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# Reduction of energy consumption in batch fluidized bed layering granulation processes by temporal separation

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ABSTRACT

Nowadays demands for product quality and energy efficiency are increasing due to ongoing industrial development and rising costs of resources. In case of fluidized bed layering granulation profitability mainly depends on the total energy input required for fluidization, evaporation of the sprayed liquid and drying, in balance with product quality and process efficiency. This paper is focuses on temporal separation of process steps like growth and liquid evaporation as one way of intensification of batch processing. In order to optimize both sub-processes, granulation and particle drying, are operated alternating by switching the spraying rate and other process parameters.

In order to obtain the required data, experimental and model based investigations for different parameter configurations are performed. The analysis of results is carried out in comparison to a benchmark case, for batch operation this comparison is based either on equal process time or product quality. The results show significant advantages of temporal separation in batch processes with respect to energy consumption while conserving product quality.



## 1. Introduction

Due to the progressive depletion of fossil resources and rising energy prices the demands on industrial processes in terms of energy savings and energy-efficient operation are increasing. Simultaneously, product quality requirements of particulate products are also increasing.

Fluidized bed layering granulation is widely used in food or pharmaceutical industry to extract particulate products from suspensions or solutions to enhance particle properties such as specific weight, fluidity and stability (Mörl et al., 2007). The main energy input is thermal and electrical energy to preheat and convey the fluidization gas, which works as an energy transfer medium for particle fluidization, heating and drying as well as for the transport of the sprayed liquids.

The working principle of fluidized bed layering granulation is sketched schematically in Fig. 1 (right). The preheated gas flow enters the particle bed from below passing through a distributor plate. In the shown top-spray configuration a suspension or solution is introduced to the process chamber from above by a two-component nozzle (Mörl et al., 2007). The liquid droplets deposit on the particles and wet the particle surface. Drying leads to solidification of these droplets and a shell is formed around the particle.

Next to the fluidized bed apparatus itself there are additional plant components ensuring correct operation and determining process efficiency, as is also shown in Fig. 1 (left) for a batch fluidized bed layering granulation plant. Both fans provide the required gas flow for fluidization and drying. Before passing through the fluidized bed apparatus

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## Nomenclature

*Latin letters*

| | |
|---|---|
| $A$ | area, surface area ($m^2$) |
| $d$ | diameter (m) |
| $G$ | growth rate (m/s) |
| $h$ | height (m) |
| $H$ | enthalpy (J) |
| $\dot{H}$ | enthalpy flow (W) |
| $k$ | heat transmission coefficient ($W/m^2$ K) |
| $M$ | mass (kg) |
| $\dot{M}$ | mass flow (kg/s) |
| $n$ | number density ($m^{-1}$) |
| $p$ | pressure (Pa) |
| $q$ | specific energy consumption (J/kg) |
| $Q$ | heat, heat consumption (J) |
| $\dot{Q}$ | heat flow, power (W) |
| $s$ | wall thickness (m) |
| $t$ | time (s) |
| $T$ | absolute temperature (K) |
| $x$ | particle diameter (m) |
| $X$ | moisture content solids ($kg/kg_{s,dry}$) |
| $y$ | mass fraction (kg/kg) |
| $Y$ | moisture content gas ($kg/kg_{g,dry}$) |

*Greek letters*

| | |
|---|---|
| $\alpha$ | volume fraction of spray zone (–) |
| . | heat transfer coefficient ($W/m^2$ K) |
| $\beta$ | mass transfer coefficient (kg/s) |
| $\epsilon$ | porosity ($m^3/m^3$) |
| $\zeta$ | dimensionless bed height (m/m) |
| $\eta$ | efficiency (–) |
| $\lambda$ | heat conductivity (W/m K) |
| $\dot{\nu}$ | normalized drying rate (–) |
| $\xi$ | normalized water content (–) |
| $\varrho$ | density ($kg/m^3$) |
| $\tau$ | residence time (s) |

*Subscripts*

| | |
|---|---|
| 0 | at time $t = 0$ |
| *bed* | particle bed |
| *dry* | dry, free of liquid or gaseous water |
| *env* | environment, ambient |
| *evap* | evaporation |
| *fan* | fan, ventilator |
| *g* | gas phase, humid air |
| *heater* | heater |
| *in* | inlet |
| *ins* | insulation |
| *jet* | jet, nozzle |
| *l* | liquid phase |
| *mech* | mechanical |
| EE | effective energy |
| *out* | outlet |
| *p* | particle |
| PE | primary energy |
| *s* | solid |
| *sat* | adiabatic saturation |
| *sh* | shell |
| *sus* | suspension, solution |
| *th* | thermal |
| *vap* | vapor, steam |
| *w* | wall |
| *wb* | wet bulb |

the heater increases the inlet air temperature up to the required value. After leaving the fluidized bed the gas flow runs through a cyclone and a filter to be cleaned from dust particles.

Currently in industrial plants the outlet gas is often emitted directly to the environment without any utilization. Because of the high amount of gas flow, which is wetted by spray injection and vaporization and enriched with the solvent, fluidized bed layering granulation offers potential for improvement of the energy efficiency. However, as a constraint, the integration of new energy reduction measures shall not affect product quality, e.g. particle size or moisture content, in a negative way.

In general the enhancement of efficiency of the total energy consumption of drying processes such as fluidized bed layering granulation can be achieved by a reduction of the evaporation load, an enhancement of the dryer efficiency or an improvement of the energy supply system as detailed in Kemp (Kemp, 2012). Therefore investigations of the process require detailed consideration of fluidized bed granulation as a particle growth and drying process on one hand and on the other hand an overall investigation of total energetic and economic performance of the process and the single components.

On the one hand heat recovery measures can be applied to utilize the waste heat of the outlet gas flow. One possibility is the installation of heat exchanger systems that can be used to recover sensible and latent heat for preheating the process gas as shown in Moraitis and Akritidis (Moraitis and Akritidis, 1997). Also heat pumps or refrigerating machines can be applied to produce heating or cooling energy for other integrated devices from waste heat like in a conventional drum dryer investigated by Braun et al. (Braun et al., 2002). Potential and resulting savings for drying systems can be estimated by process integration via pinch analysis described in Kemp (Kemp, 2005, 2012). Djaeni et al. (Djaeni et al., 2007; van Boxtel et al., 2012) show that process integration of a zeolithe adsorption–desorption system into a drying plant can remarkably reduce the energy consumption of a dryer. Also low-temperature steam power cycles, e.g. Organic-Rankine-Cycles (ORC), can be used to generate electrical power using temperature level of outlet gas for heat addition (Schuster et al., 2009). The feasibility of these mentioned energy recovery technologies has to be analyzed critically because of the low temperature level of the waste heat (320–350 K).

On the other hand process intensification can be considered in order to increase the dryer efficiency. Enhancement of the drying potential by pre-dehumidification of the inlet gas and solids or injection of highly concentrated solution for reduction of introduced solvent mass can lead to an improvement of energy utilization. Also new heating concepts like direct heating by inductive energy input investigated by Stresing et al. (Stresing et al., 2011) or immersed heating surfaces can be investigated.

All these described measures for heat recovery, reutilization and intensification require additional plant components and equipment, which leads to higher investment costs.

So separation of functionalities can be performed to intensify the process and increase its capacity without additional equipment. Separation of functionalities in this context means a spatial division of individual subprocesses for continuous operation or temporal division for batch operation. In continuous operation mode that can mean a spatial partition of the process chamber into vertical or horizontal cascades, where spraying, pure drying and cooling take place in different vessels. For batch fluidized spray granulation temporal separation of the process steps growth and drying can be realized.

Temporal separation of sub-processes within a complex process can benefit energy consumption and product quality, as shown in Michaud et al. (Michaud et al., 2007) for vacuum contact drying of crystalline powders. In order to optimize granulation and particle drying with respect to the inner process energy utilization, temporal separation of functionalities is applied to fluidized bed layering granulation. In this case separation means that liquid injection is stopped and switched on during the process. The process is divided in two parts, granulation or growth period and drying period. Since during injection in the growth period particle drying also takes place, the process period called drying period in this article is a pure drying period, i.e. no spray injection. This subdivision allows an intensification of both sub-processes,