Agglomeration Technology: Equipment Selection

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Desired product attributes is only one of the considerations to take into account when choosing agglomeration equipment

A virtually endless number of process options are available for agglomerating powders in the chemical process industries (CPI). These processes can be divided into two main categories: agitation and compression. Agglomeration by agitation includes granulation processes, such as fluidized-bed, disc, drum, and mixer granulators. Agglomeration by compression includes compaction processes, such as tabletting, extrusion, roll presses and pellet mills. Process choice is affected by certain feed attributes as well as a host of ancillary decisions. This article focuses on equipment selection criteria for granulation and compaction processes. The mechanisms of agglomeration were reviewed in an earlier article [*1*], and additional detailed information on agglomeration is available elsewhere [*2–7*].

Wet granulation

Granulation processes vary from low to medium levels of applied shear and stress, producing granules of low to medium, and in some cases, high density [*2*]. Ranked from lowest to highest levels of shear, these processes include fluidized-bed, tumbling and mixer granulators. In wet granulation, agglomeration is promoted by the addition of binders and solvents.

Fluidized-bed granulators. In fluidized-bed granulators, particles are supported and mixed by a heated gas. This action also induces drying. Proper gas-distributor design is required to maintain solids mixing, heat and mass transfer; and to prevent unstable operation that could cause the bed to defluidize or collapse. Batch and continuous designs are available (Figures 1a and 1b), as well as spouted-beds and coaters. Liquid binder is sprayed through an atomizing two-fluid nozzle located above, in or below the bed. Both aqueous and solvent solutions are used, which requires solvent recovery considerations. Spray distribution, atomizer design and humidity control are crucial to proper operation. Bag filters or cyclones are needed to remove entrained dust from the exit air.

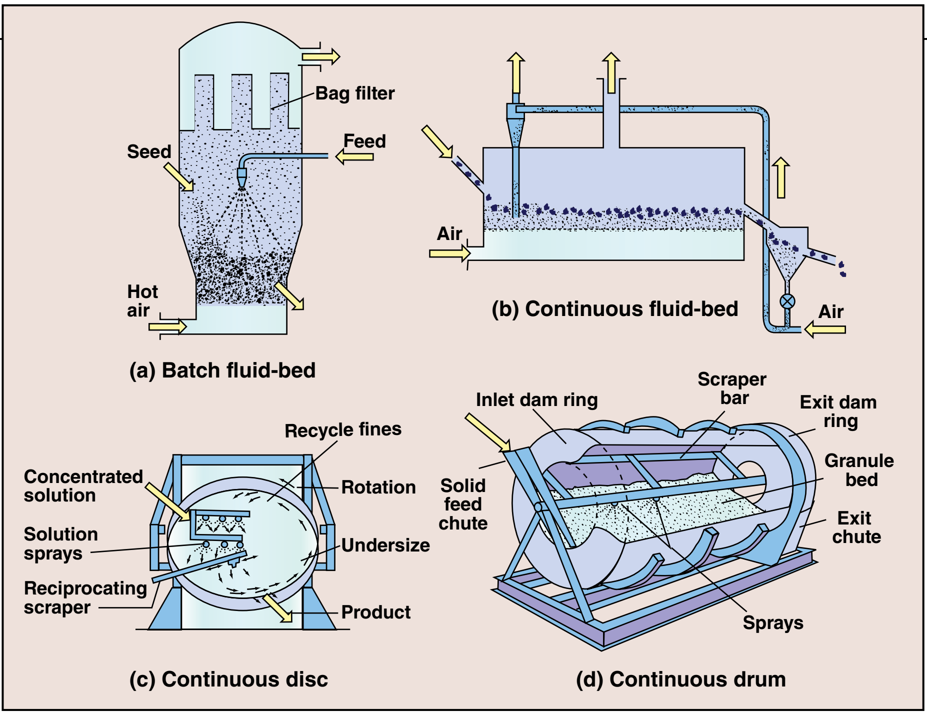
Batch processes in a wide range of batch sizes are used to agglomerate fine powder to produce high porosity granules. Alternatively, slurries of feed materials may be sprayed onto a bed of seed particles to produce high-strength, layered granules. Continuous fluidized beds, generally of a serpentine design, produce layered granules. Recycle of off-size material is very common and involves ancillary equipment for continuous classification, crushing and grinding. Seed material is often introduced to the initial stages to promote process stability. Spouted-bed designs are used for coating applications, as well as precision granulation where growth is localized within the upward-conveying draft tube.

Tumbling granulators. In tumbling granulators, particles are set in motion by the tumbling action caused by the balance between gravity and centrifugal forces. Common designs include continuous, inclined disc and drum granulators (Figures 1c and 1d) with throughput ranges of 1–100 ton/h and 1–5-min residence times. Disk granulators consist of a rotating pan with a rim, typically tilted at horizontal angles of 50–60 deg. Drums consists of a cylinder, inclined at a horizontal angle of 3–10 deg, which may be either open-ended or fitted with annular retaining rings. Tumbling granulators generally produce granules in the size range of 1–20 mm and are not suitable for making granules smaller than 250 µm. Granule density generally falls between that of fluidized-bed and mixer granulators and it is difficult to produce highly porous agglomerates in tumbling granulators.

Rotational speed and incline angle are set to maintain proper tumbling action. Solids are introduced continuously by volumetric or gravimetric feeders. Gravimetric feeding often improves granulation performance due to smaller fluctuations in feedrates. Such fluctuations act to disrupt the rolling action of the solids bed and can lead to poor distribution in moisture, agglomerate growth and local surface buildup of solids. Wetting fluids for growth are applied by a series of single-fluid-spray nozzles distributed across the face of the bed. Solids feed and spray nozzle locations have a pronounced effect on granulation performance and granule structure. Distributor-pipe feeding systems are used in drums with simultaneous chemical reaction (for example for fertilizers).

A key feature of disc operation is the inherent size classification. Centripetal forces throw small granules and ungranulated feed high onto the disc, whereas large granules remain in the eye and exit as product. Size segregation leads to exit of product granules only from the eye at the rim of the disc. This classification substantially narrows exit-granule size distribution, allowing discs to operate with little or no pellet recycle at a yield of 70–80% on the first pass.

Drums have no output size classification and high recycle rates of off-size product are common. Holdup in the drum is between 10 and 20% of the drum volume, with drum lengths ranging from 2–5 times the diameter. Drum granulation plants often have significant recycle ratios (2:1 to 5:1) of both undersize and crushed oversize granules. This large recycle stream has a major effect on circuit operation,



(a) Batch fluid-bed

(b) Continuous fluid-bed

(c) Continuous disc

(d) Continuous drum

FIGURE 1. Low-shear granulation processes include both batch and continuous choices, such as the granulators shown here

stability and control. Surging of recycle streams and limit cycle behavior are common, which significantly affects granule exit-size distribution.

Mixer granulators. Mixer granulators induce granulation through mechanical agitation. A wide selection of mixing-tool designs is available. Differences in equipment, impeller and chopper geometry result in very wide variations in shear rate and powder flow patterns among manufacturers. Great caution should be exercised in transferring formulations and empirical knowledge between mixer designs. Further, geometric similarity is not maintained in scaleup of most commercial equipment. Controlling the amount of liquid phase, wet mass rheology, and the intensity and duration of mixing determines agglomerate size and density. Due to the strong compaction and kneading action in mixer granulators, this equipment produces denser, less spherical granules, typically with less liquid phase.

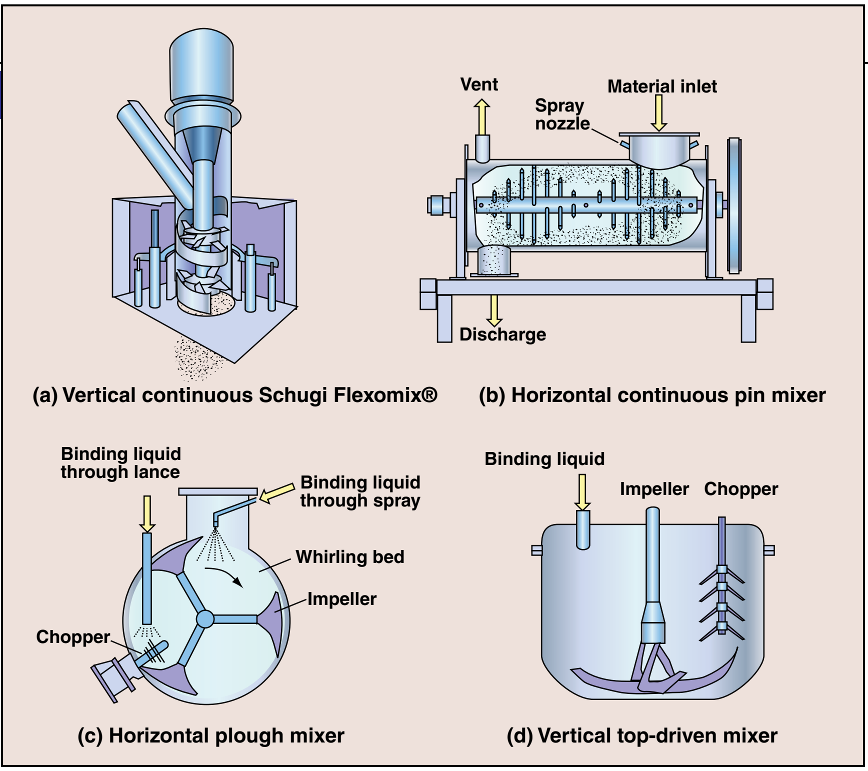
Low shear mixers include ribbon or paddle blenders, planetary mixers, orbiting screw mixers, sigma blade mixers and double cone or V-blenders that operate with rotation rates or impeller speeds less than 100 rpm. Both batch and continuous equipment are common. Mixing times in these granulators are quite long (20–40 min) and many have been replaced with high shear mixers.

High speed mixers include continuous shaft mixers and batch mixers. Continuous shaft mixers have blades or pins rotating at high speed on a central shaft in both horizontal and vertical shaft designs (Figures 2a and 2b). Examples include the vertical Schugi mixer and horizontal pin mixers, which operate at high speed (200 to 3,500 rpm) to produce granules of 0.5 to 1.5 mm with a residence time of a few seconds. Intimate mixing is achieved. However, little time is available for substantial product growth or densification, and the granulated product is generally fine, irregular, and fluffy with low bulk density. Capacities may range up to 10–200 ton/h with power requirements of up to 200 kW. Continuous high-speed mixers are often followed by additional mixers operating at a higher residence time and lower shear to promote additional growth and densification.

Batch high-shear mixer granulators are valued for their robustness in processing a range of powders as well as the ease with which they can be enclosed and cleaned (Figures 2c and 2d). Plow shaped mixers rotate on a horizontal shaft at 60–800 rpm. Most designs incorporate an off-center high-speed cutter or chopper rotating at a much higher speed (500–3,500 rpm), which breaks down over-wetted powder mass and limits the maximum granule size. The scale range is 10–1,200 L with granulation times on the order 5–10 min, which includes both wet massing and granulation stages operating at low and high impeller speed, respectively.

Granulator selection. Four key rate mechanisms contribute to all granulation processes [*1, 3–7*]. These are wetting and nucleation, coalescence or growth, consolidation, and attrition or breakage. It is vital to keep in mind the high degree of interaction between granulation mechanisms, formulation properties and process equipment in making equipment selection. Batch fluidized beds can produce one of the lowest density granules, and are an example of low deformable growth. Low deformability processes are stable in that consolidation generally occurs on a slower time scale than growth, allowing more independent control of granule size versus granule density than is possible in high deformability processes. Growth rate is controlled by spray rate and bed moisture. Fluidized beds must operate in a droplet-controlled wetting regime (Figure 2 in Ref. 1). Small drop penetration times and low spray fluxes are required to prevent binder pooling and defluidization. Poorly wetting powders or binders of initially high viscosity are precluded. Consolidation of granules can be increased independent of growth through increasing bed height, bed moisture or process residence time. Simultaneous drying allows solidification of binder within a granule during the granulation time, which arrests the densification process allowing production of porous granules. However, with seed recycle and slurry sprays, it is also possible to produce much denser, layered granules. The inherent stability of low deformability processes allows considerable manipulation in granule properties and ease of scaleup.

At the other extreme are high shear mixers, where blades and choppers induce binder distribution and growth, producing medium to dense, irregular granules. Mixers operate as a deformable growth process, where in most cases it is difficult to control granule density independent of size. Mixers have an advantage in that they can process plastic, sticky or poorly wetting materials, and can spread viscous binders, operating in a mechanical dispersion regime of wetting [*1*]. On the other hand, they may equally process



(a) Vertical continuous Schugi Flexomix® (b) Horizontal continuous pin mixer

(c) Horizontal plough mixer (d) Vertical top-driven mixer

FIGURE 2. In high-shear mixers, blades, pins and choppers induce binder distribution and growth

powders of fast wet-in time and may benefit in this case from spray nozzles when operating with low spray flux. However, associated with the flexibility in processing a wide variety of materials, high shear mixers can be very difficult to scale up due to large shifts in the competition between growth and densification, wetting regimes, and powder mixing with batch size. Shifts in nucleation and growth mechanisms with scaleup are not uncommon, making it difficult to compare pilot studies with full-scale operation.

Tumbling granulators produce uniform, spherical granules, and lie between fluidized beds and mixers in terms of shear rate and granule density, operating between low deformable growth at small scale, and moving towards deformable growth at very large scale. They have the highest throughput of all granulation processes.

In the case of non-deformable growth (for example in fluidized beds and tumbling granulators), granule size typically progresses through rapid, exponential growth in an initial nucleation stage, through a transition stage and finishes with slow growth in a final balling stage (Figures 3 and 5 in Ref. 1). In the initial nucleation stage when the average size is less than a limiting granule size (referred to as D_c in Ref. 1), the granule size distribution typically widens. This increase in the width of the granule size distribution is in proportion to the average, mean size. When the mean size approaches D_c in the balling stage, the distribution then begins to narrow [10]. During growth, granule internal porosity often decreases with time as the granules are compacted. In this most common case, size is controlled by spray rate, bed moisture and mixing rate. Increasing speed, such as drum rotation rate, will speed growth due to higher collision rates and mixing. Growth is independent of the granule viscous Stokes number, binding fluid viscosity and granule inertia [1]. This independence of growth on inertia again makes scaling and operation of fluidized beds and tumbling systems easier than for their deformable growth counterpart of mixers.

The limit of growth in non-deformable systems varies inversely with viscous Stokes number [1]. Such limits are generally not achieved in fluidized beds, but may be achieved in tumbling granulators, especially in long drums with high residence time. In this case, it is possible for the size distribution to narrow if growth limits are approached. This maximum achievable size will increase with increasing binder viscosity, and decreasing granule density or rotation rate. Prior to this limit, size would increase with the number of rotations occurring with the given residence time. Therefore, one cannot predict the impact of rotation rate without knowing where in the growth profile the product exists.

In the deformable growth attained in mixers, two regions of operation may be identified — and it is absolutely vital that regions of growth be identified to appropriately control the process. For increasing deformation Stokes number, increases in impeller speed or decreases in formulation yield stress will increase growth rate in the initial, non-equilibrium region of growth, whereas the opposite holds true in the later, equilibrium growth. As with low-deformable processes, the size distribution generally widens in the non-equilibrium stage, but later may narrow as the limit of growth is achieved for the given impeller speed. Raising impeller speed in this later stage of growth will decrease size. Note that increasing bed moisture acts to lower wet-mass yield stress and increase kneading, deformation and growth. And as pointed out, it is possible for shifts between equilibrium and non-equilibrium growth to occur between scales of operation [1,4,6].

Compaction and extrusion

Pressure compaction is carried out in two classes of equipment (Figure 3). These are dry processes (molding, piston, tabletting, briquetting and roll presses [8]), in which material is compacted between two opposing surfaces; and paste extrusion devices (pellet mills, screw extruders, table and cylinder pelletizers [9]), in which material undergoes considerable shear and mixing in the presence of a fluid carrier while being pressed through a die. Here, agglomeration is driven by mechanical deformation of the feed to achieve intimate packing of the feed particles.

Tablet presses. Tablet presses produce shapes of superior appearance with strict specifications in weight, geometry, hardness and dissolution behavior (Figure 3a). Molding presses operate at much slower rates and are used for more intricate shapes. Good flow properties are required for rapid, consistent die filling as well as proper die lubrication (low die friction) to prevent capping and delamination. For fine feeds this often requires a preprocessing operation of either wet granulation or dry agglomeration, which includes for example, roll pressing or slugging.

Modern high-speed rotary tablet presses have dual feed-compression stages, and typically compress the tablet from both ends. Poor mechanical properties lead to a variety of flaws, including: delamination and capping; sticking to punch surfaces; localized cracks often due to recycled or hard materials; and poor tablet dissolution due to over-compacted regions.

Roll presses. Roll presses force material into the gap between two rotating rolls (Figure 3b) and provide a mechanical advantage, amplifying the incoming feed pressure to a maximum value that occurs at minimum gap. This maximum pressure and roll dwell time control agglomerate quality for given feed properties. Smooth or corrugated rolls produce solid sheets, which are subsequently broken down and classified to a desired agglomerate size range. The degree of confinement increases for opposing corrugated patterns that produce cigar-like agglomerates to pocketed rolls of briquetting presses (Figure 3c).

As flow properties and permeability decline, allowable roll feed and production rate will drop. This may be compensated by force-fed and vacuum-feed systems, wider rolls of smaller diameter and circumferential grooving of rolls. Multiple screw designs are effective in distributing the feed pressure for wide rolls. Forcing rolls beyond their permeability limited speed leads to erratic feeding and fluidization in the gap, and inconsistent granule quality. Nip pressure should be used for scaling granule quality and not roll loading. This maximum pressure controls sheet density and is a very strong function of friction and compressibility.

Extrusion. In extrusion, powder in a plastic state is forced through a die, perforated plate or screen. These processes can operate wet or dry to produce narrowly sized, dense pellets. Wet extrusion is often followed by spheronization techniques to round the product. Types of extruders include screw extruders (such as axial end plate, radial screen and basket designs), and pelletization equipment (such as rotary cylinder and ram extruders; Figure 3, d,e and f). Material undergoes substantial shear in the equipment, and operation and product attributes are strongly influenced by the frictional interaction between the powder and wall. In ram extruders, material is directly consolidated between two opposing surfaces. Extrusion processes can exert the highest applied force of any size-enlargement device to give the highest density product.

In wet extrusion, wet mass rheology and friction control the pressure needed to induce die extrusion and this pressure increases with desired throughput. The actual pressure that can be developed by the sliding action of the barrel is a decreasing function of throughput, and it increases with increasing barrel and decreasing screw friction. These relationships are referred to as the die and screw characteristics of the extruder, respectively [5]. Their intersection determines the operating point, or throughput of the extruder, which may shift with wear of dies, screws and barrels over equipment life due to changes in wall friction and die entrance effects. Lastly, the rheological properties of the liquid phase are equally important. Poor rheology can lead to separation of the fluid and solid phases, large rises in pressure, and undesirable sharkskin-like surface appearance on the granulate [*5, 9*].

Equipment selection. Process performance in extrusion and dry compaction equipment is very sensitive to powder flow and mechanical properties of the feed, and generally produces much denser compacts or agglomerates than wet granulation. As discussed previously [*1*], compaction improves with increased stress transmission (controlled by lubrication and die geometry), decreased deaeration time (increasing powder permeability and decreasing production rate), increased plastic/permanent deformation and increased powder flowability. These features impact process selection to varying degrees [*2*].

In the case of dry compaction, the compaction pressure must exceed the inherent hardness of the material. Therefore, the necessity to form permanent bonds following stress unloading makes it difficult to process brittle, hard materials. Appropriate binders can be added, or wet extrusion/pellet mills used. Small amounts of moisture are common. It must be kept in mind, however, that the incompressibility of the fluid can limit the maximum achievable density and strength of the compact. Abrasive materials cause substantial equipment wear and may require special materials of construction. Elastic materials may also present problems in dry compaction, especially tabletting, as large elastic recovery promotes flaw development. Alternatively, abrasive, hard, brittle, elastic materials can be processed in wet granulation equipment provided that lower density and the additional operating and investment costs of drying are allowed (also required in wet extrusion). On the other hand, non-wetting materials are easily processed in compaction processes, which is not the case in wet granulation with the exception of high shear mixers.

Wall friction impacts both stress uniformity, as well as developed pressures in wet extrusion. In the case of unconfined roll pressing, high friction is often desirable to pull material into the rolls with greater force. However, for tabletting, wall friction angles greater than five degrees often lead to non-uniform compact stress, capping and delamination. In addition, the required pressure, ejection forces and likelihood of flaw development in tablets increase with increasing wall friction. This generally requires the addition of lubricants to aid tabletting. Briquetting machines and patterned rolls fall between these cases, dependent of pocket design. In the case of wet extrusion, high barrel friction, low screw friction, and low die friction is desirable for developing large die-face pressures, which controls die extrusion rate.

If large powder deaeration is required, increased air entrapment may occur within the die or feed zone, resulting in lowered feed and production rates, and increased flaw development due to gas pressurization within the compact. Either low permeability, or materials undergoing large void volume changes, will exacerbate this problem. In the case of roll pressing and wet extrusion, this may be addressed by vacuum and forced fed systems or other deaeration allowances, increased dwell time, or increased recycle rate. In the case of tabletting, however, this is generally handled ei-

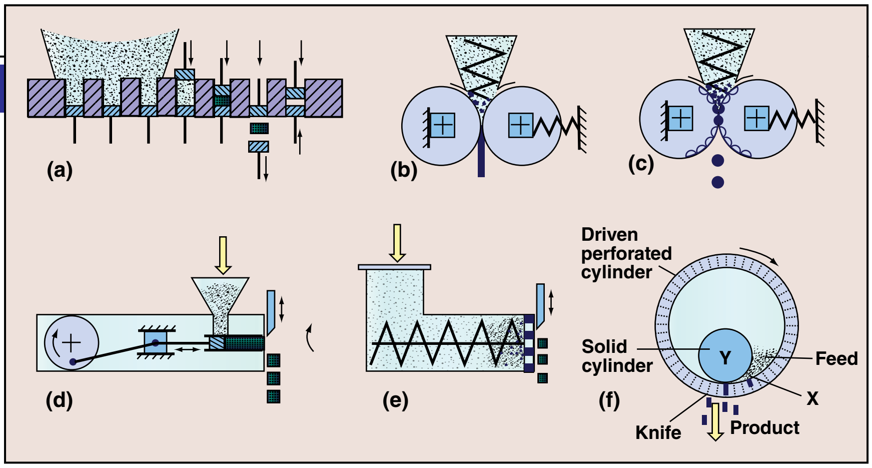


FIGURE 3. Examples of compressive agglomeration include: For dry compaction, (a) tabletting, (b) roll pressing, (c) briquetting, (d) ram extrusion; and for paste extrusion, (e) screw extrusion and (f) concentric-roll palletizing

ther by upstream wet granulation or roll pressing to produce a denser, free flowing feed. Such two-stage densification systems are common for fine, low permeability materials, an example being high recycle roll pressing.

As compaction processes are inherently continuous, powder feedrate is critical. Flowrate into die chambers and through clearances is generally a very strong function of diameter. Erratic flow is possible for cohesive/low permeability powder. Little allowance is possible for tabletting except two-stage processing, for example upstream agglomeration to improve flow. In the case of rolls, forced/vacuum feeding, increased dwell time, and wider rolls of smaller diameter provide some relief.

Overall considerations

The choice of agglomeration equipment is subject to a variety of constraints and should ideally be made on the basis of the desired final product attributes and special processing requirements (such as heat and moisture sensitivity [2]). In practice, however, there are many other considerations that include a company's historical process experience with a given technology, operating and investment costs, local availability and cost of key ingredient and utilities, retrofitting and building consideration, ease of dust containment and ease of equipment cleanout.

Agglomerate porosity and size distribution control agglomerate end-use properties and are important first considerations, along with agglomerate appearance and the ability to utilize moisture or solvents. Wet granulation produces low to medium density granules of varying sphericity. Binders are typically utilized, and drying of solvents is required, with the associated energy and dust/air handling costs. If denser agglomerates are required, dry compaction or wet extrusion should be considered, although it is worth noting that reasonably dense granules are possible with two-stage mixer processing. Dry compaction is suitable for moisture sensitive materials. Appearance considerations might suggest tabletting, or wet granulation (fluidized bed, drum, pan) or extrusion combined with spheronizing for free-flowing, nearly spherical granules.

Various technologies have feed material limitations. With the exception of high shear mixing, wet granulation requires wettable formulations whereas this is not a concern in compaction. On the other hand, hard, brittle, abrasive, elastic materials are difficult to process in dry compaction and can present equipment wear problems in wet extrusion. These mechanical properties do not present any limitation in wet granulation, outside of increased attrition rates. Lastly, materials of low permeability can present limitations in continuous processes, especially in dry compaction, as discussed above.

Heat, solvent or pressure sensitivities may preclude a process. An example would be the stability of polymorphs. High frictional heating is possible in mixing, as well as pressure sensitivity in all compaction and extrusion processes. Moisture or solvent may already exist in the powder, for example in wet cakes, making drum tumbling and wet extrusion processes attractive. In some cases, simultaneous reaction is desired, which is possible in high shear mixing, drum and wet extrusion processes. One-pot processing encompassing mixing, granulation and drying make both fluidized beds and mixers attractive choices. Pre- and post-processing requirements must be determined, and in this regard, the level of recycle that can be tolerated is an important consideration. As an example, drum wet granulation and dry roll pressing often require high levels of recycle for successful operation, and this can present issues of product degradation. Lastly, each process has unique sensitivities to fluctuations in raw ingredient properties, as well as the ease of scaleup. Ranking equipment from best to least forgiving with regard to tolerance to ingredient fluctuations gives: fluidized bed, tumbling (pan and drum), mixer, wet extrusion, tabletting, and roll pressing processing. ■

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TABLE 1. PROCESS SELECTION CONSIDERATIONS FOR WET GRANULATION EQUIPMENT

	Process:					
Attributes	Batch Fluid Bed	Continuous Fluid Bed	Continu-ous Disc	Continu-ous Drum	Batch Mixer	Continu-ous Mixer
Process Characteristics						
Typical pre/post processing	C	C, R	B,D,C,R	B,D,C,G,R	D,C	D.C,T
Ease of dust/toxicity containment	Y	Y	N	N	Y	Y
Ease of cooling or heating	H	H	L	L	H	H
Typical level of recycle	L	L-M	L	H	L-M	L-M
Heat activated granulation	N	N	N	N	Y	Y
Simultaneous drying / reaction	Y	Y	N	Y	Y	Y
Competing deformable growth	N	N	?	?	Y	Y
Stable non-deformable growth	Y	Y	Y	Y	N	N
Acceptable Feed						
Sensitive to small feed variations	L	L	L	L	M	M
Heat or pressure sensitive	Y	Y	Y	Y	?	?
Able to process induction time	Y	Y	N	?	Y	? (1)
Poor wettability / high viscosity	N	N	N	N	Y	Y (1)
Product Appearance Attributes						
Flowability for metering	M-H	M-H	VH	M-H	M	M
Product form	SG	SG	VSG	SG	IG	IG
Width of size distribution	M	M	L	M	M-H	M-H
Size range, mm	0.2–1	0.1–3	0.5–20	2–20	0.1–3	0.1–3
Production, ton/h or kg/batch	100–900	50	0.5–800	0.5–800	100–500	50
Product density	L-M	L-M	M	M	M-H	M-H

General comments: Binder required. Either solvent required, or in some cases, heat-activated binder. Maximum feed of 500 µm smaller preferred. Moisture no more than 80% pore saturation. Able to process brittle, abrasive, elastic, most plastic materials.
Definitions: Y=yes, N=no, ?=possible
zzΩΩ
Processing: C=Classification, R=Recycle, B=Blending, D=Drying, G=Grinding, T=Two-stage
Notes: (1) Dependent on contact time.

TABLE 2. PROCESS SELECTION CONSIDERATIONS FOR COMPACTION EQUIPMENT

	Process:						
Attributes	Roll Pressing (smooth)	Roll Pressing (pattern)	Tabletting	Ram/ Piston Extrusion	Pelleting Mills	Radial Extrusion	Axial Extrusion
Process Characteristics							
Typical pre/post processing	B,G,C,R,T	T,B	T,B	T,B	B,C,D,R	B,C,D,R	B,C,D,R
Ease of dust/toxicity containment	M	M	H	H	M-H	H	H
Ease of cooling or heating	H	M	L	H	L	H	H
Typical level of recycle	M-H	L-M	O	O	L	L	L
Heat activated granulation	N	N	N	N	N	Y	Y
Solvent	N	N	N	N	Y	Y	Y
Simultaneous reaction	N	N	N	N	N	Y	Y
Acceptable Feed							
Sensitive to small feed variations	VH	H	H	VH	VH	H	VH
Can process hard materials	N	N	N	N	Y	Y	Y
Can process low permeability	Y	?	N	N	Y	Y	Y
Can process low wall friction	N	Y	Y	Y	N	?	?
Product Appearance Attributes							
Flowability for metering	M	M	M	M	M	M	M
Product form	IG	B	T	IT	C-SG	C-SG	C-SG
Width of size distribution	M-H	VL	O	O	L	L	L
Size range, mm	0.2–5	5–50	5–10	5–10	0.5–3	0.5–3	0.5–3
Production, ton/h or kg/batch	50	50	1	5	10	5	5
Product density	H	H	H-VH	H-VH	H-VH	M-H	VH

General comments: Binder not required except for some hard mateirals. Small levels of moisture common; must be low or compaction arrested. Minimum feed of 100 μm, unless deaeration/vacuum provided. Moisture no more than 80% pore saturation. Non-wettable material acceptable.
Definitions: Y=yes, N=no, ?=possible
Product form: L=low, M=medium, H=high, V=very, G=granular, S=spherical, I=irregular, T=tablet form, C=cylindrical
Processing: C=Classification, R=Recycle, B=Blending, D=Drying, G=Grinding, T=Two-stage
Notes: (1) Dependent on contact time.

CONSIDERATIONS FOR CHOICE OF AGGLOMERATION PROCESS

- Final product attributes, in particular agglomerate size, size distribution, voidage, strength, and dissolution behavior
- Form of the active ingredient (dry powder, melt, slurry, or solution), and the amount and nature (hydrophobic, hydrophilic, moisture or heat sensitivity, polymorphic changes)
- Need for moisture-sensitive (dry processing) or heat-sensitive formulations
- Robustness of a process to handle a wide range of formulations, as opposed to a dedicated product line
- Air and solvent handling requirements, as well as degree of unit containment due to dust or solvent hazards
- Desired scale of operation, and type (batch vs. continuous). Ease of process scale-up and scale-down, as well as range of granule property control at one scale
- Multiple unit operations in one vessel (such as granulation, drying and coating in a fluidized-bed)
- Process monitoring capabilities, and ease of integration into process control schemes
- Maintenance and utility requirements. Ease of cleaning to prevent cross-contamination
- Integration of size enlargement equipment into existing process plant
- Existing company and supporting vendor experience with specific equipment