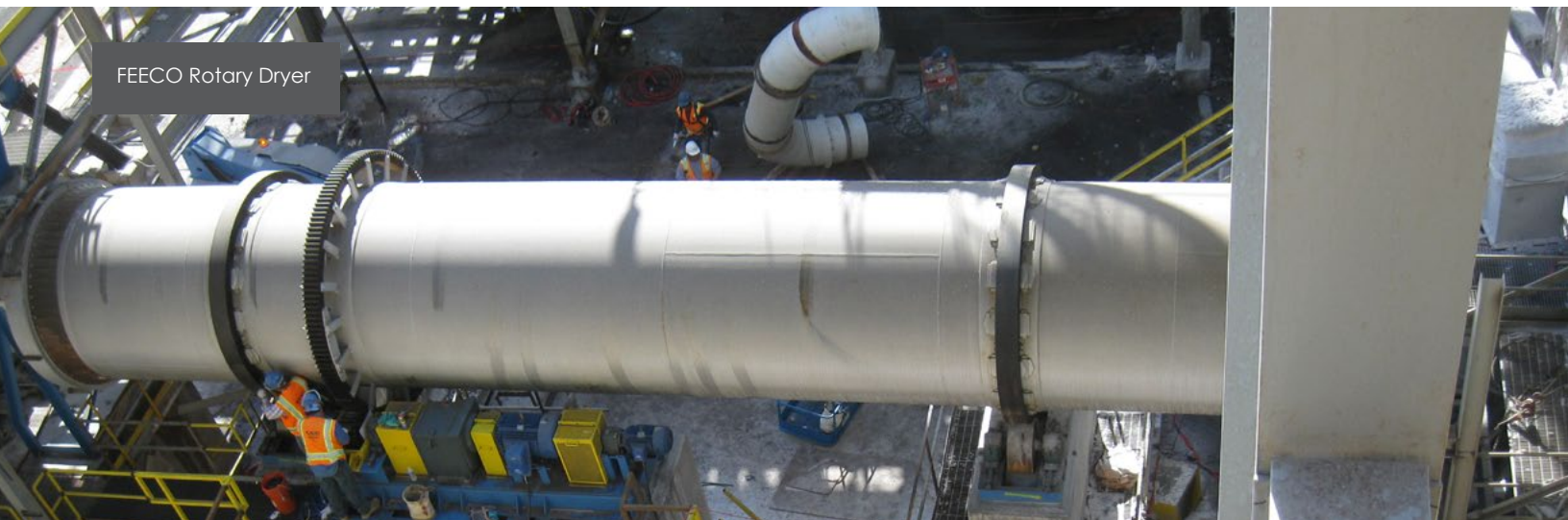
There are many aspects to consider when choosing a binder in the agglomeration process. Industry, use, cost, and availability will all have an effect on which binder will work best for the job.

THE ROLE OF DRYING IN AGGLOMERATION

Drying plays a critical role in the agglomeration process. When used prior to agglomeration, drying prepares material feedstock for agglomerate formation, and has a direct effect on how material will perform during agglomeration. Used after agglomeration, drying cures pellets into their final, strong form. In both applications, drying is vital to producing a premium end product.

PRE-DRYING

Implementing a drying stage prior to agglomeration brings material feedstock down to the level of moisture needed for optimum agglomeration to occur. This reduction in moisture also helps to improve subsequent



FEECO Rotary Dryer

processing steps by reducing the potential for issues like clumping, which can be common with hygroscopic materials, such as potash. If not dried first, materials such as these can quickly clog subsequent processing equipment, causing processing issues, inefficiencies, and even problems with the end product.

DRYING IN THE PELLETIZING PROCESS

As a post-agglomeration step, drying helps to refine the end product. In pelletizing, drying essentially cures the “green” (wet) pellet into its final, hardened form. This improves handling, as well as end product characteristics, by creating a strong pellet that is capable of withstanding further handling and transportation, but can still break down when needed. When carried out in a [rotary dryer](#), the drying stage has the added benefit of “polishing” the pellets, further rounding them as they tumble through the drum.

With some materials, a co-current air flow serves to flash off residual moisture as material enters the drum. This creates a hardened, re-crystallized surface on the pellet or granule.

To reduce potential caking issues during the drying stage, knocking systems are often utilized to dislodge any material that may be sticking to the interior of the drum. Again, this may be needed in situations where hygroscopic materials are being processed.

HOW DRYING WORKS

With most materials, reaching a target moisture range (or even an exact percentage) is required for the final product. Choosing a dryer that is designed around the unique requirements of the material to be processed will produce the best results.

Characteristics such as a material's angle of repose, bulk density, particle size distribution, specific heat, and more, will all have an effect on how the material will behave in a dryer, and subsequently, how that dryer should be designed to work with the material to produce the desired results.

Rotary dryers work by tumbling agglomerates in a drum for a set retention time. As the drum rotates, flights pick up the material and shower it through the

drying air. This maximizes heat transfer between the material and drying air, and offers a uniform, efficient drying solution.

A quick note on choosing an industrial dryer...

When it comes to drying bulk solids and agglomerates, the choice often comes down to a rotary dryer or [fluid bed dryer](#). The choice is sometimes dictated by the industry or material, with fluid bed dryers typically serving the pharmaceutical and food industries, and rotary dryers serving more industrial applications such as fertilizers and minerals. It's worth noting too, that fluid bed dryers are less suited for heavy materials such as ores, because it requires so much energy to fluidize them. Generally speaking, however, both dryers are a sufficient industrial drying option, with each offering their own advantages and disadvantages.

Rotary dryers are valued for their high throughput, their heavy-duty build, and their ability to accept variance in feedstock.

Fluid bed dryers offer a smaller footprint, increased exhaust gas flow, and a lower capital cost.

It is also worth mentioning that cooling is sometimes desirable after drying. Cooling agglomerates is useful when material will need to be immediately packaged, or stored in a silo, because it helps to prevent caking issues during storage. Similar to the choice between rotary dryers and fluid bed dryers, the same principles typically apply when choosing between a rotary cooler and fluid bed cooler.

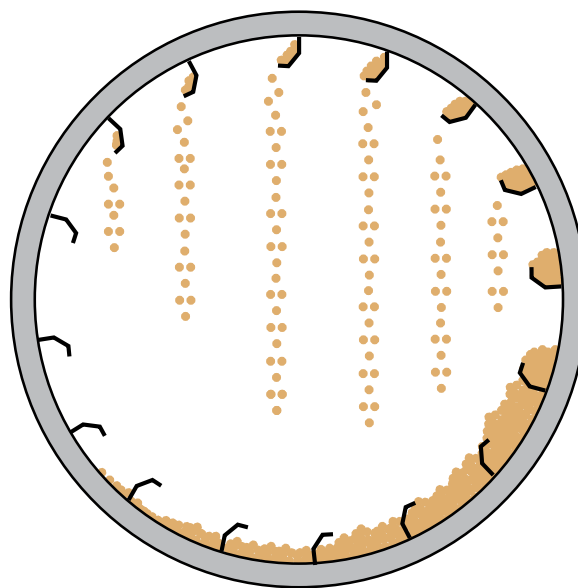


Diagram: The diagram above illustrates how flights in a rotary dryer pick up material, carry it over, and drop it through the stream of drying air, creating what is called a "curtain" of material, a technique which maximizes heat transfer efficiency.

COATING

Coating is a finishing process used prolifically throughout industries working with agglomerates to meet a wide variety of objectives. A surface treatment for particles, coating can be used to enhance specific characteristics of a pellet, granule, or other agglomerate, be it a mineral, chemical, or otherwise. Coatings are frequently applied in order to maintain product integrity, mitigate issues such as dust and/or attrition, or even to improve product performance.

REASONS FOR COATING

Coatings can offer a variety of benefits depending on the material and application. The diverse market of available coatings has created an opportunity to meet a range of goals concerning the performance and handling of agglomerates. Some of the most common reasons for coating a material include:

REDUCED DUST & ATTRITION

Dust is not only a nuisance, but depending on the material, may be hazardous as an air pollutant. Additionally, the creation of dust and fines can affect the bottom line; dust can become windblown in some applications, yielding unpredictable and undesirable results, and often resulting in product loss. For these reasons, the control of dust is one of the most common reasons why agglomerates are coated.

Dust is an especially common issue with granules that were created via roll compaction, due to the jagged edges of the granules that can break down into fines (a phenomenon referred to as attrition).

Coatings can be used to reduce the opportunity for the creation of dust and fines by creating a barrier on the exterior of the granules that helps to prevent product breakdown. A common example of this can be seen in the fertilizer industry, where granules and pellets are often coated with anti-dusting agents to mitigate issues associated with dust. This ultimately improves handling and transportation, as well as application.

Similarly, products that are “soft” can benefit from coating; coating can prevent the breakdown of product during transportation.

MITIGATION OF CAKING & MOISTURE ABSORPTION

The undesirable clumping of particles, referred to as caking, is often a challenge when working with bulk materials and also accounts for one of the primary reasons for which agglomerates are coated.

Caking often occurs during transportation and stor-

age, or while on product shelves, and can occur with many types of materials.

Anti-caking agents can be used as a coating on granules to prevent crystalline structures from forming between agglomerates, ultimately reducing caking and maintaining the integrity of the product.

Similarly, various oils, waxes, clays, polymers, latexes, and more can all be used to prevent moisture absorption. This is commonly seen in fertilizers such as urea, KCl, ammonium sulfate, and more, which become very soft and have the potential to cause caking if allowed to absorb moisture.

IMPROVED FLOWABILITY

The flowability of a product can sometimes be a challenge when working with bulk materials. Flowability refers to the flow and handling properties of a material in bulk. This affects how material will move through a processing facility, including discharge from rail cars, moving from one conveyor to another, from a hopper to process equipment, and more.

As a surface treatment, coatings can help to improve the flow properties of a material by adjusting the surface characteristics. Granules with a rougher surface quality will have a higher angle of repose (the angle at which a material can be piled before it begins to slide against itself). A high angle of repose can cause issues in terms of flowability. Conversely, a material with a smooth surface quality will have a lower angle of repose, meaning that it will slip against itself at a lower angle. This helps to ensure that granules flow more freely through bins and hoppers and between

Urea pellets before and after coating in the FEECO Innovation Center



transfer points and the like.

Various coating types can be used to improve the surface characteristics of a granule, ultimately improving the flowability and handling qualities of the material.

ENHANCED APPEARANCE

Coating is also frequently used for aesthetic purposes; a coating can lend a smooth, shiny surface to otherwise dull granules. This can take a product from average to premium, increasing its marketability.

Coatings can also be used to color particles. This is frequently seen in the roofing industry, where granules are coated in a variety of pigments to create specific colors for use on asphalt shingles.

IMPROVED PRODUCT PERFORMANCE

Coatings can also be used to influence the way a product performs. A coating can affect the solubility of a product, or be used to control the release properties, such as in the fertilizer industry.

Coatings can also be used to add another ingredient to the product formulation. For example, cat litters are

frequently coated with a clay material to promote the clumping action cat owners desire.

In other cases, "coatings" are used as the carrier themselves in order to improve product performance. This is seen in the fertilizer industry where clay pellets are coated with materials such as herbicides, pesticides, or fungicides. The clay pellets are highly absorbent and can effectively absorb the applied materials. The resulting pellets are similar in size and weight to fertilizers, allowing them to be spread easily with the same equipment.

MAINTAINING PRODUCT INTEGRITY

As has been shown, coatings can be used to ensure product integrity is maintained in a way that allows granules to arrive at their end use in the form in which they were intended. Maintaining the integrity of some products may also serve as a safety measurement. For example, coal dust and sulfur pellets can be a risk of explosion; coatings can be used to reduce this dangerous potential.

COATING SELECTION

There are many types of coatings available, from mineral oils, clays, and waxes, to polymers, latexes, and silicas, and just about everything in between. In some cases, multiple coatings, or a combination of coatings, may be required to achieve the desired results. In selecting a coating(s) for a particular application, many factors need to be taken into consideration. Some of the most critical factors to consider in coating selection are explained here.

INDUSTRY AND APPLICATION

Much like binder selection, the industry and/or end use of a product may dictate which coating(s) would be most appropriate. For example, coatings that may pose toxicity risks to soil would not be an appropriate coating for a soil amendment, while a vegetable derivative would provide an effective coating and could also possibly add value to the product.

COST

Cost is often a primary factor in coating selection. Some coatings may offer a high performance solution, but be too costly to be practical. This is especially a concern in industries where margins are already slim.

EASE OF APPLICATION

Ease of application is also an important consideration. Some materials are easily applied and distributed throughout a bed of material (such as oils, waxes, some polymers, and latexes). The contact action of rolling and tumbling between the pellets aids in transferring the coating uniformly across all the pellets. Conversely, other coatings might be good in theory, but are challenging and costly to apply. This is often the

case with materials such as hot melts, dyes, and acids, because the material does not readily spread on contact. These difficult coating materials may require a specially designed spraying system to assure uniform coating distribution.

THE COATING PROCESS

Coating is typically carried out using a pugmill mixer (paddle mixer) or coating drum, with the latter being the most common. In each case, the equipment should be designed to promote a uniform coating of particles. Variables such as spray location, flow rate, nozzle type, and more can all be tailored to achieve optimal results.

PUGMILL MIXERS

The kneading and folding over motion of the pugmill mixer promotes a homogeneous mixture of liquid and solid feed. When a pugmill mixer is used for coating, the process may sometimes be referred to as conditioning.

Granules are fed into the inlet of the pugmill mixer and a spray nozzle system tailored to the coating sprays the coating over the material. The mixing action thoroughly coats the product.

COATING DRUMS

[Coating drums](#) are similar to agglomeration drums; a rotating drum imparts a tumbling action on the bed of granules, which helps to uniformly distribute the coating. As the drum rotates, a spray system affixed to the interior of the drum sprays the tumbling bed with the desired coating material.

PUGMILL MIXER OR COATING DRUM?

The choice between which type of equipment will suit the needs of a particular project is a commonly faced choice. While testing is integral in determining the best approach, other factors come into play as well. With both types of equipment, two factors are especially important in achieving optimal results: the spray system and the movement of the pellets.

A good spray system is needed to effectively and uniformly distribute the coating across the bed of material. Choosing the right spray system is particularly important when working with a challenging coating, such as a hot melt.

The bed action is also important; the bed of pellets needs to move in a way that maximizes exposure of the pellets to the coating to enable all pellets and all sides of the pellets to be evenly coated. The action of the bed and the spray system chosen will need to work seamlessly together to obtain the desired results.

The choice between the two types of equipment is dependent on many factors, including:

- Which approach will yield the most uniform coating distribution
- Capacity
- Product Degradation
- Spatial Footprint
- Coating Tackiness
- And more...

CURING

Coatings are typically applied in a very thin layer and often do not require an additional drying step. How-

ever, some coatings may require a "curing" step, in which the coated agglomerates are processed in a [rotary kiln](#) to essentially bake on the coating. This is seen in the roofing industry where granules are coated with a coloring agent and then fired in a rotary kiln to finish the product.

COATING: THE IMPORTANCE OF TESTING

Because there are so many variables (base material, coating type, equipment and process variables), it is often desirable to test coatings to determine which type will offer the best results, both in terms of processing and performance, as well as the process and equipment variables needed to produce the desired results.

Testing in a facility such as the FEECO Innovation Center can help to work out these variables and fine-tune the process parameters to meet the unique objectives of the project. Variables might include:

- Coating type and concentration
- Material and coating flow rates
- Nozzle type
- Retention time
- Spray locations
- And more...

SIZE REDUCTION

Agglomeration processes often rely on size reduction equipment to reach ideal particle size distribution for feedstock, or to break down over-size material to put back into the process as recycle.

PARTICLE SIZE DISTRIBUTION

Often times, in order to achieve the desired end product characteristics, a range in particle size distribution

is desirable. This range in particle sizes helps to create a more cohesive pellet or granule, because smaller particles will fill in the spaces between larger ones. A feedstock with too large a particle size would result in a weak pellet, due to the increased amount of void space between particles in the final pellet. In this case, particle size reduction provides the feedstock with the smaller particle size needed to create a pellet of optimum strength.

RECYCLE

After pellets have gone through the process loop, they are typically screened by size, where on-size product is separated out to move on to packaging or shipping, and under- and over-size pellets go back into the process, so they can be processed into on-size pellets, a process referred to as “recycle.” Here, under-size pellets typically go right back to the start of the process loop, while over-size pellets must be broken down prior to re-entering the process.

Employing a recycle loop aids in minimizing product lost because it was not on-size, making sure as much product is produced as possible.

As mentioned, some processes even require a certain amount of recycle to provide a process buffer, should any upsets in the process occur. Having recycle on-hand to put into the process can mean the difference between reliable, continued production of the desired product, or downtime and product lost.

While there are a variety of size reduction equipment types available, one option—the [hammer mill](#)—offers a reliable size reduction tool for many applications.

Sometimes referred to as crushers, hammer mills provide an efficient solution for breaking down over-size granular materials at a high rate of production, without the use of a grinding action. They are particularly robust and adept at processing demanding materials.

HOW HAMMER MILLS WORK

FEECO hammer mills utilize a central rotating shaft, fitted with several “hammers” affixed to pivots on the shaft. As the shaft spins, the hammers are swung via rotational energy, causing them to collide with the material, breaking it up into smaller particles.



FEECO Hammer Mill

Hammer mills are flexible and can be used in a variety of applications. Because of their heavy-duty construction and high-capacity processing capabilities, hammer mills are most commonly utilized in mineral agglomeration and fertilizer production applications.

In a typical pelletizing process where the hammer mill is used in the breakdown of over-size pellets, the hammer mill is placed after screening in the process flow. In certain low-energy impact situations where the

hammer mill is intended to break down raw material in order to reach ideal particle size distribution, the hammer mill would simply be placed at the beginning of the process.

WHY A FEECO HAMMER MILL?

FEECO hammer mills are robust and built for reliable processing in a high-capacity setting; with a heavy steel housing, over-sized bearings, and specially hardened chain hammers, they are built for longevity, despite rigorous processing conditions. In addition to their heavy-duty build, FEECO hammer mills feature a removable quarter panel for easy access and simplified maintenance, a removable screen, as well as a non-clogging design. Ample clearance within the machine helps to aid the flow of material, preventing buildup and subsequent downtime.

TESTING PARTICLE CHARACTERISTICS IN THE FEECO INNOVATION CENTER

The following examines particle characteristic testing and gives an in-depth look at testing agglomerates in the FEECO Innovation Center.

Each agglomeration method tested in the FEECO Innovation Center can produce agglomerates of different size, shape, solubility, and density, among other things. Similarly, within each method of agglomeration, manufacturers are often targeting a set of parameters that will ensure their agglomerates perform as intended. The variety of processing methods gives manufacturers control over how they want their agglomerated materials to look, feel, and behave during commercial use.

FEECO process engineers often perform tests prior to processing a material, during processing, and after agglomerates are produced. These tests are crucial to process and product development, and help us create agglomerates to meet each customer's unique needs. Testing helps predict potential behavior in the field by gathering information on characteristics ranging from shape, to crushing behavior, and even attrition, to help manufacturers determine if the agglomerates will fit their anticipated application.

Listed here are some of the most commonly performed tests in the FEECO Innovation Center.

ATTRITION

Attrition tests are used to determine the amount of degradation that will occur during handling—that is, the amount of product that will break down into fines. As one can imagine, the least amount of attrition is desirable, as it causes product loss, as well as dust-related issues. Testing during product development can help process engineers make adjustments to the process, such as a formulation change, or addition of binder, in order to reduce the occurrence of attrition.

This test is accomplished with an attrition tester—a machine that simulates the conditions under which granules rub against each other, causing edges to break off into fines. On-size pellets are put into the machine, agitated, and then measured to see what portion of the sample is still on-size.

CRUSH STRENGTH

Crush strength tests are used to determine the crush strength of an agglomerated pellet, or in other words, how much pressure it takes to crush the pellet com-

pletely. If crush strength is low, it takes little pressure to break pellets during normal handling, but if crush strength is high, then the pellet is stronger and can withstand more handling without premature degradation. Crush tests are performed on a single pellet, using metal plates to gradually apply increasing pressure to the pellet.

Target crush strength is an important characteristic in creating a pellet that will perform as needed.

Reaching a target crush strength is particularly essential to the fertilizer industry; fertilizer pellets must be strong enough to withstand processing, bagging/storage, transportation, and even spreading without breakage. Yet, the pellets must still be capable of breaking down in standard field conditions.

GREEN/WET STRENGTH

Green/wet strength tests are essentially crush strength tests, but performed on a wet pellet prior to drying instead of a finished pellet. Pellets need a certain amount of strength to withstand the number of drop points during processing, such as when moving from one conveyor to another. Green/wet strength tests are frequently conducted to confirm that the pellets are ready for the next processing steps, or to determine if the agglomeration process needs adjustment.

COMPRESSION

Similar to crush strength, compression tests look at how the agglomerated material behaves under stress, but as a whole, instead of just as a single pellet. FEECO process experts use a controlled product amount and a hydraulic press to perform these tests. This type of test is most commonly utilized on kiln products, and

more specifically, on proppants. Proppants must be able to endure extreme amounts of pressure to hold open rock fissures, allowing natural gas or oil to flow out. If proper strength were not attained, proppants would crush under pressure, defeating their purpose. They would also subsequently clog veins to the main wellbore, inhibiting extraction. Furthermore, compression is important when it comes to materials like frac sand, or concrete additives, which are required to stand-up to heavy loading—not as an individual particle, but as a unit.

Here's how the test works: the material sits in the bottom of a cylinder, and a smaller, solid cylinder enters the larger one. The smaller cylinder is then pressed onto the material, crushing it at a specified rate of pounds per square inch.

BULK DENSITY

As the name suggests, bulk density tests determine the density of agglomerates. This is measured by taking a container of known volume, filling it with agglomerates, and then weighing it. The weight/volume reveals the material's bulk density.

Bulk density is significantly important in sizing equipment according to material and processing needs (i.e. tons per hour of production). An operation producing paper sludge at 10 tons/hour and weighing 20 pounds per cubic foot would look much different than a limestone operation with product weighing 70 pounds per cubic foot, for example. Certain products may also require a specific bulk density for a variety of reasons, such as packing or shipping purposes, consumer use, or maintaining pellet integrity during use. As with other

particle characteristics, the ability to test agglomerate density ensures a product will meet the needs of its intended application.

PHYSICAL CHARACTERISTICS

Agglomerate shape is crucial in many industries where the end product will go directly to market. Many companies and industries want spherical or oblong particles, whereas other customers request different shapes to match their needs. While agglomerate shape can be determined simply by viewing the final product, it can be evaluated in greater detail using a microscope, which captures detailed particle images, allowing further evaluation of the agglomerate shape, in addition to surface quality and other features unseen by the naked eye. This in-depth view provides tangible confirmation that the agglomerates have met their precise expectations.

SOLUBILITY

Also referred to as a dissolving test, solubility tests indicate how a material will dissolve in water. These tests often require nothing more than a simple beaker of water, and, of course, the product to be tested. Several items are recorded and analyzed in solubility tests, including:

- 1) Time
- 2) Temperature
- 3) If the material dissolves
- 4) How much of the material dissolves

These tests are extremely valuable for fertilizer and soil amendment products, ensuring that the product breaks down at the optimal rate under standard field conditions. In addition, solubility tests are useful in

testing how well coating agents perform.

SIEVE ANALYSIS

Sieves are used to measure particle size distribution, specifically what percentage of on-size pellets are produced from the agglomeration process, as well as the amount of over- and under-size particles.

Sieves are made up of a circular, metal frame with a screen-like wire mesh in the bottom. Various sieves, each with different standardized mesh sizes, are available to measure the particle size distribution of agglomerates. FEECO also uses advanced particle analysis technology to measure particle size distribution in real time. *For more information on advanced particle analysis, see page 42.*

FLOWABILITY

Flowability tests reveal how agglomerates move, or “flow,” as a unit. Flowability is measured by pouring material onto a makeshift chute positioned at various angles, and observing how the material moves from point A to B. In this test, the angle of repose is examined: the steepest angle, from 0-90°, of descent in relation to the horizontal surface to which the material can be piled without falling.

Flowability is particularly imperative in regards to the design of material handling equipment. A conveyor transporting pellets may be designed differently than one carrying compacted granules, for example, because a round, smooth pellet cannot be piled as steeply compared to a rougher, more jagged granule (because of the angle of repose).

MOISTURE CONTENT

FEECO process engineers use a specialized device, called a moisture analyzer, to record the amount of free moisture present in agglomerates. With most materials, reaching a target moisture range, or even an exact percentage, is required for the final product. This ensures agglomerates perform as desired, and do not result in clumping or breakdown issues.

While manual moisture analysis testing is still widely practiced, the Innovation Center uses a highly advanced, in-line moisture analysis device. Manual moisture testing can still be carried out, but the more advanced device allows for real-time measurement and analysis without destructive sampling or disruption of the process.

TEMPERATURE

Temperature is often recorded during testing, especially in thermal applications. Process engineers measure the inlet temperature of the rotary dryer, the gas, air, and material, for example—all necessary to know while configuring the most effective drying process.

Temperature is also recorded for kiln tests, as process temperatures are an integral part of controlling chemical reactions or phase changes that take place in the kiln.

WHEN IS TESTING CONDUCTED?

It's significant to note that these tests are either completed prior to processing, during, or after test work has been completed. In some cases, all tests, or a combination, can be performed at each of the testing stages. The chart on page 38 highlights tests often

conducted, and when they are most likely to be carried out.

Each of the tests noted here are done for multiple purposes: to help determine the material handling components, agglomerate and end product characteristics, equipment selection, and to gather data necessary for process scale-up. Furthermore, the overall goal of these tests is to produce an end product which meets the customer's unique needs. By analyzing a sample at various stages of processing, sometimes during all stages, process engineers are able to fine-tune process variables and make the necessary adjustments. All tests are recorded and provide a "recipe for success" on the process used to create agglomerates unique to the application and material source.

AUTOMATION

FEECO is a Rockwell Automation partner, providing integrated process control solutions, both as a service in the Innovation Center, and as part of a system purchase.

FEECO and Rockwell Automation process control solutions are provided with current technology, motor control centers, programmable logic controllers, and data collection systems with advanced technologies for reporting.

The FEECO Innovation Center features a Rockwell Automation PLC/MCC system, which utilizes current technologies for optimizing testing operations. During the testing process, this provides for optimal process transparency; various data points can be monitored, trended, and adjusted in real-time, all from a single interface or mobile device. This includes everything

Limestone pellets on a sieve in the FEECO Innovation Center

from current (amps), feed rate, and flow rate, to horsepower, speed, and torque, and just about everything in between. This system allows for unparalleled data collection and reporting capabilities.

Customers can select only the variables they want to see, from the exact timeframe they're looking for, to generate the reports they need. This especially gives returning customers a big advantage, allowing them to pick up exactly where they left off.

CONCLUSION

Agglomeration is a valuable process in all forms, capable of turning difficult-to-handle materials into easily handled agglomerates, and adding value along the way. There are many types of agglomeration, with the choice between them often depending on desired end product characteristics, the material to be processed, and the most cost-effective solution.

Despite the variety that exists within the agglomeration industry, one thing is clear: the benefits that agglomeration can offer continue to extend into more and

more industries, prompting increased focus on turning material problems into solutions through developing better processes and optimizing existing ones.

FEECO has been an agglomeration expert since 1951 and can offer customers the best in material testing, process design & optimization, product development, and custom agglomeration systems and equipment.

To learn how agglomeration can benefit your material, or for further information on processing equipment or material testing, contact a FEECO expert today!

TABLE: COMMONLY CONDUCTED PARTICLE CHARACTERISTIC TESTS

The chart below illustrates common particle characteristic tests and when they are most often carried out during testing in the FEECO Innovation Center.

	Prior to Processing	During Processing	After Processing
ATTRITION			X
CRUSH STRENGTH			X
GREEN/WET STRENGTH		X	
COMPRESSION			X
BULK DENSITY	X		X
PHYSICAL CHARACTERISTICS	X	X	X
SOLUBILITY			X
SIEVE ANALYSIS	X	X	X
FLOWABILITY	X	X	X
MOISTURE CONTENT	X	X	X
TEMPERATURE	X	X	X

*Note: This is not an exhaustive list, and may vary per discretion of the process engineer. Misc. / additional tests may be performed, depending on the unique material, processing requirements, and desired end product.



The [FEECO Innovation Center](#) offers a variety of options for those looking to test agglomeration processing methods. Whether you're looking to develop a product, solve a material problem, or optimize your existing product or process, the FEECO Innovation Center can help.

The FEECO Innovation Center is well equipped to suit small batch tests on a single piece of equipment, as well as continuous process loops combining multiple pieces of equipment. Testing in a continuous process loop allows you the opportunity to work out process variables, providing a recipe for process scale-up. Depending on your needs, we offer comprehensive testing options in four categories:

1. Feasibility/Proof of Concept - An initial, non-witnessed batch testing phase in which the possibility of creating a product is explored.

2. Proof of Product - A more in-depth batch testing phase in which more time is spent determining whether a product can be made to desired specifications.

3. Proof of Process - A continuous testing phase that aims to establish the equipment setup and parameters required for continuous production of your specific material.

4. Process/Product Optimization - An in-depth study to optimize your specific material's characteristics and/or production parameters in an industrial setting.

Tests commonly conducted in the FEECO Innovation Center include:

- Pelletizing (Rotary Drum or Disc)
- Conditioning
- Mixing
- Coating
- Micro-Pelletizing

AVAILABLE TEST EQUIPMENT

The FEECO Innovation Center offers a wide range of available test units and support equipment, as well as the necessary material handling components. This includes:

- [Disc Pelletizers](#)
- [Rotary Drum Granulator](#)
- [Pin Mixers](#)
- [Pugmill Mixer](#)
- [Coating Drum](#)
- Hammer Mill
- Screens
- Dryers
- Kilns
- Feeders

QUESTIONS THAT CAN BE ANSWERED THROUGH TESTING:

Will my material agglomerate?

Can agglomeration solve my material problem?

Which method of agglomeration will best suit my material?

What equipment configuration will be required to produce the desired results?

What binder, if any, will work best for my material?

Can my product be improved?

How can I optimize my existing process?

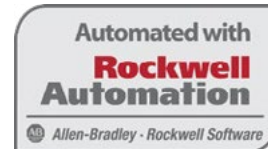
How much can dust/product loss be reduced?

REPORTING & DATA IN REAL TIME

Our state-of-the-art system allows you to monitor various data points, trending them, and even adjusting process variables in real time, all from a single interface, or even from a remote device. This allows for a user to view process data and respond accordingly during production.

FEECO is a Rockwell Automation partner, providing integrated process control solutions, both as a service in the Innovation Center, and as part of a system purchase. FEECO and Rockwell Automation process control solutions are provided with current technology, motor control centers, programmable logic controllers, and data collection systems with advanced technologies for reporting. The Innovation Center features a Rockwell Automation MCC system, which utilizes current technologies for optimizing testing operations. Data gathered includes:

- Current (Amps) ^{RT}
- Feed & Product Rates ^{RT}
- Flow Rates ^{RT}
- Fuel Usage ^{RT}
- Horsepower ^{RT}
- Speed (Hz) ^{RT}
- System Pressures ^{RT}
- Temperature ^{RT}
- Torque ^{RT}
- Screen Analysis of Feed & Product



(^{RT}) indicates that the data can be tracked in real time.

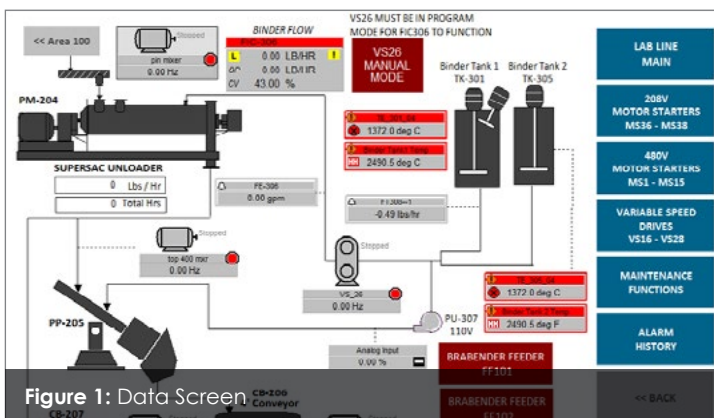


Figure 1: Data Screen

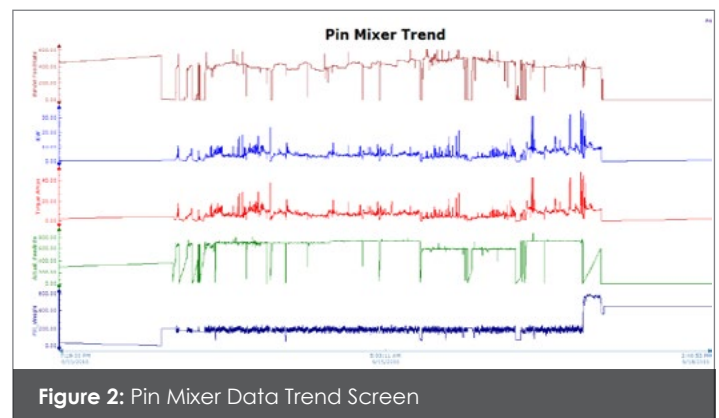


Figure 2: Pin Mixer Data Trend Screen

FEECO can integrate third party equipment into your control system, giving you complete process tracking and visualization. Secure remote access to the system by a Rockwell Automation expert provides unparalleled troubleshooting capabilities.



MATERIAL TRANSFORMATIONS

Completed through testing in the Innovation Center

BEGINNING MATERIAL

FINAL END PRODUCT

		Agglomeration	Drying	Blending	Thermal	Compaction
Ammonium Sulfate	Granular Fertilizer					•
Ash (Wood, Fly)	Granular Fertilizer	•	•			
Bentonite Clay	Cat Litter Granules	•	•			•
Biomass	Biochar, Activated Carbon		•		•	
Bone Meal	Granular Fertilizer	•	•			
Calcium Carbonate	Granular Fertilizer	•	•			
Calcium Chloride	Ice Melt Pellets	•	•			
Calcium Sulfate	Granular Fertilizer	•	•		•	
Carbon Black Dust	De-dusted Pellets	•	•			
Cell Phone Batteries	Lithium, Zinc Metal Recovery				•	
Cement Kiln Dust	Granular Calcium Fertilizer	•	•			
Ceramic/Aluminum	Refractory	•	•			
Clay	Proppants				•	
Clay	Cat Litter, Oil Dry Granules, Encapsulate Seeds	•	•	•		
Coal Dust	De-dusted Coal Pellets	•	•			•
Compost (Yard Waste)	Granular Fertilizer	•	•	•		
Copper Dust	Metal Recovery Pellets	•	•	•		
Corn Cobs	Cat Litter, Oil Dry Pellets	•	•	•		
Diatomaceous Earth	Filter Agent	•	•			
Dredge Sludges	Non-leaching Granules	•	•	•		
Electric Arc Furnace(EAF) Dusts	Metal Recovery	•	•	•		
Ethanol Plant Waste(DDG)	Animal Feed	•	•	•		
Foundry Dust	Metal Recovery	•	•	•		
Glass Batch	Glass Blend	•	•	•		
Gold Ore Dust	Precious Metal Recovery	•	•	•		
Grain Dust	Non-explosive Pellets	•	•	•		
Gypsum	Granular Fertilizer	•	•			
Gypsum Wallboard Waste	Granular Fertilizer, Cat Litter Pellets	•	•	•		
Humate	Granular Fertilizer	•	•	•		
Iron Ore	Metal Recovery Pellets	•	•			
Iron Oxide	Metal Recovery Pellets	•	•	•		
Kaolin Clay	Paper Coating	•	•			
Lime (Wastewater Treatment Sludge)	Granular Calcium Fertilizer	•	•	•		
Limestone	Granular Calcium Fertilizer	•	•	•		
Manure – Cattle/Chicken/Hog	Granular Fertilizer	•	•	•		
MAP Fertilizers	Granular Fertilizer	•	•	•		
Mined Frac Sand	Dried Frac Sand		•			
Municipal Wastes	Granular Fertilizer, Fuel Pellets	•	•	•		
Nickel Ore	Metal Recovery Pellets	•	•			
Nitrogen Fertilizers	Granular Fertilizer	•	•	•		
NPK Blends	Granular Fertilizer	•	•	•		•
Paper Sludge	Granular Fertilizer, Cat Litter	•	•	•		
Paper Sludge	Bright White Clay				•	
Petroleum Coke Dust	Fuel Pellets	•	•	•		•
Phosphates Powder	Granular Fertilizer	•	•	•		
Potassium Chloride	Granular Fertilizer	•	•	•		•
Raw Coal	Purified Coal				•	
Saw Dust	Cat Litter, Fuel Pellets	•	•	•		•
Soda Bottles	Recycled Plastic				•	
Soy Flour	Animal Feed	•	•	•		
Steel Dusts and Sludges	Metal Recovery Pellets	•	•	•		•
Sugar	Sugar Pellets	•	•	•		
Sulfur Dust	Non-explosive Pellets	•	•	•		
Sulfur Stack Emissions	Granular Fertilizer	•	•			•
Talc Ore	Sterilized Baby Powder				•	
Tar Sands Waste Sludge	Substitute Fuel Pellets	•	•	•		
Titanium Dioxide	Pigment Pellets	•	•			•
Titanium Metal Shavings	Metal Recovery	•	•	•		
Tungsten Oxide	Metal Recovery Pellets	•	•			•
Zinc Oxide	Metal Recovery Pellets	•	•			•

Agglomeration: Drum, Pan Pelletizer, Pin Mixer

Drying: Rotary Drum Dryer, Fluid Bed Dryer

Blending: Pug Mill

Thermal Process: Rotary Kiln

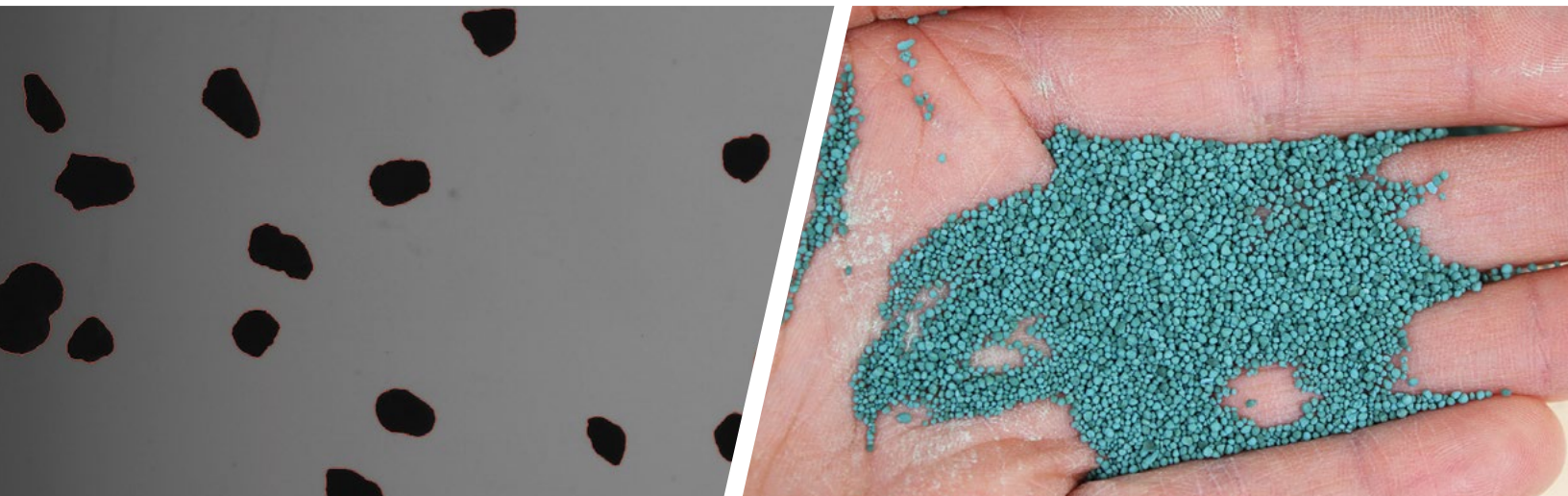
Roll Compaction: Roll Compactor

SCHEDULE A TEST

To discuss your testing needs with one of our process engineers and schedule a test, contact us today at:

FEECO.com/contact

ADVANCED PARTICLE ANALYSIS WITH MICROTRAC



BENEFITS OF ADVANCED PARTICLE ANALYSIS

FEECO has partnered with Microtrac, a leader in particle characterization, to offer advanced particle analysis capabilities, both during testing in the Innovation Center, and as part of a system purchase.

The Innovation Center is equipped with an in-line PartAn 3-D PRO from Microtrac, giving us the ability to analyze multiple variables in real time without disrupting production. The integration of the PartAN 3-D PRO provides precision results in real time, without the delay, risk, or inaccuracy associated with manual sampling. This improved efficiency often translates to faster start-ups and fewer shutdowns.

In addition to improved production, the risks associated with manual sieving, such as lost tonnage and lower product quality are also mitigated.

HOW IT WORKS

The PartAn 3-D PRO can analyze particles in the size range of 15 μm to 35,000 μm , with 3D size and shape for particles ranging from 35 μm to 35,000 μm .

The unit uses a high-speed, high-definition camera to capture images of the particles in motion as they move past the camera. Through 3D Dynamic Image

Analysis (DIA), a number of particle characteristics are instantly measured, without disrupting the process.

The system can be integrated into various points in the process depending on what data is desired. The analyzer is capable of measuring 32 variables, with some of the most common including:

- Size
- Shape
- Thickness (unlike 2D DIA)
- Surface roughness (indicates poor flowability, or unwanted agglomeration)
- Density
- Transparency
- 3D capabilities

The pairing software system can be customized to report only on items of interest and even offers filtering, graphing, and data comparison capabilities.

PARTICLE ANALYSIS DURING TESTING IN THE INNOVATION CENTER

Advanced particle analysis is ideal in many test settings; whether you are developing a new product or process, or you want to test how a process change will affect product output, the ability to gather multiple

variables in real time provides a bird's eye view of process performance, streamlining these critical R&D stages. In combination with our Rockwell Automation Control system, material testing and process development has never been more intuitive.

PARTICLE ANALYSIS IN COMMERCIAL PRODUCTION

Implementing an advanced particle analysis system as part of your commercial process flow provides a number of benefits.

Real-time data makes maintaining product quality easier and more efficient than ever, helping you to maintain maximum product consistency and salability. This real-time data also allows you to immediately recognize a change in output specifications, reducing off-spec product and maximizing efficiency.

No matter what your goals, advanced particle analysis is an invaluable tool in streamlining the process and product development stages, as well as maximizing commercial production efficiency.

For more information on how particle analysis can benefit you, contact us today!

ADDITIONAL RESOURCES

For further information or reading on agglomeration, we have provided some additional resources below. Please note that the inclusion of any resource or company is not an endorsement and the views of that resource do not reflect those of FEECO International.

ASSOCIATIONS & PUBLICATIONS

Institute for Briquetting and Agglomeration (IBA)

www.agglomeration.org

Powder Bulk Solids

www.powderbulksolids.com

BOOKS

The Science and Engineering of Granulation Processes (Particle Technology Series)

by Jim Litster and Bryan Ennis

ISBN-13: 978-1402018770

Particle Technology and Engineering: An Engineer's Guide to Particles and Powders: Fundamentals and Computational Approaches

by Jonathan P.K. Seville and Chuan-Yu Wu

ISBN-13: 978-0080983370

Agglomeration Processes: Phenomena, Technologies, Equipment

by Wolfgang Pietsch

ISBN-13: 978-3527303694

Agglomeration in Industry, 2 Volume Set: Occurrence and Applications

by Wolfgang Pietsch

ISBN-13: 978-3527305827

ABOUT FEECO

FEECO International, Inc. was founded in 1951 as an engineering and equipment manufacturer. We are recognized globally as an expert in industry-leading process design, engineering capabilities (including everything from process development and sample generation, to feasibility studies and detailed plant engineering), custom equipment manufacturing, and parts and service. We serve a range of industries, including fertilizer and agriculture, mining and minerals, power/utility, paper, chemical processing, forest products, and more. As the leading manufacturer of processing and handling equipment in North America, no company in the world can move or enhance a concept from process development to production like FEECO International, Inc.

The choice to work with FEECO means a well-rounded commitment to quality. From initial feasibility testing, to engineering, manufacturing, and parts and service, we bring our passion for quality into everything we do.





For more information on agglomeration, material testing, custom equipment, or for help with your agglomeration operation or problem material, contact FEECO International today!

FEECO US Headquarters

3913 Algoma Road | Green Bay, WI 54311 USA

Phone: 920-468-1000

[FEECO.com/contact](https://www.feeco.com/contact)